

ESTABLISH SKID RESISTANCE THRESHOLDS FOR LOCAL AUTHORITY ROADS IN THE UK USING STATISTICAL MODELS

by

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ABSTRACT

Skid resistance is considered as one of the contributing factors that affect traffic accidents; it is considered as an important property of a road surface that is required to maintain a safe road network. The main aim of this thesis is to establish new skid resistance thresholds for local authority roads. This will be accomplished through the following objectives: 1. to define new site categories based on accident layouts at different network features (e.g. junctions, roundabouts) and the relationships between accidents and geometric characteristics (such as radius of curvature and gradient), 2. to estimate the impact of traffic characteristics (natural logarithm of annual average daily flow, percentage of heavy vehicles, and speed limit); geometric characteristics (radius of curvature, gradient, number of lanes and number of minor accesses); and pavement characteristics (skid resistance, rut depth, and texture depth) on both accident frequency and rate, and 3. To analyse the relation of the expected accident frequencies and rates as a function of skid resistance. This study has included A-road networks for Norfolk, Oxfordshire and Nottinghamshire counties in England, UK. These networks are divided into different site categories these site categories are: 1. non-event; 2. bends (0 - 250) m; 3. bends (250 – 500) m; 4. roundabouts; 5. junctions; 6. gradients. Four different datasets for the period 2005-2010 have been merged to construct the final unique dataset for this study. They are: 1. accident data, 2. traffic data; 3. geometric data; and 4. pavement characteristics data. A series of fixed and random parameters Negative Binomial models have been employed to investigate the effect of skid resistance on accident frequency at different site categories for the three counties. The datasets were modelled by total accidents, by road surface condition (i.e. dry and wet), and by severity level (i.e. fatal and serious or slight). In the same way fixed and random Tobit models have been employed to investigate the effect of skid resistance on accident rate. The model estimation results suggest that skid resistance is negatively associated with the frequency and rate for all accident types at all site categories. A 10% increase in skid resistance leads to a decrease in total, dry, wet, slight, and

serious and fatal accident frequencies at network level by 12.24, 10.21, 16.34, 10.68 and 4.92%, respectively. A 10% increase in skid resistance (SCRIM value) leads to a decrease in total, dry, wet, slight, and serious and fatal accident rates at network level by 6.32%, 10.62%, 12.52%, 3.31%, and 4.87%, respectively. This thesis contributes to knowledge in terms of accident prediction approach, showing that application of random parameters modelling as a new approach applied in the UK to estimate accident frequency and rate on A – road networks. This method is introduced as a sufficient approach for the researcher due to the ability to account and correct for heterogeneity, which can arise as a result of several factors relating to the characteristics of traffic, geometric and pavement characteristics. In addition, the random parameters model approach provides a reasonable understanding of the main factors that affect accident frequency and rate. Therefore, this approach allows the researcher to identify and control for confounding factors that may bias estimation. In addition, new skid resistance thresholds for different site categories are established based on the analysis of expected accident frequencies (outputs of random parameters Negative Binomial models); and the analysis of expected accident rates (outputs of random parameters Tobit models) as function of skid resistance.

This thesis is dedicated to my parents

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DECLARATION

The research presented in this thesis was conducted at the Nottingham Transportation Engineering Centre, University of Nottingham between August 2014 and September 2018. I declare that the work is my own and has not been submitted for a degree of another university.

Hamid Ahmed Awad Alacash

The University of Nottingham

I declare that the contents and the work described in this thesis were performed at the University of Nottingham, Faculty of Engineering from August 2014 to September 2018 under my supervision.

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CHAPTER ONE

INTRODUCTION

CHAPTER ONE: INTRODUCTION

1.1 Background

According to the World Health Organisation (WHO) (2013), more than 1.25 million people die and between 20 and 50 million are injured every year as a result of traffic accidents. The same organisation forecasts that by 2030, highway-linked accidents will be the 5th leading cause of death in the world. An accident is defined as a sudden event which is both unwanted and unintended or a particular chain of events that leads to harmful results (ECD *et al.*, 2010). The numerous problems associated with accidents together with their complexity place them among the most challenging problems that need to be addressed by policymakers and other stakeholders.

There are substantial costs linked to road accidents such as human costs, explicit costs to the economy such as lost production, medical costs linked to road accidents, costs associated with damage to property and vehicles, and costs linked to administration by the police and insurance providers (Department for Transport, 2008). For instant, International Road Traffic and Accident Database (IRTAD) (2017) estimated that the socioeconomic costs of road traffic accidents for the European Union countries is estimated to be more than 500 billion EUR, representing approximately 3% of their gross domestic product. IRTAD (2017) reported that 26132 human beings died and 1079720 were injured in road accidents during 2016. On the other hand, Department for Transport (2016) estimated the total socioeconomic cost of road accidents in Great Britain to be more than £11 billion in 2016. The UK Department for Transport reported that an aggregate of 181384 road casualties which resulted from 136621 accidents occurred in Great Britain for 2016. Out of these casualties, 1792 killed, 24101 seriously injured and 155491 slightly injured (Department for Transport, 2016).

However, the International Road Traffic and Accident Database (IRTAD, 2017) listed United Kingdom as one of the safest countries in the world with a death incidence of 3.4 for every 1 billion vehicle-kilometres. In comparison to other countries in the European Union, the US, and Japan.

1.2 Accident cause

In the last century, there has been significant progress in accident theory as it moved from the idea of accident proneness, which proposed that certain individuals are predisposed to be involved in accidents in comparison to others. Accidents as events are based on processes with a number of interacting elements involved (Benner, 2007). One of the leading modern theories is the Swiss cheese model, suggested by Reason (2000), which proposes that accidents occurred as a result of an accident path managing to permeate all layers of defence in prevalent circumstances. Even though Reason's (2000) model was developed with an organisational application in mind, it was also shown to work in the area of road safety, where the vehicle, environment, and driver form part of the foundation of layers of defence, as shown in Figure 1-1.

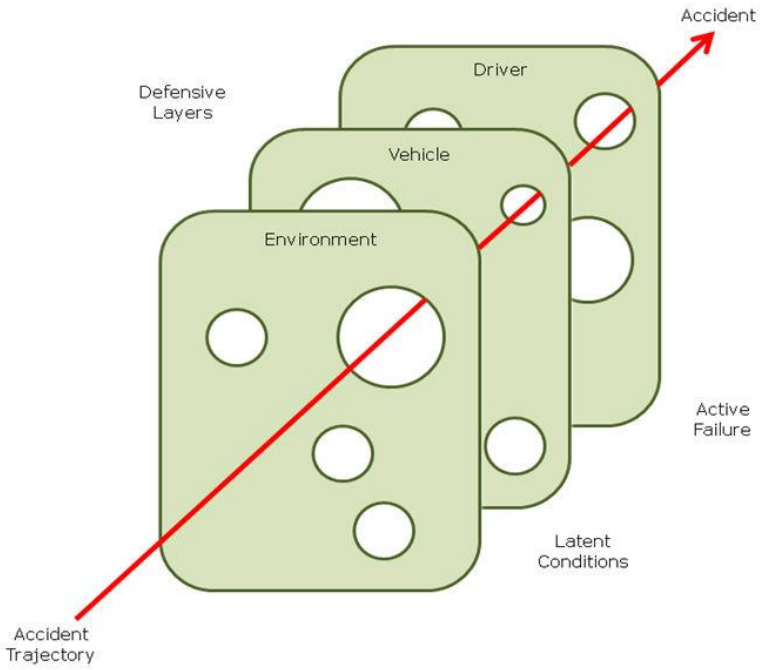


Figure 1-1: Adapted depiction of Reason's (2000) Swiss cheese accident Model

Reason (2000) observed that in almost all cases, there are two elements that should be present in order for an accident path to permeate the layers of defence and result in an accident. First, there should be a risk within the system (a dormant or latent condition). Second, an active failure should exist, which requires individuals taking

part in the system to act in an unsafe manner, whether they do so on purpose or not. The underlying need for an active failure in the Swiss cheese model is supported by an earlier work of Treat *et al.* (1979), which concluded that 57% of accidents could be credited solely to drivers, 3% to prevailing road conditions, and 2% to the condition of vehicle, as summarised in Figure 2-1. The other 37% of accidents can be credited to two or more causal factors.

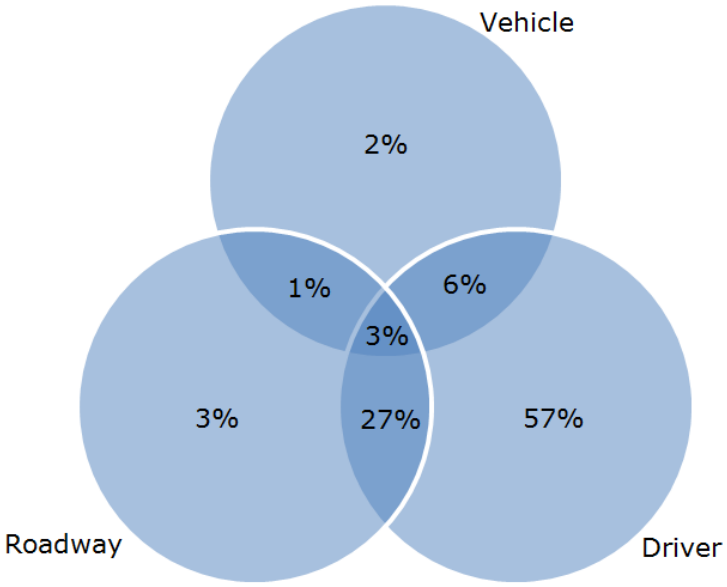


Figure 1-2: Accident causal factors (Treat *et al.*, 1979)

Different perspectives are employed in the examination of the relationship between these factors and accidents including external conditions, behaviour, and infrastructure, particularly since the middle of the 20th century. However, owing to the uniqueness and intricacy involved in road accidents, the explanation of such phenomena remains vague. However, it is broadly agreed that pavement characteristics such as skid resistance (friction), rut depth, texture depth and roughness play a major role in traffic safety. Based on the broad supply of road construction materials, technologies, and a growing need for comfort and safety among road users, the construction and maintenance of roads are starting to pay increasing attention to the surface properties of pavements.

1.3 Research motivation

Even though the rates of road accidents in the Western world have experienced a decrease in the last few decades, the reality is that the number of accidents is still way too high (WHO, 2013). Department for Transport (2016) reported that in 2016, there were 136621 road accidents in the Great Britain with 17% of these accidents leading to death or serious injury of at least one person. A large portion of such accidents occurred on A-road segments. Thus, even though the length of A-roads comprises only 12% of the total road network, it still accounts for almost half of the accidents in the entire UK road network (Department for Transport, 2016).

A large body of literature concludes that skid resistance is a significant factor contributing to accidents (Wallman and Astrom, 2001; Viner *et al.*, 2005; Flintsch *et al.*, 2009; Mayora and Pina, 2009). From the literature, it becomes clear that on a particular segment of a road under traffic, when skid resistance is low, loss of control is more likely, creating road conditions that are not safe. Hence, road authorities attempt to establish a minimum skid resistance threshold value. In the UK skid resistance thresholds are mostly used by highway agencies for the management of pavement friction, namely, the investigatory level (IL) (Rogers and Gargett, 1991; Henry 2000; Hall *et al.*, 2009). IL denotes the skid resistance value where an agency needs to start the process of monitoring the skid resistance of a pavement and levels of accidents with the aim of starting to put together preventive and restorative measures. The establishment of these limits happens when a substantial escalation in accident risk lower than those values starts to be noted. An example of this practice in the UK is the process that involves the implementation of a systematic skid resistance plan on strategic roads (Highways Agency, 2004). Using a skid resistance evaluation, decisions on the maintenance of the evaluated site are taken, when it is observed that measures are either equal to or lower than the IL.

1.4 Research contribution

Accident modelling is key in providing information on the relations between traffic, geometric and pavement characteristics, with accidents. The first contribution of this

study emphases the application of random parameter modelling as a new approach, estimating accident frequencies and rates occurring on A road networks in Norfolk, Oxfordshire and Nottinghamshire in England, UK. In addition, this approach is consider appropriate due to its ability to account and correct the heterogeneity which can rise from several factors relating to traffic, geometric and pavement characteristics. The second contribution of this study is defined new site categories for local authority roads (A-roads). Moreover, the analysis of the expected accident frequency and rate (output of frequency and rate models) as a function of skid resistance enables the definition of threshold values for skid resistance.

1.5 Problem statement

The agency responsible for the strategic roads in the UK introduced a new standard for skid resistance in January of 1988. This was done through the standard referred to as HD 28/88 in the Design Manual for Roads and Bridges (Highways Agency, 1988). This standard founded on studies, spanning several decades, which had brought together the impact of skid resistance on accident risk and introduced an approach to the management of skid resistance in strategic roads. However, Roe *et al.* (1998) reported that by 1999, results obtained from some studies showed that there was a need for a review of the standard. This suggested review would include a complete study of the relation between accidents in the UK and skid resistance. Through this, it was established that there were areas where the policy implementation required some improvements. Subsequently, the Highways Agency decided to review the skid resistance standard and policy for the conditions that prevail today. The design manual for bridges and roads was then introduced in 2015 and the latest version of the skid resistance policy for strategic roads called HD 28/15 was introduced (Highways Agency, 2015). The Highways Agency (local authorities) in the UK employs the skid resistance policy, HD 28/15, in its definition of site categories and uses it to set the skid resistance thresholds for these site categories in A-road networks. Notwithstanding this reality, there are still some challenges in arriving at the appropriate skid resistance thresholds for local A-roads, owing to the

fact that there are variances between local authority roads and strategic roads with regard to the flow of traffic, geometry of roads, and vehicle speeds. For this reason, the thresholds established for strategic roads are not necessarily suitable for A-roads managed by local authorities.

1.6 Aim and Objectives

In the light of problem statement clarified above, the main aim of this thesis is to establish new skid resistance thresholds for local authority roads (A-roads). This will be achieved through the following objectives:

- To review the impact of traffic, geometric and pavement characteristics on accidents.
- To define new site categories based on accident layouts at different network features (e.g. junctions, roundabouts) and the relationships between accidents and geometric characteristics (such as radius of curvature and gradient).
- To estimate the impact of traffic, geometric and pavement characteristics on accident frequency based on random parameters Negative Binomial model results.
- To estimate the impact of traffic, geometric and pavement characteristics on accident rate based on random parameters Tobit model results.
- To compare the impact of traffic, geometric and pavement characteristics on both accident frequency and rate.
- To analyse the relation of the expected accident frequencies as a function of skid resistance.
- To analyse the relation of the expected accident rate as a function of skid resistance.

1.7 Thesis Outline

This thesis consists of nine chapters:

- Chapter 1 presents the introduction of the research area and topic. It highlights the research background, research motivation, research

contribution, problem statement, and it also contains thesis aims and objectives.

- Chapter 2 presents a literature review of the various factors affecting skid resistance and skid resistance policy in different countries. The chapter reviews the various factors (traffic, geometrics and pavement characteristics) affecting road accidents. Finally, the chapter reviews statistical modelling and methodologies applied to accident data.
- Chapter 3 presents the methodology and data sources and describes the methods used in this thesis. The chapter starts with statistical tools used to build best fit models. This is followed by statistical approaches developing models for total, dry, wet, slight, and serious and fatal accident frequencies and rates. Finally, accident descriptions, traffic, geometrics and pavement characteristics data will be provided.
- Chapter 4 illustrates the model strategy procedure used to build the best fit models for the next Chapters (5 and 6).
- Chapter 5 presents and explains the results of the statistical models developed for the total, dry, wet, sight, and serious and fatal accident frequencies, using random and fixed parameters Negative Binomial models.
- Chapter 6 presents the statistical modelling as applied to total, dry, wet, sight, and serious and fatal accident rates, using random and fixed parameters Tobit models.
- Chapter 7 discuss and compare the effect of traffic, geometric and pavement characteristics on the expected accident frequencies (Chapter 5) and the expected accident rates (Chapter 6).
- Chapter 8 explains how to establish skid resistance thresholds for different site categories and for various accident aggregations (based on the results provided in Chapters 5 and 6).
- Chapter 9 summarises the findings and outlines their contributions to contemporary knowledge. The chapter also explores thoughts and ideas for future research directions are provided.

CHAPTER TWO

REVIEW OF LITERATURE

CHAPTER TWO: REVIEW OF LITERATURE

2.1 Overview

This chapter has been broadly divided into three sections. This first section summarises research studies related to skid resistance properties, the main factors that impact skid resistance and the management of skid resistance. This first part consists of three main sections, the first section defines skid resistance and explains the mechanism of this process. The second part focuses on factors affected by skid resistance. The final section discusses management methods for skid resistance of roads in the UK, Australia, and New Zealand.

The second section provides a summary of findings from previous studies on the relationship between accidents and traffic characteristics (annual average daily flow, heavy vehicle percentages, speed limits), geometric characteristics (radius of curvature, gradients, number of lanes, number of minor accesses), and pavement characteristics (skid resistance, rut depth, mean texture depth). Finally, the last section reviews the main statistical approaches used in accident analyses.

2.2 Skid resistance

Dunford (2013) defines the concept of skid resistance of a pavement as the contribution of the pavement surface to the interaction between the tyre- pavement interaction and the friction force. Changes linked to a vehicle altering its direction or speed results in the development of forces at the tyre-pavement interface. The reaction caused by these forces is referred to as friction. Hence tyre-pavement friction is considered as a critical element to reduce the possible road accidents especially for wet pavement (Flintsch *et al.*, 2012). However, Najafi *et al.* (2017) also report that studies conducted recently have also proved that pavement friction also has a significant impact on accidents that occur during dry conditions. Hence, more accidents have been recorded on roads that have less friction than on those where friction is higher (Hall *et al.*, 2009). Pavement friction has been defined as "the force that resists the relative motion between a vehicle tyre and a pavement surface" (Hall *et al.*, 2009). Figure 2-1 presents the above definition (braking wheel).

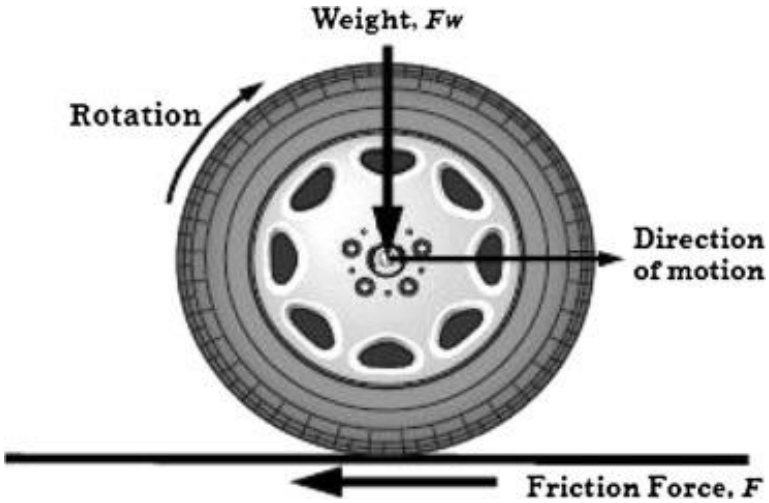


Figure 2-1: Illustration of forces acting on a rotating tyre (after Hall *et al.*, 2009)

2.2.1 Mechanisms of pavement friction

Two mechanisms are responsible for pavement friction: hysteresis and adhesion (as is illustrated in Figure 2-2). Adhesion emerge from molecular bonds in areas of high pressure which are caused by the lack of evenness of the road pavement. Hysteresis happens as a result of the loss of energy because of the rubber from which the tyre is made deforming non-elastically around the pavement surface's depressions and protuberances (Cairney, 1997).

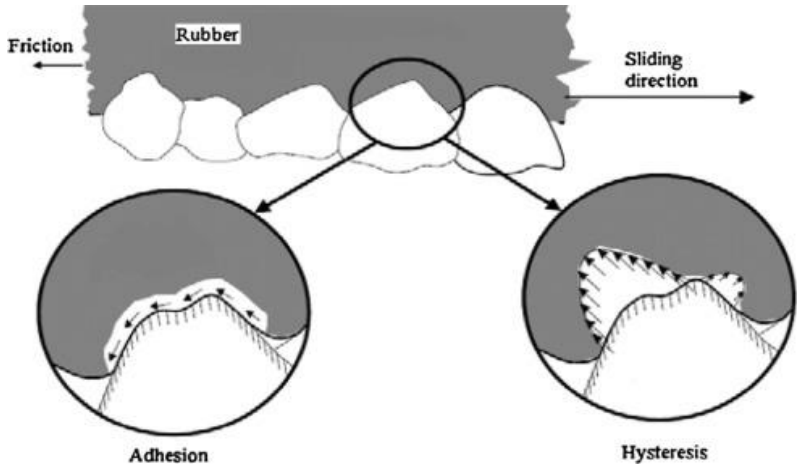


Figure 2-2: Key mechanisms of tyre-pavement friction (after Hall *et al.*, 2009)

2.3 Factors affecting skid resistance

2.3.1 Pavement surface texture

Hall *et al.* (2009) define pavement surface texture as the deviances of the surface of the pavement from the true planar surface. Permanent International Association of Road Congresses (PIARC) (1987) uses the wavelengths of the deviations as a basis for defining the scales of surface texture. Based on this pavement texture is divided into two categories: Micro-texture with wavelengths from 0 mm to 0.5 mm; Macro-texture with wavelengths from 0.5 mm to 50 mm. These texture scales make a different contribution to the friction between the tyre and the pavement.

2.3.1.1 Micro-texture

Micro-texture is a fine-scale texture which is a function of the aggregate particle mineralogy (Noyce *et al.*, 2005). The micro-texture value depends on the roughness of the aggregate particles (Jayawickrama and Thomas, 1998; Noyce *et al.*, 2005). Adhesion in the friction process is controlled by the micro-texture (Noyce *et al.*, 2005). Adequate micro-texture for pavement surfaces can have significant effects in overcoming sliding problem due to thin water films, which accumulate on road surfaces and cause vehicle sliding, especially in wet weather. Micro-texture plays an important role in wet weather; it increases frictional forces by pressing on thin water films in the contact area between the tyre and the pavement surface (Do *et al.*, 2000). In addition, micro-asperities affects the drainage of pavement surface water (Rohde, 1976; Taneerananon and Yandell, 1981; Do *et al.*, 2000). The size and number of micro-asperities on a surface can control the amount of the water discharged from the surface (Savkoor, 1991); therefore, reductions in e.g. hydroplaning can be implemented by using good micro-texture and macro-texture materials. Ong *et al.* (2005), observed that pavement surfaces with mixtures containing coarse aggregates, with a micro-texture range between 0.2 mm and 0.5 mm can have positive effects by raising the speed of hydroplaning. These authors found that pavement surfaces with a 0.1 mm micro-texture depth, saw hydroplaning

speeds increase by 1%, while for pavement surface with more than 0.1 mm micro-texture depth was the hydroplaning speeds increase by 22%.

2.3.1.2 Macro-texture

Macro-texture refers to the coarse-scale texture of the road surface. Macro-texture is a function of the size, shape, and distribution of coarse aggregates in asphalt concrete mixtures. There are two main effects of macro-texture on the friction coefficient of a pavement surface. Firstly, an appropriate macro-texture provides an adequate depth of water that accumulates on the pavement surface during wet weather, allowing it to discharge (Roe *et al.*, 1991; Ong and Fwa, 2007). This factor providers a dry contact area for the tyre on the surface, reducing hydroplaning and providing a good contact between the road surface and tyre (Bonnot and Ray, 1977; Rogers and Gargett, 1991, Cenek *et al.,* 2002, Chelliah *et al.*, 2002). Ding and Wang (2018) evaluated the effects of different asphalt mixtures on hydroplaning. An important finding from this study is that increasing macro-texture depths caused increases in hydroplaning threshold velocities. The results showed that by increasing macro-texture depths by 0.5 mm, there was a 33% increase in the frequency of hydroplaning. Secondly, the contribution of macro-texture on skid resistance was clearly observed through hysteresis (Hall *et al.*, 2009). Hysteresis refers to deformations that occur between the tyre and the pavement surface (Roe *et al.*, 1991, Roe, *et al.,*1998). The tyre rubber stores deformation energy due to compression of the tyre on the road surface, but when the tyre is retrained to the relaxation situation part of the stored energy will be lost. A hysteresis force is created between the macro-texture (aggregate particles of more than or equal to 0.5 mm) and the tyre at the tyre-road interface (Hall *et al.*, 2009).

2.3.2 Aggregates properties

The aggregate properties have a significant impact on the skid resistance of wearing layers of the roads (Forster, 1989); because it's the main part of the asphalt mixture,

the percentage of the aggregate in the bituminous mix varied from 92 to 96% by volume of the hot mix asphalt (Shah and Abdullah, 2010), therefore, the aggregate properties can be one of the main factors that have ruled the value of skid resistance for the pavements surface. This section consists of two parts related to the aggregate properties that it may influence on the friction properties of the road surface. The first part evaluated the effect of the aggregate polishing on skid resistance, while the second part evaluated the shape, size and spacing of the aggregate particles in the asphalt mixture on the friction properties.

2.3.2.1 Polish resistance

An aggregate's polish resistance refers to its ability to maintain its micro-texture after it has been subjected to shearing and grinding by continuous traffic loadings. The phenomena are evaluated by the polished stone value (PSV). A PSV test is carried out using two machines: the accelerated polishing machine which is used for the polishing process, and the portable skid resistance tester which measures the degree of specimen polish, after the polishing process. The PSV test procedure is represented by the standards; BS 812 part 114, BSEN 1097-8, ASTM D3319 and AASHTO T279. Research by the UK Road Research Laboratory confirmed a significant relationship between the aggregate's polish resistance and skid resistance.

2.3.2.2 Size, shape and spacing

The size, shape and spacing of aggregate particles in pavement surfaces have a primary effect on the friction coefficient of the road surface. Cenek *et al.* (1998) stated that the aggregate properties such as size, shape and spacing had significant effects on skid resistance. There are two types of aggregate used in hot mix asphalt; coarse and fine aggregate. Many studies (Abdul-Malak *et al.*, 1996; Crouch *et al.*, 1996) have demonstrated that coarse aggregates have greater effects on skid resistance than fine aggregates; therefore, this section focuses on the effects of coarse aggregate shapes on the friction of pavement surfaces. The particles of coarse aggregates used in asphalt concrete mixtures have many shapes, such as rounded, cubical, angular, flaky or elongated particles. These shapes can influence the skid

resistance of wearing course layers. The effects of coarse aggregate shapes on friction properties on pavement surfaces, has been recognised by Shah and Abdulla (2010). The main finding of this study demonstrated that mixtures with angular shapes had the highest British Pendulum Number (BPN) values in wet and dry conditions, in comparison with other mixtures which had elongated or flaky coarse aggregate shapes. In addition, Sengoz *et al.* (2014) observed that there was a significant relationship between the aggregate shape and the friction properties of the hot mixture asphalt. The results obtained from this study indicate that mixtures with crushed aggregate had higher values of friction coefficient than the same mixture properties with uncrushed aggregate. Therefore, the relationship between skid resistance and aggregate shape or angularly within wearing course is almost certain. In spite of this, the few studies that focus on the effects of aggregate spacing on skid resistance, the aggregate gap is a significant contribution to the value of skid resistance. A field study conducted by Fwa *et al.* (2003) described the effects of aggregate gap width in asphalt mixtures on the BPN. This study demonstrated that skid resistance was influenced by the spacing between aggregate particles. The test results demonstrated that the skid resistance was negatively affected by increasing the aggregate gap width from 2 to 10 mm, for the two types of aggregate used in this study, steel slag and granite. The results showed that decreases in skid resistance for the two types of aggregate was 32 and 15%, respectively, in dry condition, while in wet condition the percentages decrease were 20 and 14%, respectively.

2.3.3 Influence of environmental factors

This section focusses on the effect of temperature and contaminants on skid resistance.

2.3.3.1 Influence of temperature

There are three groups of temperature affecting on the road pavement friction, these groups are air, tyre and pavement temperature. Previous studies have demonstrated that there is a high correlation between these three elements of temperature. For

example, Henry and Hill, (1981) examined the relationship between three types of temperatures, which are air, pavement and tyre, this study is concluded that three types of temperature has a high correlation between them as shown in Equations (2-1), (2-2) and (2-3):

$$T_t=8.54+0.810T_A \quad (2\text{-}1)$$

$$T_t=6.78+0.558T_p \quad (2\text{-}2)$$

$$T_A=0.87+0.573T_p \quad (2\text{-}3)$$

Where:

T_t= Tyre temperature (^oC).

T_P= Pavement temperature (^oC).

T_A= Air temperature (^oC).

2.3.3.1.1 Air temperature

Many studies have evaluated the effects of air temperature on skid resistance, such as Jayawickrama and Thomas (1998) in Texas, USA, Anderson *et al.* (1986) in New York and Pennsylvania, USA and Runkle and Mahone (1980) in Virginia, USA. These studies found significant effects of air temperature on skid resistance. For example, Jayawickrama and Thomas (1998) showed that skid resistance at 40 mi/hour (SN_{40}) tended to decrease as temperature increased.

2.3.3.3.2 Tyre Temperature

The increasing in the temperature of measurement pieces due to the increasing in temperature of the surrounding condition during the test caused a decreasing in the value of skid resistance. Oliver (1989) evaluated the effect of tyre temperature on the magnitude of skid resistance in Australia. They stated that the decrease in skid resistance obtained from SCRIM was related to the increasing in the tyre temperature which is resulting from the increasing of both air and pavement temperatures (see Equation 2-4).

$$SFC_t/SFC_{25} = 0.563 + 45.9 / (T + 80) \quad (2\text{-}4)$$

$$T = 12.3 + 0.48 (T_a + T_p) \quad (2\text{-}5)$$

Where:

SFC_t = side force coefficient of SCRIM at tyre temperature t,

T = tyre temperature (°C),

T_a = air temperature (°C), and

T_p = pavement temperature (°C).

Moreover, Hosking and Woodford (1976) introduced similar equations between pavement friction and tyre temperatures. These equations were adopted by the Transportation Road Research Laboratory (TRRL) in the UK. In summary, changing the temperature affects the properties of the rubber which is used in the majority of skid resistance tools, because it has an effect on the hysteresis component of the friction force. Hysteresis refers to the loss of energy in the tyre rubber that slides over the pavement surface; this loss is due to increases in temperature. Jayawickrama and Thomas (1998) observed that at higher temperatures, the tyre rubber becomes more flexible and loses contact energy to the pavement surface, therefore, higher temperatures decrease in skid resistance.

2.3.3.3.3 Pavement temperature

A significant impact of pavement temperature on the skid resistance value for road surface. In 1979 Dahir *et al.*, evaluated the relationship between pavement temperature and the skid resistance value, they concluded that the SN value decrease when the pavement temperature is increased as shown in the regression formula in Equation (2-6):

$$SN_{OR} = 5.09 – 0.232 T_p \quad (2\text{-}6)$$

Where:

SN_{OR} = short-term weather-related component of the skid number intercept.

T_P = pavement temperature (°C).

Similarly, Oliver (1989), studied the effects of pavement temperatures on skid resistance values obtained from the British pendulum tester (BPT). These authors determined a significant relationship between skid resistance values, as measured by BPT, and the pavement surface temperature, as shown in Equation 2-7:

$$SR_{Vt}/SR_{V20} = 1 - 0.00525\ (T_p - 20) \qquad (2\text{-}7)$$

Where:

T_p = pavement temperature (°C),

SR_{Vt} = the skid resistance value obtained at temperature t (°C), and

SR_{V20} = the skid resistance value obtained at (20 °C).

2.3.3.2 Influence of contaminants

Contaminations of pavement surfaces can have major effects on the skid resistance of roads. These contaminations have a direct effect on contact areas between tyres and the pavement surface (adhesion and hysteresis forces). Contamination is an important issue in the friction process, especially in wet weather when contaminants are mixed with water between the tyre and pavement surface. The hazardous contamination effects for road users can be established at first rainfall, as these contaminations build a slippery, thin layer on the road surface (coating the pavement texture), causing a reduction in skid resistance of the pavement surface.

Figure 2-3, cited from Bennis and De Witt (2003), explains the variations in skid resistance, in the presence of contaminants, during rain over a five minute experimental span. This figure shows that skid resistance of the pavement surface during the first minute (dry weather) was 0.82. A significant reduction in this value occurs when rain starts to fall, the skid resistance drops from 0.82 to 0.37. This sharp reduction is caused by the rain and contaminants on the road surface (by creating a thin coating on the pavement). With continuous rainfall, this coating is gradually washed away and removed from the surface, therefore the skid resistance increases slightly under wet weather conditions (the effect of rain only). From the figure, skid resistance progressively returns to the original value (skid resistance in dry conditions), when rainfall ends.

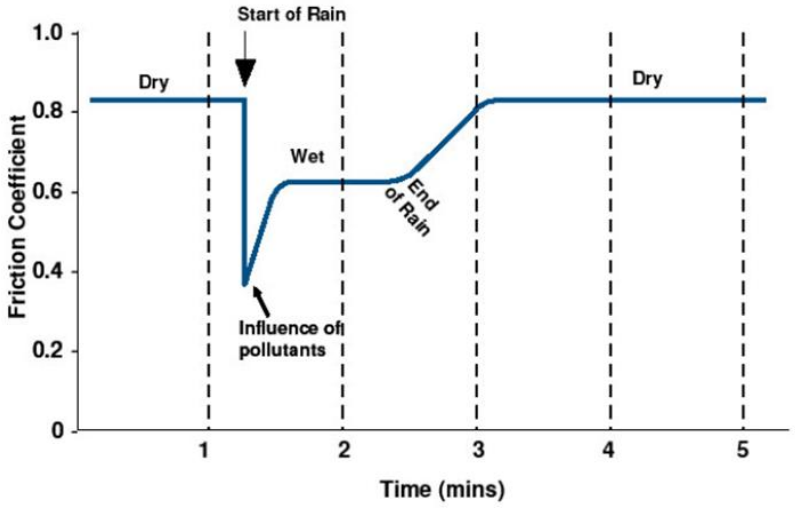


Figure 2-3: Effect of surface contamination on the skid resistance during the rain event (Bennis and De Witt, 2003)

2.4 Measurement of skid resistance

As shown in Table 2-1 there are several implements are used to measure the friction of the pavement surface. There are three primary operating principles when using implements to measure friction: side force coefficient (SFC), longitudinal friction coefficient (LFC), and stationary, sliders, or slow-moving measurement principles. The use of the LFC principle involves the establishment of a controlled sliding process of the tyre by applying a braking force. The effect of this is the vehicle when is blocked and rotates slower than the vehicle's forward speed. Tools which operate based on this principle use a broad array of slip ratios is deployed in the evaluation and comparison of vehicle and tyre speeds (Flintsch *et al.*, 2012; Andriejauskas *et al.*, 2014). Flintsch *et al.* (2012) note that the SFC principle employs an instrumented measuring wheel fixed at what is referred to as the slip angle, to the direction in which the vehicle is travelling. This slip angle brings about friction between the road and the tyre as it leads to the tyre slipping over the road surface. A resulting sideways force along the axle of the wheel in them measured (Flintsch *et al.*, 2012; Andriejauskas *et al.*, 2014) . Then the SFC is given as a ratio of the sideways force to the perpendicular reaction between the pavement surface and the tyre. Stationery,

sliders or slow-moving measurement principle covers devices usually employed in stationary testing. This is the group that most laboratory devices fall. Rubber sliders which are fixed to either a rotating head or pendulum arm are used by these devices and slow down during contact with the pavement surface. Greater detail about the variability of tyre-pavement friction properties can be obtained through the use of Continuous Friction Measuring Equipment (CFME). They operate on either the SFC or LFC principle and, according to Flintsch *et al.* (2012) have gained increasing attention across the world. Yager (2014) provides more details regarding the commonly used CFMEs. It is reported that CFMEs are sensitive to testing speed and water film thickness. Najafi *et al.* (2013) report that measurements obtained from Grip Tester, a CFME, are affected by grade with better accuracy mostly obtained on flat surfaces. In Europe, skid resistance is usually measured using the sideway-force coefficient routine investigation machine (SCRIM). SCRIM was developed in the early 1970s by UK by TRRL. In SCRIM a test wheel is applied to the surface of the road under the force of a vertical know. The test-wheel is basically a mounted mid-machine which is placed in line with the track and at an angle of 20° travel direction. Once the wheel is applied on the road, the surface of the road is wetted using a water jet in the front of the wheel. This is done so that the forwards movement of the vehicle results in the sliding of the test wheel in the forward direction on the wet road while at the same time rotating freely in its own plane. A correlation of the wet skidding resistance of the surface of the road to the force generated by the resistance to sliding is then performed. The sideway component that is measured in this procedure allows the calculation of the SCRIM coefficient. According to the British Standards Institution, SCRIM test is performed at 50 km/hr (British Standards Institution, 2006).

Table 2-1: Summary of skid resistance measuring devices (Descornet *et al.,* 2006; Andriejauskas *et al.*, 2014)

Title	Measurement principle	Main parameters	Tyre and wheel load	Measurement device view
ADHERA	Longitudinal friction coefficient (LFC)	Water film thickness: 1.0 mm; Measures macrotexture; Measurement speed: 40, 60, 90, 120 km/h; Measurement interval: 20 m	PIARC smooth profile tyre 165R15 (180 kPa); Wheel load: 2500 N	
BV-11	Longitudinal friction coefficient (LFC)	Slip ratio: 0.17 or 17%; Water film thickness: 0.5–1.0 mm; Measurement speed: 70 km/h; Measurement interval: 20 m	Trelleborg type T49 tyre (140 kPa); Wheel load: 1000 N	
Grip Tester	Longitudinal friction coefficient (LFC)	Slip ratio: 0.15 or 15%; Water film thickness: 0.5 mm; Measurement speed: 5–100 km/h; Measurement interval: 10–20 m or other	254 mm diameter smooth profile ASTM-tyre (140kPa); Wheel load: 250 N	
Road STAR	Longitudinal friction coefficient (LFC)	Slip ratio: 0.18 or 18%; Water film thickness: 0.5 mm; Measures macrotexture; Measurement speed: 30, 60 km/h Measurement interval: 50 m	PIARC tyre with tread; Wheel load: 3500 N	
ROAR DK	Longitudinal friction coefficient (LFC)	Slip ratio: 0.2 or 20%; Water film thickness: 0.5 mm; Measures macrotexture; Measurement speed: 60, 80 km/h Measurement interval: >5 m	ASTM 1551 tyre (207 kPa); Wheel load: 1200 N	
ROAR NL	Longitudinal friction coefficient (LFC)	Slip ratio: 0.86 or 86%; Water film thickness: 0.5 mm; Measures macrotexture; Measurement speed: 50, 70 km/h Measurement interval: 5–100 m	ASTM 1551 tyre (200 kPa); Wheel load: 1200 N	
RWS NL Skid Resistance Trailer	Longitudinal friction coefficient (LFC)	Slip ratio: 0.86 or 86%; Water film thickness: 0.5 mm; Measurement speed: 50, 70 km/h; Measurement interval: 5–100 m	PIARC smooth profile tyre 165R15 (200 kPa); Wheel load: 1962 N	
SCRIM	Sideway friction coefficient (SFC)	Slip angle: 20°; Water film thickness: 0.5 mm; Measures macrotexture; Measurement speed: 50 km/h; Measurement interval: >10 m	Avon SCRIM smooth profile tyre 76/508 (350 kPa); Wheel load: 1960 N	
Skid do-meter BV-8	Longitudinal friction coefficient (LFC)	Slip ratio: 100% or 14%; Water film thickness: 0.5 mm; Measurement speed: 40, 60, 80 km/h; Measurement interval: 30–50 m	AIPCR tyre with longitudinal tread 165R15; Wheel load: 3500 N	

Title	Measurement principle	Main parameters	Tyre and wheel load	Measurement device view
SKM	Sideway friction coefficient (SFC)	Slip angle: 20°; Water film thickness: 0.5 mm; Measurement speed: 50 km/h; Measurement interval: 100 m or other	Smooth profile tyre; Wheel load: 1960 N	
SRM	Longitudinal friction coefficient (LFC)	Slip ratio: 15% or 100%; Water film thickness: 0.5 mm; Measurement speed: 40, 60, 80 km/h; Measurement interval: 20 m or other	AIPCR tyre with longitudinal tread 165R15; Wheel load: 3500 N	
TRT	Longitudinal friction coefficient (LFC)	Slip ratio: 25%; Water film thickness: 0.5 mm; Measurement speed: 40–140 km/h; Measurement interval: 20 m or other	Smooth profile ASTM tyre; Wheel load: 1000 N	
SRT-3	Longitudinal friction coefficient (LFC)	Slip ratio: 100%; Water film thickness: 0.5 mm; Measurement speed: 60 km/h	Tyre with tread (200 kPa)	
IMAG	Longitudinal friction coefficient (LFC)	Slip ratio: 100%; Water film thickness: 1.0 mm; Measurement speed: 65 km/h	PIARC smooth profile tyre; Wheel load: 1500 N	
DFT Dynamic Friction Tester	Rotating friction	For stationary measurements	–	
SRT Pendulum	Pendulum test	For stationary measurements	–	
T2GO	Slow-moving measurement; Longitudinal friction coefficient (LFC)	Slip ratio: 20%; Used for pedestrian/bicycle paths, road marking	Two 75 mm width tyres	
VTI Portable Friction Tester (PFT)	Slow-moving measurement; Longitudinal friction coefficient (LFC)	Used for pedestrian/bicycle paths	–	

2.5. Management of skid resistance

Many highway agencies around the world have different standards for the management of skid resistance. These agencies use different approaches to set adequate thresholds for highways, based on relationships between skid resistance and local traffic accident rates, especially in wet weather. These agencies build their standards by using a number of statistical techniques to prove relationships between the skid resistance of pavement surfaces and traffic accident rates. These techniques are (Jellie, 2003):

- Before and after studies: this technique measures the traffic accident rate for a specific section of highway before and after surfacing. It evaluates the increase in skid resistance due to resurfacing on the traffic accident rate, by comparing the traffic accident rate before and after the resurfacing.
- Comparison with the Norm studies: this technique is based on the identification of sites as reference sites or control sites for the whole network. These sites are used to compare the traffic accident rates and skid resistance for these sites, with other sites for the same network.
- Regression studies: This technique uses a regression correlation between skid resistance and accident rates. Then, the changes in skid resistance on traffic accident rates can be evaluated.

2.5.1 UK approach

Giles (1957) proposed the first comprehensive standards on skid resistance, suggesting four site categories based on the requirements for wet skid resistance and a minimum coefficient of friction, as measured by the sideways force coefficient (SFC) device at 30 mph (SFC30). The requirements were based on comparisons between SFC data at 'accident black-spots' and SFC taken at random, at similar sites. The site categories had SFC30 limits of 0.6, 0.5, 0.4, and no requirements (Table 2-2).

Table 2-2: Suggested site categories and sideway force coefficients (Giles, 1957)

Category	Type of site	Sideway force coefficient on the wet surface at 30 mi/hr. with a smooth tyre
A	"Most difficult sites", such as: 1. Roundabouts 2. Bends with radius less than 500 ft on fast derestricted roads 3. Gradients, 1:20 or steeper, of length greater than 100 yd 4. Approaches to traffic lights on derestricted roads	Above 0.6
B	"General requirements", i.e: Roads and conditions not covered by categories A and C	Above 0.5
C	"Easy sites", e.g.: Mainly straight roads with easy gradients and curves and without junctions and free from any features such as mixed traffic, especially liable to create conditions of emergency	Above 0.4
D	"Proved sites" Roads with coefficients below 0.4 which, because of factors such as very slow or infrequent traffic, cannot be shown by accident studies to be above normal danger	

In 1970, earlier target values were reviewed and included in the UK Ministry of Transport's Marshall Committee report (Marshall, 1970). The category for no SFC was removed, and the requirement for the highest category was reduced from 0.6 to 0.55. Based on this earlier work Salt and Szatkowski (1973) developed LR 510: '*A guide to levels of skid resistance for roads which defined desirable levels of wet skidding resistance, based on the difficulty of the site*'. This guide recommended different skid resistance values for:

- Most difficult sites (roundabouts and sharp bends)
- Average difficult sites (motorways and high-speed roads, heavily trafficked urban roads)

- Other sites (mainly straight roads with easy gradients and curves and no junctions)

The main difference with the (TRRL) proposals was that they included risk ratings, which could be determined locally, for the accident potential geometry and location of each site. In 1976, the UK Highways Agency, then the UK Department of Transport, promulgated the Technical Memorandum H16/76 which stipulates requirements for aggregates and depths of texture for new bituminous roads based on different types of highway layout and traffic flow. The UK National Skid Resistance Survey undertaken by (Rogers and Gargett, 1991), and the subsequent accident risk analysis, confirmed the findings of LR 510. These initiatives took the work of Salt and Szatkowski (1973) further by defining site categories more precisely, according to accident rate.

An assessment of the benefits of monitoring road networks and the introduction of standard UK HD 15/87 in 1988, demonstrated it would be 'extremely cost effective' in reducing road casualties, with a predicted return of £5.5 for every pound spent due to accident reductions. This mandatory standard (later contained in HD 28/88 and HD 28/94) recognised that skid resistance in practice could vary significantly, due to the nature of individual sites within site categories. It therefore specified thresholds for investigation (ILs) rather than thresholds for intervention. Sites with skid resistance and/or surface textures at, or below the appropriate IL were then subjected to site investigations to evaluate whether or not monitoring and/or remedial action was needed to improve skid resistance, or if an alternative action was needed, to improve the site in some other way. In attempting to equalise the risk of skidding accidents across the strategic roads in the UK, the varying characteristics of the network (including geometry and other factors) were defined in terms of 13 site categories e.g. dual carriageway non-events, single carriageway non-events, approaches to major intersections, bends of less than 250 m etc. These site categories were given an IL that was specified in terms of the Mean Summer SCRIM Coefficient (MSSC). The HD 28/94 standard has been recently revised to incorporate the findings of the accident risk study undertaken by Viner *et al.* (2005). The main

concepts of the earlier standard were proven, and they remain features of the revised standard published as HD 28/15. The new developments, incorporated into the revised standard, are summarised:

- The incorporation of developments to the SCRIM and new updated survey procedures;
- Removal of slow speed testing at sharp bends and roundabouts (due to improvements in the SCRIM measurement system);
- Rationalisation of the SCRIM site categories from 13 to 10;
- Revision of some investigatory levels, and,
- Introduction of a range of ILs for each site category.

The UK approach classified the site category for strategic roads into 10 categories (Table 2-3).

Table 2-3: Site categories and (IL) (Highway Agency, 2015)

Site category and definition		Investigatory level at 50km/hr							
		0.30	0.35	0.40	0.45	0.50	0.55	0.60	0.65
A	Motorway								
B	Dual carriageway non-event								
C	Single carriageway non-event								
Q	Approaches to and across minor and major junctions, approaches to roundabouts and traffic signals								
K	Approaches to pedestrian crossings and other high-risk situations								
R	Roundabout								
G1	Gradient 5-10% longer than 50m								
G2	Gradient >10% longer than 50m								
S1	Bend radius < 500m – carriageway with one-way traffic								
S2	Bend radius < 500m – carriageway with two-way traffic								

2.5.2 Australia approach

The main principle of the Australian approach for skid resistance standards was based on the friction demand for different sites and sections of highways. (Neaylon, 2011)

Identified factors that had significant impacts on friction demands:

- Average annual rainfall
- Population density.
- Topography.
- Traffic volume.
- Climate/ seasonal rainfall.

Thus, using these factors, Australia was divided into four zones based on friction demand:

Zone 1: Low Skid Resistance Demand

- Hot and dry weather (the probability of rain is very low).
- Very low traffic.
- Flat terrain (desert area).
- Dispersed road network.

Zone 2: Medium Skid Resistance Demand

- Hot and dry weather (the probability of rain is very low).
- Low traffic.
- Flat terrain (non-desert area, with small areas of undulating terrain).
- Road network intensity is more than zone 1.

Zone 3: High Skid Resistance Demand

The characteristics of this zone are due to climate, traffic levels and terrain (very similar to conditions in the UK):

- Wet weather (the probability of rain is high).
- High traffic volume.
- Undulating terrain.
- Road network intensity is more than zone 2.
- High population density.

Zone 4: High Density Urban

This special zone represents the large cities in Australia such as Brisbane, Sydney and Melbourne:

- Wet weather (the probability of rain is very high).
- Very high traffic volume.
- Undulating terrain.
- Road network intensity is more than zone 3.
- Very high population density.

In 1982, ILs of skid resistance are in SCRIM units (SFC50) were originally obtained from the UK practice and started being used in Australian practice. However, there are major differences between the UK and Australia when it comes to climatic conditions, the geometry of the road, and traffic volumes, thus, the skid resistance ILs being revised in 1996 and incorporated into the guidelines of the Australia roads in 2003. The prevailing skid resistance ILs for different site categories are illustrated in Table 2-4.

Table 2-4: Investigatory Level of Skid Resistance in Australia (Neaylon, 2011)

Site category	Site description	Investigatory levels of SFC50 AT 50 Km/hr or equivalent						
		0.30	0.35	0.40	0.45	0.50	0.55	0.60
		Corresponding risk ratings						
		1	2	3	4	5	6	7
1	Traffic light-controlled intersections	Investigation Advised						
	Pedestrian/school crossings Railway							
	Roundabout approaches							
2	Curves with tight radius =< 250 m							
	Gradients >=5% and >= 10% 50 m long							
	Freeway/highway on/off ramps							
3	Intersections							
4	Manoeuvre-free of undivided roads							
5	Manoeuvre-free of divided roads							
Site category	Site description	Investigatory levels of SFC50 AT 50 Km/hr or equivalent						
		0.30	0.35	0.40	0.45	0.50	0.55	0.60
		Corresponding risk ratings						
		1	2	3	4	5	6	7
6	Curves with radius =<100 m	Investigation Advised						
7	Roundabouts							
Key to thresholds at or below which investigation is advised								
	All primary roads, and for secondary roads with more than 2500 vehicles per lane per							
	Roads with less than 2500 vehicles per lane per day							

2.5.3 New Zealand approach

New Zealand' s skid resistance standards are based on those adopted by the UK, with some adjustments based on analyses performed in 1997, involving wet skidding injury accidents in New Zealand, over the period 1990-1994 (Transit and Roading, 2005). Transit New Zealand first published TNZ T/10 in 1999 '*Specification for skid resistance investigation and treatment selection*' (from which ILs are shown in Table 2-5). A revised and current specification was published in 2002 (Transit New Zealand, 2002). The T/10 specification also specifies Threshold Levels (TLs) for each site category, which are set 0.1 below the IL. Transit New Zealand's policy defines skid resistance for five site categories of IL and TL, using Mean Summer SCRIM Coefficients (MSSC) to standardise wet-road skidding accident risks across the network (Cook *et al.,* 2004).

Table 2-5: Skid resistance investigatory levels (NZTA T10, 2013)

Site category	Skid site description	Investigatory level	Threshold level
1	Approaches to Railway level crossings	0.55	0.45
	Approaches to Traffic signals		
	Approaches to Pedestrian crossings		
	Approaches to stop and give way-controlled intersections (where state highway traffic is required to stop or give way)		
	Approaches to roundabouts		
	Approaches to bridges		
2	Urban curves <250m radius	0.50	0.40
	Rural curves <250m radius		
	Rural curves 250–400m radius		
	Down gradients >10%.		
	On ramps with ramp metering		
3	State highway approach to a local road junction	0.45	0.35
	Down gradients 5 – 10%		
	Motorway junction area including on/off ramps		
	Roundabouts, circular section only		
4	Undivided carriageways (event–free)	0.40	0.30
5	Divided carriageways (event–free)	0.35	0.25

2.6 Factors affecting road accidents

The relationships between accidents and traffic characteristics (annual average daily flow heavy vehicle percentage, speed limits), geometric characteristics (radius of curvature, gradients, number of lanes, number of minor accesses), and pavement characteristics (skid resistance, rut depths, mean texture depths) have been subject to a number of studies. The effects of these factors are discussed below.

2.6.1 Traffic characteristics

2.6.1.1 Annual average daily flow

Literature considers traffic flow as one of the most significant antecedents of accidents. Average Daily flow (i.e. ADF) or Annual Average Daily Flow (i.e. AADF) are used by most studies to represent traffic flow. The reason why these variables are popular is that they are easily available in traffic datasets. A large number of authors have found AADT to have a relative correlated with traffic accidents in varying roadway features, meaning that the busier the road, the more accidents are expected on it. For instance, Ma *et al.* (2017) employed Negative Binomial and random effect Negative Binomial models in their investigation of the association between the frequencies of accident occurring on a 50 km expressway in China between 2006 and 2008 and prospective influencing factors. Conclusions drawn indicate that the AADF, have significant effects on the frequency of accidents. In addition, Li *et al.* (2017) employed Negative Binominal for rural roadways with two lanes in Pennsylvania using an inclusive set of data which included more than 21,300 distinct roadway segments and accident data collected over a period of eight years. From the results, it was concluded that the AADF, have significant positive effects on the frequency of accidents. Another study conducted by Anastasopoulos and Mannering (2009) investigated the factors which impact on accident frequencies from interstate highways in rural Indiana. For this study, they employed random parameters Negative Binomial models. Based on the results of their study, the authors advance the argument that in the vast majority of road segments there is an increase of accidents with increasing AADF with only a few segments seeing decreasing numbers

of accidents. Alarifi *et al.* (2017) employed the Bayesian Multilevel Poisson-lognormal approach with the aim of predicting accident numbers in 208 roadway segments and 247 signalized intersections along 20 Florida corridors. With regards to major variables for roadway segments in the form of signalised intersections, the AADF was concluded to have a positive association with the occurrence of accidents at roadway segments. In a related study, Wang *et al.* (2017) presented the use of Multivariate Poisson lognormal modelling with the objective of estimating accidents according to severity and type at three-way stop-controlled intersections, four-way signalized, and four-way stop controlled intersections in the state of Minnesota and also in road segments in rural Washington state that have two lanes. Demonstrations by the model's coefficient estimates are that AADF have a significant effect on accident counts by accident severity and type. A predictive model for roads in urban areas that has the capacity to approximate the number of accidents for three highway sections in Italy's urban road network was developed by Gianfranco *et al.* (2018) using a Negative Binomial model. These segments included a three- or four-way junction, a roundabout and a straight stretch of road. Results from the modelling showed that accident occurrences in the three situations are considerably positively linked to AADF. Random parameters Negative Binomial model was applied by Rusli *et al.* (2017) in the examination of factors that contribute to single vehicle accidents along rural roads passing through mountains in Malaysia. Conclusions from this study indicated that AADF was positively linked to single vehicle accidents.

2.6.1.2 Heavy vehicle percentages

A number of authors have concentrated their efforts on the impact of the percentage of heavy vehicles on traffic accident employing various models. For instance, Sun *et al.* (2013) established the safety performance function for Chinese freeways using Negative Binomial model. The results showed that increasing heavy vehicle percentages were associated with increases in accident frequencies. Garach *et al.* (2016) explored the link between the frequency of accidents and a number of variables related to geometry, exposure, context, and consistency for two-lane rural

roads in Spain passing through flat terrain using Negative Binomial model. Again, results from this study proved that the percentage of heavy vehicles has a high influence on accidents. There is a positive sign in this variable: the higher the percentage of vehicles, the higher the higher the number of accidents.

The study by Kibar *et al.* (2017) focused on finding the relation between traffic, geometric road characteristics and truck accidents for interurban multilane roads that are divided in Ankara on the Aksaray–Eregli route in Turkey employing Negative Binomial model. Based on the model they developed, it was concluded that heavy vehicle percentages where a significant variable: increased heavy vehicle percentages showed a positive effect on the truck accident rate. In addition, Hosseinpour *et al.*(2014) presented factors that affect both severity and frequency of head-on collisions which happened on 448 segments of five federal roads in Malaysia. For this study, they used random-effect negative monomial model. Using the results obtained from the model, it was concluded that heavy vehicle traffic is positively linked to head-on collision frequency.

In Ohio, a Negative Binomial model was used by Schneider *et al.* (2009) to conduct an analysis of truck accidents in arterial and collector two-lane road's horizontal curves. The results produced showed that the substantial increase in accidents involving trucks is associated with the percentage of the heavy vehicle as a proportion of daily traffic. An approach was established for the analysis of the influence of the percentage of heavy vehicles on accidents in various kinds of interurban roads in Spain, through the application of Negative Binomial regression model. Results from the use of this model showed that, with varying highway types, the effect of heavy vehicles on safety is negative, which is turned into a significant increase in the number of accidents on single carriageway roads (Ramírez *et al.*, 2009).

The study by Wang *et al.*(2015) employed a hierarchical Bayesian model with the aim of estimating the aggregate number of accidents occur on segments along eight arterials roads in the suburbs of Shanghai in China. Like the other studies above, results showed that as the traffic of heavy vehicles increased, so also did the number of accidents. A similar study by Dong *et al.* (2014) created and presented a

multivariate regression model of car, car truck, and truck accidents frequencies using data on accidents happening in urban signalised intersections in Tennessee. Findings from this study indicated that there was a significant positive correlation between truck percentage and car-truck and truck accident frequencies. Kamla *et al.* (2016) studied the effect that heavy vehicles have on roundabout accidents using random parameters Negative Binomial model to develop models that can be used for the prediction of accidents for an aggregate of 70 roundabouts on A-class roads and motorways in the United Kingdom. The results indicated that the number of accidents increase as the truck percentage also increase.

2.6.1.3 Speed limit

There is a substantial amount of studies of the relationship which exists between speed limit and accidents. One of these was commissioned by Hauer *et al.* (2004) who created a statistical model which forecasts the frequency of on non-intersection accidents in four-lane undivided roads passing through urban areas in Washington. The modelling highlighted that roads, where low speeds were recorded, had increased risk. These findings are in agreement with those of Zhang and Ivan (2005) who employed Negative Binomial generalized linear models in their evaluation of the impact of geometric features on roadways on the occurrence of head-on accidents on roads with two lanes in Connecticut. From this study, results showed that increasing speed limits at roadway segments were associated with lower head on accidents. In another study, Rista *et al.* (2018) commissioned a study to assess the impact of traffic and roadways geometric on the safety performance of roads in urban and suburban arterial segments in Nebraska, USA, using random parameter Negative Binomial models. Ten years of accidents, traffic volume, and roadway geometric data were analysed to discern differences in sideswipe frequencies; same direction and rear-end accidents across four functional classes of urban arterial roads. The results revealed that increasing speed limits led to decreases in frequency of both sideswipes and rear-end accidents. Another study by Zhao *et al.* (2018) conducted an analysis of accidents which occurred on approaches of signalised intersections on collector

roads and urban arterials using a multivariate Poisson Log-normal. Data for accidents on 634 signalised intersection collected over a period of ten years was collected. The urban areas used for the study were Lincoln and Omaha, Nebraska. The authors classified the accidents into three segments based on their severity: light, moderate, and severe accidents. The authors concluded that approaches with speed limits that are 45mph or higher are linked to lower accident frequencies for all three categories.

2.6.2 Geometric characteristics

2.6.2.1 Radius of curvature

When it comes to the impact of road geometric characteristics on traffic accidents, one of the most commonly accepted notions is that sharp curves are associated with higher frequencies of accident. Peters and Iagnemma (2009) show that curves whose radiuses are small, which usually do not permit the required sight distance, are associated with more errors made by drivers and raise the lateral acceleration can result in the driver being unable to adequately control the vehicle. Milton and Mannering (1998) identify curve radius as one of the significant variables in road accidents. To estimate the yearly accident frequency on sections of principal arterials in Washington State, they used Negative Binomial regressions. Their findings indicate a robust correlation between the frequency of accidents and the radius of a horizontal curve: the bigger the horizontal curve, the lower the number of accidents. These results are in agreement with the conclusions drawn by Aram (2010) who concluded that where radii were less than 200 m accidents increased. Negative Binomial regression was employed by Li *et al.* (2017) in their development of regionalised safety performance functions (state-wide with district-specific indicators, district-level and county-level) for roadways with two lanes in Pennsylvania. According to the results of the analysis, the predicted aggregate accident frequency has a positive correlation with horizontal curve density and the curvature degree per mile. In another study, Rusli *et al.* (2017) used a random parameter, Negative Binomial model, to conduct an examination of factors which contributed to accidents involving a single vehicle travelling along rural roads and passing through mountains on

Malaysian highways. The study findings show that there was a negative association between the radius of curvature and single vehicle accidents.

2.6.2.2 Gradient

Roadway segments with high vertical grades are linked to high frequencies of accident. This is a reality supported by the study conducted by Miaou *et al.* (1992) who suggest a Poisson regression model approximate the rate of truck accidents on rural roads in an interstate in North Carolina. The model suggests that vertical grade was a major variable for increased truck accident rates. A similar study by Choueiri *et al.* (1994) also concluded that there is a tendency for accidents to increase in a linear manner as the grades increase. This is also a view supported by Shankar *et al.* (1995) who employ both the Negative binomial distributions and the Poisson in their evaluation of the impact of road geometric and environmental elements on accident rates in the rural areas of Washington State. The authors arrive at the conclusion that gradient seems to have a strong positive impact on the frequency of accidents. When compared to sections that have gradient of less than 2 percent, the segments with gradient exceeding 2 percent will have a substantial increase in the frequency of accidents by 14 %. Similarly, in his study, Harwood *et al.* (2000) arrived at the conclusion that with the increasing slope of the roadway segment, also came an increase in the number of traffic accidents. Results from the analysis showed that the rate of traffic accidents increased by between 3 and 14 % for slopes ranging between 2 and 8 %. Zeng *et al.* (2017) used three Bayesian hierarchical models for predicting monthly accident counts on freeway segments in Guangdong Province, China, in 2014. The results of the model indicate that there is a positive correlation between segment gradient and accident frequency.

2.6.2.3 Number of lanes

The majority of authors who conducted examinations on the impact of the number of road lanes on accidents arrived at the conclusion that the number of lanes is proportional to the frequency of accidents (Persaud, 1992; Milton and Mannering,

1998). However, estimates by Ma and Kockelman (2006) indicate that there is a relationship between the decrease in non-fatal accidents and the number of lanes and that it does not affect fatal accidents. The authors fail to deliver a clarification, but this is a result which could be understood to mean that when roads have more lanes the congestion is reduced and hence such roads would experience fewer accidents when compared to those that are congested and they are not fatal. With the aim of determining the impact of lane numbers on the frequency of accidents Park *et al.* (2010) did a comparison of roads that have six lanes with those with 8 lanes. The authors arrived at the conclusion that roads with 8 lanes had fewer accidents than those with 6. According to the authors, the reason behind this could be that roads with 8 lanes provide more space for a driver to manoeuvre and avoid accident. Park and Lee (2017) observed a similar perspective in exploring the impact of number of lanes on traffic accidents. They used seven major intersections in the USA state of Washington and employed a random parameter, Negative Binomial model. The results show that all segments with a low or standard number of lanes had a bigger effect on the rate of traffic accidents.

2.6.2.4 Number of minor access

A significant body of literature has been produced in the evaluation of access point number on traffic accidents. Mayora and Rubio (2003) created models for two distinct kinds of segments of roads with two lanes: 1 km fixed length segments and network links that join two successive nodes whose lengths differed and ranged between 3 and 25 kilometres. It was concluded that there is a positive correlation between access density and accidents. Eisele and Frawley (2005) published a study where they deliver a description of the association between access rate and accident rate data collected from 11 test corridors in Oklahoma and the Texas States using linear regression analysis. The conclusions show that there is a tendency for the accident rate to increase with increasing access density. This is a finding that is in agreement with that of Dinu and Veeraragavan (2011) who created models for the forecasting of accidents for night-time and day-time accidents over an accident history of three

years of almost three years of accident history involving almost 200km of segments of two-lane undivided roads in India using random parameters Negative Binomial model. In addition, Gianfranco *et al.* (2018) used a Negative Binomial model in their attempt to estimate the number of accidents on straight sections on a road network in urban Italy. The researchers concluded that there appears to be a positive relationship between accident occurrences and the parameter of the access point. Literature also reports a robust relationship between the access point and accident frequency at intersections. For instance, Alarifi *et al.* (2017) proposed a Bayesian Multilevel Poisson-lognormal joint model in their estimation of accidents for 247 intersections which are signalised and 208 segments of the road from the Broward and Orange counties in the state of Florida. Results produced from these models indicate that the aggregate number of intersection access points, as an aggregate of the access points inside the influence area escalates, so does the aggregate number of accidents. Similarly, Alluri *et al.* (2015) conducted an investigation on the effect of access features on accidents for 131 roundabouts in Florida's commercial areas. Conclusions from this analysis show that in areas with more access features, there were more accidents.

2.6.3 Pavement characteristics

2.6.3.1 Skid resistance

A number of studies have indicated how the severity and frequency of accidents are impacted on by pavement friction (skid resistance). In the UK, an accident model for skid resistance (SCRIM) on a single carriageway was developed by Viner *et al.* (2005). Using this model, the authors forecasted a 65% reduction in accident rates if skid resistance increased from 0.35 to 0.6. Kuttesch (2004) concluded that there is a statistically noteworthy effect of skid resistance on wet accident rates. This could be inferred to suggest that wet accidents rates escalate as the skid numbers fall down. Based on the conclusions, the researcher recommended that the threshold value should be set at 40 skid number in order to manage skid resistance in highways in Virginia.

Another study conducted by Mayora and Pina (2009) conducted an evaluation of the impact of skid resistance on both wet and dry accidents using data obtained from 1750 kilometres of two-lane roads in Spain. Conclusions were that with the increase in skid resistance values, there was a decrease in the rate of accidents. The mean projected safety impact of improving skid resistance from an average SCRIM value below 50 to values above 60 is a decrease in wet accidents by 68 % for tangent sections. On the other hand, the projected decrease in curves is greater when compared to tangents, with an average of 84 %. The same authors also propose a skid resistance threshold of 55 and 60 for tangent and curves, respectively.

Najafi *et al.* (2017) conducted an evaluation of skid resistance on both wet and dry accidents for different kinds of urban roads in New Jersey. They employed regression models with the aim of verifying the impact of skid resistance on the rates of wet and dry accident. They arrived at the conclusion that skid resistance is not only linked to wet accident rates but also affects the dry accident rates. In their own probability-based study performed on Turkish roads with four-legged signalised intersections study, Saplioglu *et al.* (2012) suggested that the rates of accident decreased with increases in skid resistance. According to the same authors, the probability that an accident will occur can be increased from 15 to 85 %, when the skid resistance number (British Pendulum Tester) decrease from 53.3 to 38. Negative Binomial models were employed by Labi (2011) who commissioned a study of the relationship existing between the frequency of accidents in terms of damage to property (PDO), injury, and fatal injury and pavement friction, using data obtained from 540 segments of two-lane rural roads in the US state of Indiana. The study concluded that road segments that have higher pavement friction had a lower number of accidents. The main collectors in rural areas had a higher reduction in the number of accidents owing to increases skid resistance. For example, the author reports that an increase of 5 units in friction resulted in a reduction of 9 % in road accidents. However, when it comes to rural minor arterials the increase in skid resistance had less effect; leading to a reduction of only 6 % in accidents. However, when compared to rural major collectors, an increase in skid resistance in minor arterials was concluded to be more

effective. Increasing the friction by 5 units lead to a reduction of fatal/injury accidents by 15 %, whereas a reduction of 8 % was recorded in rural major collectors.

2.6.3.2 Rut depth

According to Huang (2004), rutting can be defined as the depression of the surface along a wheel path. It could result from sub-grade of deformation of the pavement. When conditions are dry, rutting could become a wheel path forcing the driver to commit more effort to get out of the rutted path. In wet conditions, rutting can be more dangerous as water can collect in the rutted path and result in hydroplaning; the separation of the vehicle tyre from the pavement as a result caused by the pressure of the fluid beneath the tyre (Start *et al.*, 1998). A study by Hollo and Kajtar (2000) showed strong correlations between rut depth and accidents during wet conditions, when compared to accidents during dry conditions. The authors found that accident risk increased at 3 mm rut depths on dry road surfaces, and at 6 mm rut depths on wet surfaces. Also, the risk of a rut-related accident increased by 20% to 30% on wet road surfaces, when compared to dry surfaces. In addition, Cairney *et al.* (2005) commissioned a study on the relation between accidents and rutting on a major highway in Victoria, Australia. This study illustrated that the accident risk related to rutting increased only in those sites where the rutting was deepest. Sites, where the depth of ruts was 20mm or deeper, had an increase of 60 % in accident risk. However, a study conducted Chan *et al.* (2009) in Tennessee (USA) observed that rut depth had a significant impact on accident rates in the dark and for accidents linked to the wet surface. This is due to the fact that at night and with wet surface, the driver is unable to act fast enough to mitigate the effects of hydroplaning and prevent accident. A study to examine the impact of pavement rutting on the rate of accidents at undivided was rural highways in Wisconsin was commissioned by Start *et al.* (1998). The researchers measured the rut depth as an average value for both directions of segments measuring 1.8 km. Results showed that accidents linked to rut escalated as rut depths became bigger than 7.6 mm. This is a view supported by Elvik *et al.* (2009) whose study concluded that rut depths can be linked to increased

rates of accidents. Similar conclusions were drawn by Anastasopoulos *et al.* (2012) in their finding that high rutting usually leads to higher rates of accident, because when rutting is excessive, it increases the possibility of hydroplaning when there is presence of moisture which could, therefore, have a contributory effect on vehicle tracking and could result in loss of control as the driver attempts to change lanes or manoeuvre the vehicle.

2.6.3.3 Texture depth

Texture depth denotes the average gap which exists between the aggregates on road surfaces (Descornet, 1990; Gyenes and Mitchell, 1994). It is defined as the vertical variations in the road surface along a longitudinal path between 0 mm and 50 mm. The texture depth of the pavement has a significant impact on the performance of a vehicle's brakes. When the texture depth is lower, the car takes longer to come to a stop after the brakes have been applied. A closer look at literature indicates that there are limited studies dealing with the relation between accidents and mean texture depth. Studies conducted in Australia, France and the UK generally agree that sites of low texture depth present higher risks for accident. In the UK, Roe *et al.* (1991) studied relationships between the texture depth of the pavement and road accidents on motorways and major and minor roads. Texture depth at accident sites were measured using sensors and compared to the texture depth of the whole road network. It was found that accident sites, with the highest risk, increased when the texture depth was less than 0.6, 0.7, and 0.8 mm respectively for minor roads, major roads and motorways. This study found that a reduction in texture depth increased the number of traffic accidents. Moreover, UK research as shown that the lowest texture depth category had approximately 160 accidents/year/100 km and the highest texture depth category had an accident rate of approximately 100 accidents/year/100 km (Parry *et al.,* 2005). In France, the relationship between the texture depth and road accidents was studied by Gothie (1993) on approximately 215 km of national roads, in the Rhone-Alpes region. The study found that accident rates varied little for higher levels of mean texture depth, but increase rapidly when

mean texture depths fell below 0.5 mm. In Australia, Tredrea (2001) evaluated the relationship between texture depth and accidents on four urban routes and four rural routes in Victoria. The author showed there was a significant relationship between accident risk and texture depth of roads in rural areas. On the other hand, no relationship between texture depth and accidents were observed for urban areas. Another study on texture depth was carried out by Cairney and Styles (2005) on roads in Australia, including the Great Eastern Highway (Western Australia), Dukes Highway (South Australia), and Princes Highway (Victoria). In Western Australia and Victoria, 20 m sections of road were considered, while in South Australia 100 m sections were considered. The authors found that as texture depth fell below a critical value, the risk of accident increased. They observed a significant relationship between accident risk and the texture depth of roads in both urban and rural areas of the Great Eastern Highway, the Princes West Highway and the Dukes Highway. On the other hand, a marginal relationship between texture depth and accidents were observed for rural sections of the Princes Highway, while for rural sections of the Dukes Highway, there were no significant relationships between texture depth and road accidents.

2.7 Accident prediction models

2.7.1 Fixed and random Negative Binomial model's application

Random and fixed parameters Negative Binomial model was applied to account accident frequency at different roadway feature. For example, Anastasopoulos and Mannering (2009) employed a fixed and random parameter Negative Binomial model to evaluate the effects of pavement, geometrics and traffic characteristics on the frequency of accidents, using five-year data, from interstate highways in Indiana, USA. This research provided a demonstration of how a random parameter Negative Binomial regression, could gain insights into how different factors could significantly influence accident frequencies. The approach allowed one to account for and correct for heterogeneity that could arise from a number of factors relating to traffic,

geometric and pavement characteristics and other unobserved factors. In another study random parameters Negative Binomial model suggested as an outstanding approach for the development of accident prediction model to estimate the accident frequency on a 200 km stretch of highway segments on a two-lane undivided rural highway, using three years of accident history on Indian highways (Dinu and Veeraragavan, 2011). The estimation of fixed and random parameter Negative Binomial models for numerous aggregations of accidents was implemented using data collected on panel accidents that occurred between 1999 and 2007 in the interstates of Washington State in the USA. Several factors, including the severity of accidents, operational type, number of vehicles involved, geography, and collision type were used for the aggregations. The results produced by this model illustrate that, in general, the improvement in log-likelihood when random parameter Negative Binomial was used was more significant when compared to the fixed-parameter Negative Binomial baseline model (Venkataraman *et al.*, 2013). Another study conducted by Chen and Tarko (2014) used random parameter models to investigate the effects of exposure variables, roadway characteristics, work zone features and temporal variables on accident frequency. The study was carried out in highway work zones using detailed data from Indiana work zones on state-maintained freeway and non-freeway roads, in 2009 and 2010. The study discussed two statistical models developed to analyse work zone safety: a random parameter model and a random effects model. This study concluded that random parameter models provided more insights and had the most accurate parameter estimations. In a study by (Kamla, 2016) which examined traffic and geometric characteristics and their impact on accident statistics in 70 roundabouts on A-class roads and motorways in the United Kingdom, fixed and random parameter Negative Binomial models were used. Conclusions drawn from this thesis indicated that the random parameter Negative Binomial model was a better option when compared to the fixed parameter model. A study conducted in Gyeonggi-Do Province of factors that affected accident frequency in 72 signalised intersections over a period of four years between 2007 and 2010, employed fixed and random parameter Negative Binomial models. The experimental

results obtained from this comparison with the fixed parameter binomial model, illustrate that the random parameter model produces better results than the fixed parameter model does. It was also concluded that the random parameter model provides a better comprehension of elements that determine accident frequencies at intersections with traffic signals (Park *et al.,* 2016). In addition, Park and Lee (2017) investigated factors that affect accidents in road segments with and without lighting systems; the authors also used fixed and random parameter Negative Binomial models. Data employed in this study were gathered from the seven main interstates (5, 82, 90, 182, 205, 405, and 705) in Washington State (USA) over a nine-year period from 1999 to 2007. The aim of this study was to alleviate the deficiency of the fixed parameter model, which forced the estimated parameters to be fixed across observations; the use of random parameters made it possible to take into consideration the unobserved heterogeneity.

Generally, evidence shows that inferences delivered by random parameter models are more superior compared with traditional fixed parameters models. It has also been shown as the better choice in terms of accounting for heterogeneity across sites resulting from unobserved factors, which could have an impact on accident frequencies.

2.7.3 Fixed and random parameter Tobit model's application

With the aim of finding alternatives to models based on accident frequency, regression models, which use accident rates as a basis, could be considered as alternate. From a statistical modelling point of view, the accident rate is a continuous random variable, as opposed to accident frequency, which is a discrete random variable. However, because of the reality that accidents in certain road segments are evaluated over time periods that are generally limited, there is always a possibility that numerous road segments may have no accidents reported during the observation period; a possibility that does not conform to assumptions made by the continuous random variable. To forecast accident rates, previous studies used fixed random Tobit models in the area of transportation. Examples on this include the study

of Anastasopoulos et al. (2012), which developed fixed and random parameter Tobit models to forecast accident rates using data collected over nine years from interstates in urban Indiana. Results obtained illustrate that the random parameter Tobit model performs better compared with the fixed-parameter model. It also provides the possibility of acquiring a better comprehension of elements responsible for accident rates on particular roadway segments. In addition, Anastasopoulos, (2016) employed data obtained over a five-year period from 2005 to 2009 in Indiana to predict fixed and random parameter multivariate Tobit count data models of accident injury severity rates. Using goodness-of-fit and forecasting accuracy measures, and the log- likelihood ratio test, it can be illustrated that the random parameter multivariate Tobit is statistically better than the use of fixed parameters. In a related study, Caliendo *et al.* (2016) implemented an analysis of severe accidents (involving injuries and fatalities) that occurred over a period of four years. Data were obtained from 260 road tunnels in Italy based on the random parameter Tobit model. This approach shows that some regression model parameters should be perceived as random variables, and therefore, contribute to the acquisition of new insights into how matching covariates impact the rate of accidents. Zeng *et al.* (2017) suggested a multivariate random parameter Tobit model when they analysed accident rates that occurred over a five-year period, between 2002 and 2006, in 224 directional road segments in Hong Kong. Results show that the multivariate random parameter Tobit model delivered a superior fit compared with the fixed parameter model, based on the deviance information criteria (DIC). Moreover, the random-parameter Tobit model made possible a more detailed comprehension of the effects of factors on accident rates according to injury severity. Hence, it can be perceived as better than the multivariate Tobit model, making it an excellent alternative for traffic safety analysis. In a related study, Park and Lee (2017) employed nine years of panel data, collected between 1999 and 2007 and linked to severe injury accidents in the state of Washington, to develop a random parameter Tobit model. Their results illustrate that the Tobit regression model with random parameters is a superior strategy when

exploring factors that impact on severe injury accident rates in roadway segments under inspection for unobserved heterogeneity problem.

2.8 Summary

In summary, this chapter has reviewed studies investigating factors that affected skid resistance, the measurement of skid resistance, skid resistance policy, factors affecting road accidents and accident prediction models:

1. Factors affecting skid resistance

- Pavement texture

Due to both adhesion and hysteresis forces induced between passing tyre and pavement surface both micro-texture and macro-texture are considered as main factors that responsible for level of friction.

- Aggregates

Aggregate properties for wearing layers, such as aggregate polishing and shape, size and spacing of aggregate particles, are main factors that have ruled the value of skid resistance for the pavements surface.

- Environmental factors

The skid resistance of pavement surfaces varies due to environmental factors, such as air, pavement and tyre temperature; and contaminants. These factors affect pavement texture properties (micro-texture and macro-texture properties).

2. Measurement of skid resistance

In terms of skid resistance measurements, several instruments can measure skid resistance. This chapter summarised the main skid resistance measurement devices. In the UK, the sideway-force coefficient routine investigation machine (SCRIM) is usually used to measure the skid resistance.

3. Skid resistance policy

Many highway agencies around the world have different standards for the management of skid resistance. These agencies use different approaches to set adequate thresholds for highways, based on relationships between accident rate and

skid resistance. This chapter highlighted the UK, Australia and New Zealand approaches to skid resistance management.

Generally, highway agencies recognise the importance of research studies in supporting the development of maintenance programmes for pavement characteristics. This is especially true for skid resistance, which must be incorporated into pavement management systems. In 1988, the Design Manual for Roads and Bridges in the UK introduced a skid resistance policy HD28/88, to identify skid resistance threshold for different site categories on strategic roads. Despite the differences between main roads and local authority roads in terms of traffic volumes, road geometrics and speed, this policy was applied to most of the local highway agencies in the UK, to manage skid resistance levels. Few studies have been carried out on skid resistance policy for strategic roads (e.g. Viner *et al.,* 2004), however no study has reviewed this policy in terms of skid resistance thresholds and site category definitions, for local authority roads in the UK.

4. Factors affecting road accidents

Improving road safety is considered as one of the most vital objectives for highway agencies. Thus, it is necessary to evaluate the main factors that effect on traffic accidents.

This chapter provided a wide review of the current literature on various factors affecting traffic accidents, including traffic characteristics (annual average daily flow, percentage of heavy vehicles, speed limits), geometric characteristics (radius of curvature, gradients, number of lanes, number of minor accesses), pavement characteristics (skid resistance, rut depths, texture depths). For all these variables, the results were not entirely consistent between studies. In summary, based on the most frequent findings of the reviewed literature:

- ✓ Roadway segments with high traffic flows are related to higher accidents.
- ✓ Increases of heavy vehicles in traffic streams generally lead to increased accidents.
- ✓ Speed limits rises at roadway segments generally lead to decreased accidents.
- ✓ Sharp curves are associated higher accidents.

- ✓ Steep vertical grades are related with higher accidents.
- ✓ Road segments with fewer lanes are associated with higher accidents.
- ✓ A positive correlation was found between accidents and access density.
- ✓ A significant reduction in accidents are related to increased skid resistance.
- ✓ A strong positive correlation was determined between rut depth and accidents, especially during wet conditions.
- ✓ Roadway segments with high texture depth is expected to have lower accidents.

5. Accident prediction models

A considerable amount of statistical approach that used to predict the frequency and rate of accidents on road segments. The literatures emphasised that random parameter approaches were proven to be the most appropriate statistical model for modelling accident counts due to:

- The random parameters model allowed the independent variable parameters to vary across accidents, leading to more accurate results. On the other hand, if independent variable parameters were considered fixed across the accident observations, the model may be biased, and provide wrong conclusions.
- The random parameters model was considered a viable approach to account for accident frequencies and rates, due to the ability of this approach to account and correct for heterogeneity, arising as a result of several factors, affecting accident frequencies and rates.

CHAPTER THREE

DATA DESCRIPTION AND METHODOLOGY

CHAPTER THREE: DATA DESCRIPTION AND METHODOLOGY

3.1 Overview

One of the main objectives of this thesis is to discover the relation between dependent variables: total, dry, wet, slight and serious and fatal accidents frequencies and rates and independent variables: traffic (natural logarithm of annual average daily flow, percentage of heavy vehicles, speed limits); geometrics (radius of curvature, gradients, number of lanes, and number of minor accesses); and pavement characteristics (skid resistance, rut depth, and texture depth). Accidents are evaluated from two aspects: accident frequency and accident rate. Accident frequency refers to the number of accidents on particular spatial units (e.g. roadway segments) during specific time periods (e.g. a year). Accident rate refers to the number of accidents per 100 million vehicles on a roadway segment, over a certain time period. This thesis will examine the effects of traffic, geometrics and pavement characteristics on these two accident aspects, using a road segment level analysis, applying two statistical approach:

- Fixed parameter Negative Binomial (FPNB) and random parameter Negative Binomial (RPNB) approaches for accident frequency models.
- Fixed parameters Tobit (FPT) and random parameters Tobit (RPT) approaches for accident rate models

the main aim of this thesis is to establish new skid resistance thresholds for local authority roads (A-roads). The analysis of both accidents frequencies (outputs of FPNB and RPNB models) and accidents rates (outputs of FPT and RPT models) as a function of skid resistance enables the definition of threshold values for skid resistance (in term of SCRIM value) for different site categories.

The following section presents the research study design and provides a summary of research stages and methods employed in this thesis. It is followed by a definition of each site category, based on the relationship between accidents and geometric characteristics (radius of curvature and gradients) and other highway features (e.g. roundabouts and junctions).

The following sections will define dependent and independent variables used in frequency and rate models, followed by a description of statistical models used for modelling accidents frequencies and accidents rates. The last section highlights an important application of accident prediction models, defining skid resistance thresholds for different site categories.

3.2 Research design

To achieve the thesis aims, several objectives have been outlined (Table 3-1)

Table 3-1: Research objectives and methods

Objectives	Methods	Chapter
To review the impact of traffic, geometrics and pavement characteristics on accidents.	Literature review	Chapter 2
To divide the networks into different site categories	The relationship between accidents and geometric characteristic and other highway features	Chapter 3
To develop the best fit statistical models that will be presented in Chapters 5 and 6	Using different statistical measurements	Chapter 4
To estimate the impact of traffic, geometric and pavement characteristics on accident frequency at different site categories.	Development of random parameters Negative Binomial models for total, dry, wet, slight and serious and fatal accident frequencies	Chapter 5
To estimate the impact of traffic, geometric and pavement characteristics on accident rate at different site categories.	Development of random parameters Tobit models for total, dry, wet, slight and serious and fatal accident rates	Chapter 6
Compare the impact of traffic, geometric and pavement characteristics on both accident frequency and rate.	Compare the results of random parameters Negative Binomial models with random Tobit models	Chapter 7
Established skid resistance thresholds for different site categories	Analysis the relation between both expected accident frequencies (results of of random parameters Negative Binomial models and rates (of random parameters Tobit models) with skid resistance	Chapter 8
Chapter 9: Conclusions and further research		

3.3 Study area

The networks selected for this analysis were the A roads networks in three counties in the UK: Norfolk (Figure 3-1) is located in East Anglia, Oxfordshire (Figure 3-2) is located in the South East and Nottinghamshire (Figure 3-3) is located in the East Midlands. All accident data for Norfolk, Oxfordshire, and Nottinghamshire were loaded into ARC GIS and geographically referenced to the British National Grid based, on easting and northing location.

Table 3-2: Number and length of A-roads in three counties in the UK

County name	Number of A roads	Total length of A roads (km)
Norfolk	35	742
Oxfordshire	31	582
Nottinghamshire	31	693

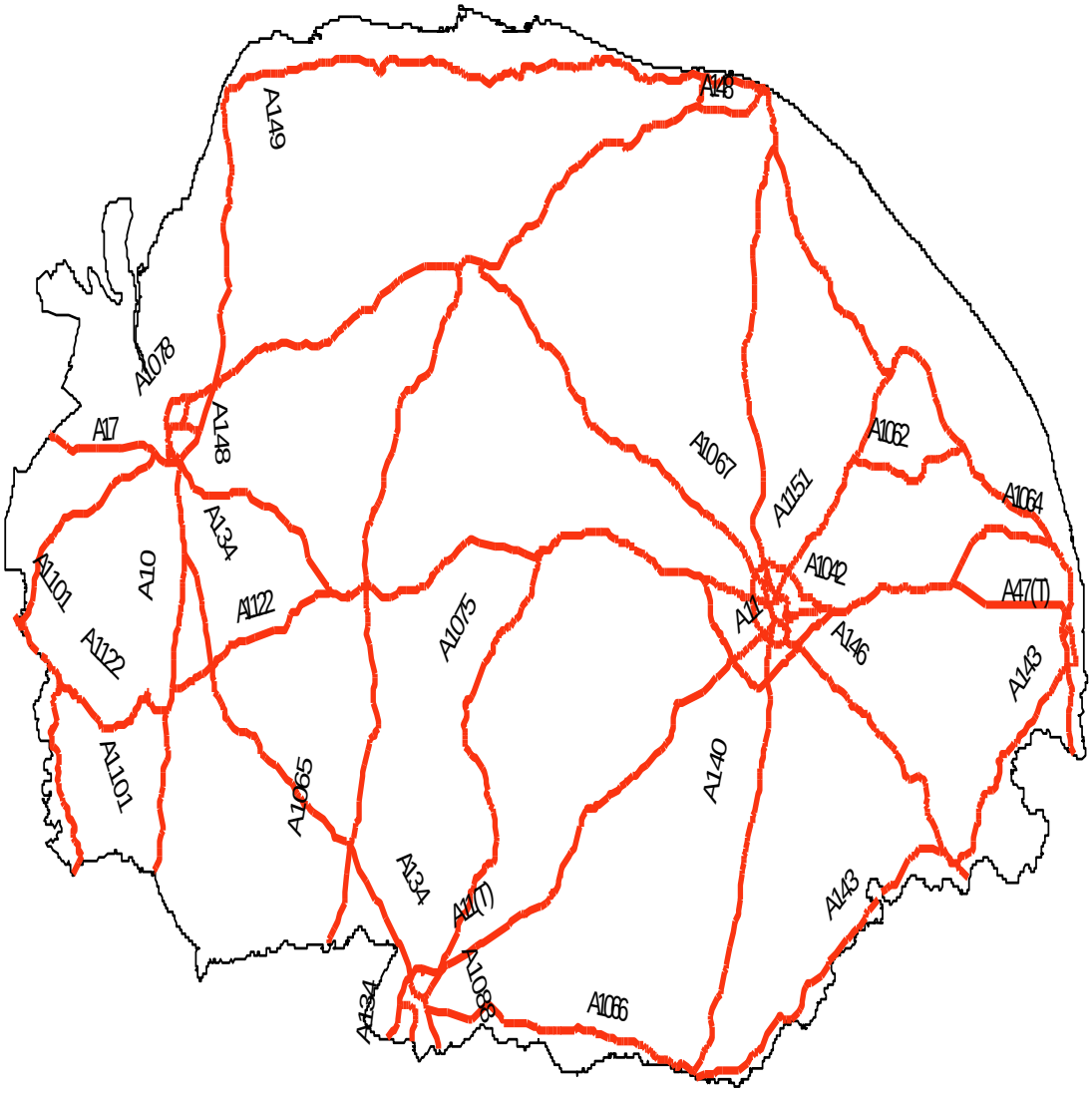


Figure 3-1: Map of the A-roads network of Norfolk County.

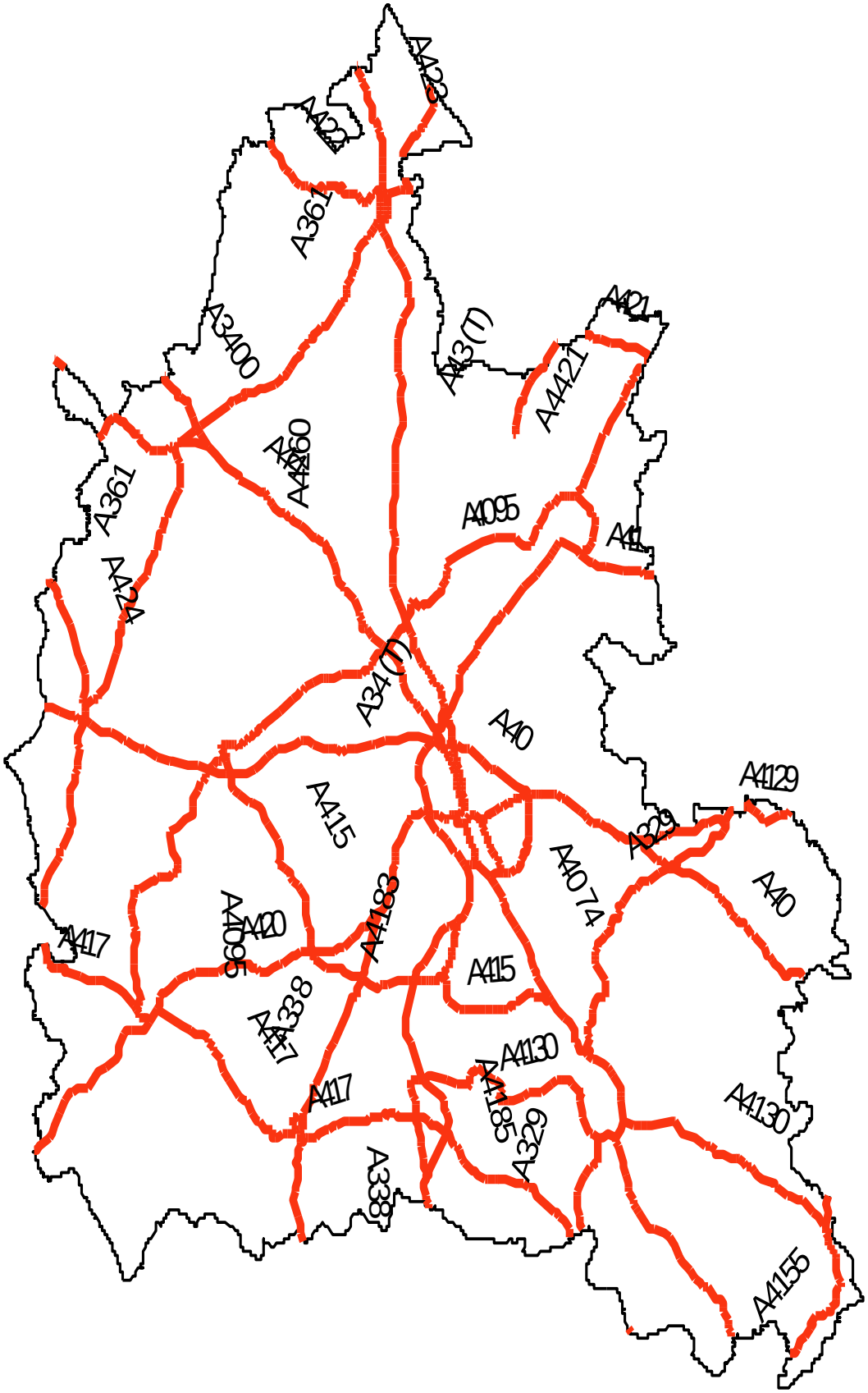


Figure 3-2: Map of the A-roads network of Oxfordshire County.

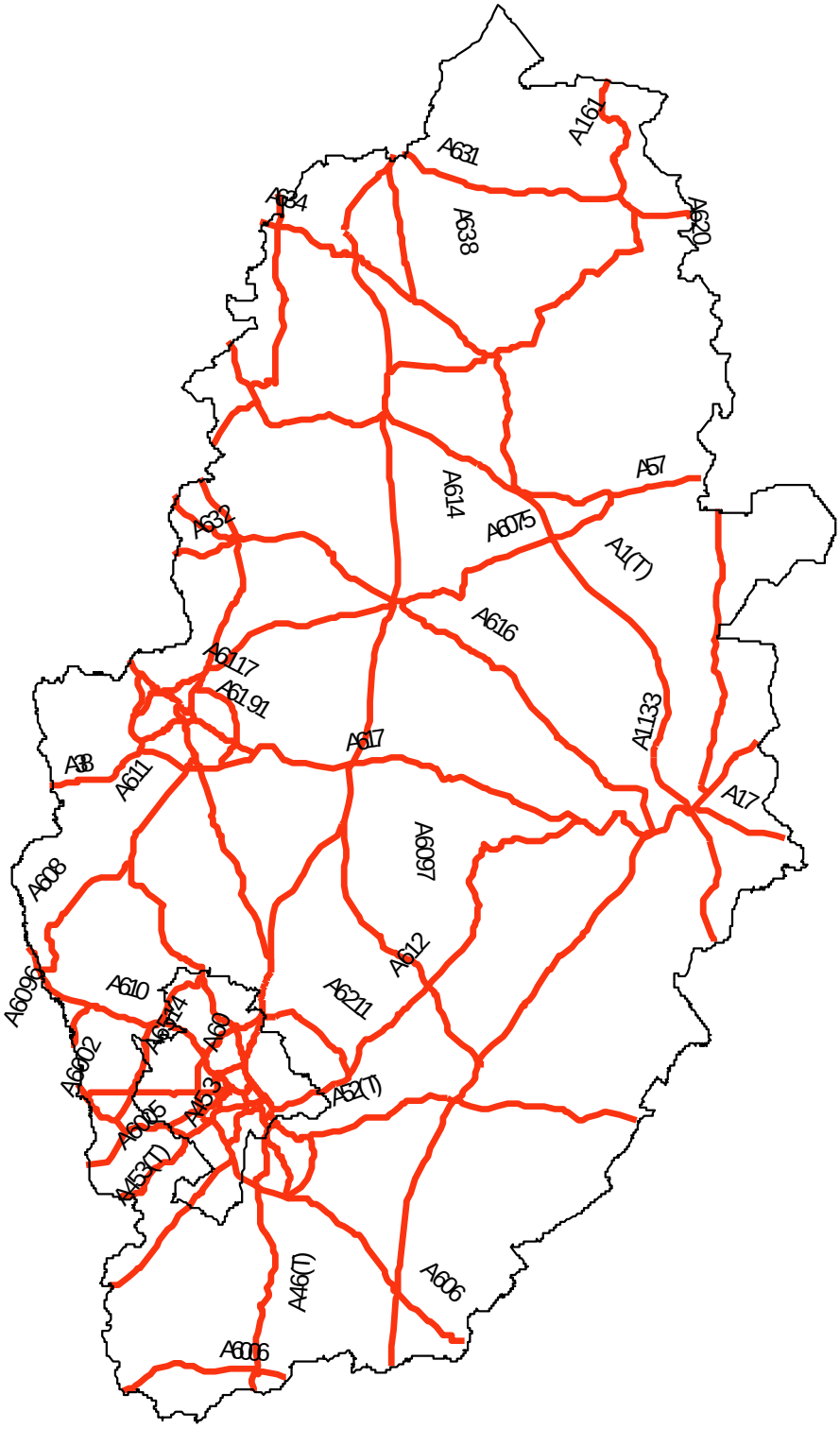


Figure 3-3: Map of the A-roads network of Nottinghamshire County.

3.4 Data source

3.4.1 Accident data

Information on accidents that occurred in the study area was obtained from the national accident database, STATS19. These data are collected by the police and included all accidents where at least one injured casualty was recorded, and it's obtained from obtained from the Department for Transport (https://data.gov.uk/dataset/road-accidents-safety-data). The accident database for this thesis included all 20742 STATS19 reports of accidents on Norfolk, Oxfordshire and Nottinghamshire the A roads network between 2005 and 2010.

3.4.2 Traffic characteristics data

Traffic data (Natural logarithm average annual daily flow, percentage of heavy vehicles and speed limit) used as independent variables in this thesis, were obtained from the Department for Transport (www.dft.gov.uk/taffic-counts) using fixed traffic counters. There were 209, 191 and 211 permanent traffic counters located on the A road network in Norfolk, Oxfordshire and Nottinghamshire, respectively. Each traffic counter comprised two induction loops and a data logger. The induction loops detected passing vehicles and measured their length and axle configuration, transmitting this information to the data logger for processing and subsequent storage. Each traffic counter stored the following information (count point number, road number, start point, end point and the length of roadway segment covered by this counter). To calculate average annual daily flow, percentage of heavy vehicles for each road way segment. Firstly, the county the roadway segment was located, was chosen. Secondly, the traffic count point number that matched the roadway segment locations were chosen, then an Excel spread sheet recorded the average annual daily flow and the percentage of heavy vehicles, downloaded from the website for Department for Transport. The average annual average daily traffic flows and the proportion of heavy goods vehicles were calculated for the selected period (2005 - 2010).

3.4.3 Geometric characteristics data

The annual Surface Condition Assessment for the National Network of Roads (SCANNER) surveys provided a large amount of information regarding geometric characteristics for the three areas included in this study (gradient and curvature). Using 48 measurements for every 10-meter section as a basis, the data is both analysed and manipulated so that it delivers a single reading for the majority of variables (UK ROADS BOARD, 2011). The geometric data (supplied by Norfolk, Oxfordshire and Nottinghamshire councils) referenced, using GPS, to the national grid that is reinforced by an inertial navigation system which advances precision while also making sure that the sporadic loss of signal does not lead to a compromise of the precision of data location referencing (UK ROADS BOARD, 2011).

3.4.4 Pavement characteristics data

In keeping with the road specifications of the United Kingdom Roads Board, the whole road network is surveyed once every two years. During these surveys, data is collected using the SCANNER Survey vehicle which scans the most left lane in a single direction per year. Based on 48 measures taken for every 10 meters, the data be scrutinized and handled so that a single reading is obtained for the majority of variables (UK ROADS BOARD, 2011). A significant amount of data on pavement characteristics such as skid resistance, rut depth and texture depth supplied by Norfolk, Oxfordshire and Nottinghamshire councils. These data are referenced, with the assistance of GPS, to the National Grid Co-ordinates with the support of the national navigation system so that precision can be guaranteed, and the effect of sporadic GPS signal loss is mitigated and does not impact the precision of the data location referencing (UK ROADS BOARD, 2011). After the pavement characteristics data has been collected for all the three counties, it is them uploaded to the pavement management systems of the respective county.

To make sure that the files are compatible with Microsoft Excel and ARC GIS (is a software used for working with maps and geographic information), that the data they contained was what is required, and that the data could be selected, manipulated,

and extracted, all files were opened and checked. After loading all datasets into ARC GIS, they were them referenced into the British National Grid. When an overview was conducted into the dataset in ARC GIS, it was concluded that the data items needed to conduct the analysis were only available for the A-road network for only five years starting in 2005 and ending in 2010. If any data was discovered not to be related to the three counties and not falling into this time period it was removed. Once the required data had been isolated in the ARC GIS, the spatial join command was then employed to connect the data at 10m long roadway segment.

3.4.4.1 Skid resistance data

In terms of skid resistance measurements, several instruments can measure skid resistance as mentioned previously in section 2.4. In the UK, the sideway-force coefficient routine investigation machine (SCRIM) was usually used to measure the skid resistance. Measurements are recorded as SCRIM Readings. A SCRIM Reading is the average Sideway Force Coefficient (SFC) multiplied by 100 for a pre-determined length of road, normally 10m, recorded as an integer. Readings for each 10m roadway segments collected within the speed range 25 to 85km/hr will be corrected to a speed of 50km/h using Equation (3-1):

$$SR_{50} = SR_S * (-0.0152 * s^2 + 4.77 * s + 799) / 1000 \qquad (3 - 1)$$

Where:

SR_{50} is the value of SR_s corrected to 50km/hr;

SR_s is the Sideway Force Coefficient, measured at test speed s, multiplied by 100;

S is the test speed.

Skid resistance is also influenced by temperature, although this effect is relatively small for the normal temperature range in the UK and is ignored under this Standard. Temperature correction shall not be applied for surveys carried out under the conditions set in this standard.

The average value of skid resistance (used in the statistical models) in term of SCRIM value for each roadway segment (50m long) measured for each 10 m for six years (2005-2010) in each site categories is calculated using Equation (3-2):

$$SR_{(Avg.)} = \frac{Avg.SR_1 + Avg.SR_2 + Avg.SR_3 + Avg.SR_4 + Avg.SR_5}{Number\ of\ 10m\ reoadway\ segemnts} \qquad (3-2)$$

$$SR_{(Avg.)} = \frac{0.44 + 0.45 + 0.42 + 0.37 + 0.38}{5} = 0.41$$

As shown in Table the average skid resistance value for 50m long roadway segment for six years is 0.41.

Table 3-3: Skid resistance (SCRIM value) for each 10m roadway segment length for different years

10 m section	Years						Avg. (10 m) for six years
	2005	2006	2007	2008	2009	2010	
SR_1	0.35	0.32	0.59	0.45	0.41	0.54	0.44
SR_2	0.41	0.43	0.45	0.38	0.47	0.55	0.45
SR_3	0.33	0.48	0.53	0.33	0.39	0.48	0.42
SR_4	0.26	0.39	0.41	0.51	0.29	0.37	0.37
SR_5	0.31	0.29	0.62	0.48	0.33	0.27	0.38
Skid resistance value for 50m long ($SR_{Avg.}$)							**0.41**

3.4.4.1.1 Variance of skid resistance value

The F test as a standard statistical approach is used in this thesis to show if the variance of skid resistance values in each years (2005, 2006, 2007, 2008, 2009 and 2010) differ significantly from the average value for the six years (2005 – 2010).

The F hypothesis test is defined as:

Null hypothesis: H_o: S^2 (all years) = S^2 (each year)

Alternative hypothesis: H_1: S^2 (all years) ≠ S^2 (each year)

The null hypothesis is based on the assumption that there is no significant different between the variance for the observation of SCRIM values for all years (2005 – 2010) and the variance for the observation of SCRIM values for specific year. On the other hand, the alternative hypothesis assumed that there is a significant different between the variance for the observation of SCRIM values for all years (2005 – 2010) and the variance for the observation of SCRIM values for specific year.

The null hypothesis that the two variances are equal is rejected if the computed F value from Equation 3-3 exceeds the tabled F value with the degrees of freedom ((v1 = number of observations for all years - 1), (v2 = number of observations for specific year – 1)).

$$F_{cal.} = \frac{S^2_{(all\ years)}}{S^2_{(specific\ year)}} \qquad (3-3)$$

Where, S^2 (all years) refers to the variation in skid resistance values for six years (205 -2010); and S^2 (specific year) refers to the variation in skid resistance values for a specific year.

Table 3-4: F test result for NT roadway segments

Years	Null hypothesis	Alternative hypothesis	F cal.	F tab.	Decision
2005	H_0: S^2 (all years) = S^2 (2005)	H_0: S^2 (all years) ≠ S^2 (2005)	0.96	1.02	Accept the null hypothesis
2006	H_0: S^2 (all years) = S^2 (2006)	H_0: S^2 (all years) ≠ S^2 (2006)	0.99	1.02	Accept the null hypothesis
2007	H_0: S^2 (all years) = S^2 (2007)	H_0: S^2 (all years) ≠ S^2 (2007)	1.00	1.02	Accept the null hypothesis
2008	H_0: S^2 (all years) = S^2 (2008)	H_0: S^2 (all years) ≠ S^2 (2008)	1.01	1.02	Accept the null hypothesis
2009	H_0: S^2 (all years) = S^2 (2008)	H_0: S^2 (all years) ≠ S^2 (2009)	0.98	1.02	Accept the null hypothesis
2010	H_0: S^2 (all years) = S^2 (2010)	H_0: S^2 (all years) ≠ S^2 (2010)	0.95	1.02	Accept the null hypothesis

Table 3-5: F test result for NE roadway segments

Years	Null hypothesis	Alternative hypothesis	F cal.	F tab.	Decision
2005	H_0: S^2 (all years) = S^2 (2005)	H_0: S^2 (all years) ≠ S^2 (2005)	0.97	1.03	Accept the null hypothesis
2006	H_0: S^2 (all years) = S^2 (2006)	H_0: S^2 (all years) ≠ S^2 (2006)	1.01	1.03	Accept the null hypothesis
2007	H_0: S^2 (all years) = S^2 (2007)	H_0: S^2 (all years) ≠ S^2 (2007)	1.00	1.03	Accept the null hypothesis
2008	H_0: S^2 (all years) = S^2 (2008)	H_0: S^2 (all years) ≠ S^2 (2008)	0.96	1.03	Accept the null hypothesis
2009	H_0: S^2 (all years) = S^2 (2008)	H_0: S^2 (all years) ≠ S^2 (2009)	0.99	1.03	Accept the null hypothesis
2010	H_0: S^2 (all years) = S^2 (2010)	H_0: S^2 (all years) ≠ S^2 (2010)	1.02	1.03	Accept the null hypothesis

Table 3-6: F test result for B1 roadway segments

Years	Null hypothesis	Alternative hypothesis	F cal.	F tab.	Decision
2005	H_0: S^2 (all years) = S^2 (2005)	H_0: S^2 (all years) ≠ S^2 (2005)	1.05	1.08	Accept the null hypothesis
2006	H_0: S^2 (all years) = S^2 (2006)	H_0: S^2 (all years) ≠ S^2 (2006)	1.07	1.08	Accept the null hypothesis
2007	H_0: S^2 (all years) = S^2 (2007)	H_0: S^2 (all years) ≠ S^2 (2007)	0.93	1.08	Accept the null hypothesis
2008	H_0: S^2 (all years) = S^2 (2008)	H_0: S^2 (all years) ≠ S^2 (2008)	1.02	1.08	Accept the null hypothesis
2009	H_0: S^2 (all years) = S^2 (2008)	H_0: S^2 (all years) ≠ S^2 (2009)	0.98	1.08	Accept the null hypothesis
2010	H_0: S^2 (all years) = S^2 (2010)	H_0: S^2 (all years) ≠ S^2 (2010)	0.91	1.08	Accept the null hypothesis

Table 3-7: F test result for B2 roadway segments

Years	Null hypothesis	Alternative hypothesis	F cal.	F tab.	Decision
2005	H_0: S^2 (all years) = S^2 (2005)	H_0: S^2 (all years) ≠ S^2 (2005)	0.92	1.07	Accept the null hypothesis
2006	H_0: S^2 (all years) = S^2 (2006)	H_0: S^2 (all years) ≠ S^2 (2006)	1.06	1.07	Accept the null hypothesis
2007	H_0: S^2 (all years) = S^2 (2007)	H_0: S^2 (all years) ≠ S^2 (2007)	1.05	1.07	Accept the null hypothesis
2008	H_0: S^2 (all years) = S^2 (2008)	H_0: S^2 (all years) ≠ S^2 (2008)	1.06	1.07	Accept the null hypothesis
2009	H_0: S^2 (all years) = S^2 (2008)	H_0: S^2 (all years) ≠ S^2 (2009)	1.06	1.07	Accept the null hypothesis
2010	H_0: S^2 (all years) = S^2 (2010)	H_0: S^2 (all years) ≠ S^2 (2010)	0.94	1.07	Accept the null hypothesis

Table 3-8: F test result for RA roadway segments

Years	Null hypothesis	Alternative hypothesis	F cal.	F tab.	Decision
2005	H_0: S^2 (all years) = S^2 (2005)	H_0: S^2 (all years) ≠ S^2 (2005)	1.11	1.12	Accept the null hypothesis
2006	H_0: S^2 (all years) = S^2 (2006)	H_0: S^2 (all years) ≠ S^2 (2006)	1.08	1.12	Accept the null hypothesis
2007	H_0: S^2 (all years) = S^2 (2007)	H_0: S^2 (all years) ≠ S^2 (2007)	0.89	1.12	Accept the null hypothesis
2008	H_0: S^2 (all years) = S^2 (2008)	H_0: S^2 (all years) ≠ S^2 (2008)	0.95	1.12	Accept the null hypothesis
2009	H_0: S^2 (all years) = S^2 (2008)	H_0: S^2 (all years) ≠ S^2 (2009)	1.08	1.12	Accept the null hypothesis
2010	H_0: S^2 (all years) = S^2 (2010)	H_0: S^2 (all years) ≠ S^2 (2010)	0.84	1.12	Accept the null hypothesis

Table 3-9: F test result for JN roadway segments

Years	Null hypothesis	Alternative hypothesis	F cal.	F tab.	Decision
2005	H_0: S^2 (all years) = S^2 (2005)	H_0: S^2 (all years) ≠ S^2 (2005)	1.03	1.07	Accept the null hypothesis
2006	H_0: S^2 (all years) = S^2 (2006)	H_0: S^2 (all years) ≠ S^2 (2006)	0.88	1.07	Accept the null hypothesis
2007	H_0: S^2 (all years) = S^2 (2007)	H_0: S^2 (all years) ≠ S^2 (2007)	1.06	1.07	Accept the null hypothesis
2008	H_0: S^2 (all years) = S^2 (2008)	H_0: S^2 (all years) ≠ S^2 (2008)	1.01	1.07	Accept the null hypothesis
2009	H_0: S^2 (all years) = S^2 (2008)	H_0: S^2 (all years) ≠ S^2 (2009)	0.97	1.07	Accept the null hypothesis
2010	H_0: S^2 (all years) = S^2 (2010)	H_0: S^2 (all years) ≠ S^2 (2010)	1.05	1.07	Accept the null hypothesis

Table 3-10: F test result for GR roadway segments

Years	Null hypothesis	Alternative hypothesis	F cal.	F tab.	Decision
2005	H_0: S^2 (all years) = S^2 (2005)	H_0: S^2 (all years) ≠ S^2 (2005)	1.08	1.10	Accept the null hypothesis
2006	H_0: S^2 (all years) = S^2 (2006)	H_0: S^2 (all years) ≠ S^2 (2006)	1.05	1.10	Accept the null hypothesis
2007	H_0: S^2 (all years) = S^2 (2007)	H_0: S^2 (all years) ≠ S^2 (2007)	0.94	1.10	Accept the null hypothesis
2008	H_0: S^2 (all years) = S^2 (2008)	H_0: S^2 (all years) ≠ S^2 (2008)	1.06	1.10	Accept the null hypothesis
2009	H_0: S^2 (all years) = S^2 (2008)	H_0: S^2 (all years) ≠ S^2 (2009)	0.99	1.10	Accept the null hypothesis
2010	H_0: S^2 (all years) = S^2 (2010)	H_0: S^2 (all years) ≠ S^2 (2010)	0.87	1.10	Accept the null hypothesis

As shown in Tables 3-4 to 3-10 the value of F calculated is less than the value of F tabled therefore; the null hypotheses is accepted for NT, NE, b1, B2, RA, JN and GR roadway segments, which assumed that there were no significant different between the variance for the observation of SCRIM values for all years (2005 – 2010) and the variance for the observation of SCRIM values for specific year with 99% level of confidence

3.5 Site categories definitions

Road networks in Norfolk, Oxfordshire and Nottinghamshire were divided into different site categories depending on accident layouts at different network features (e.g. junctions, roundabouts) and the relationships between accidents and geometric

characteristics (radius of curvature and gradient). The definitions of network level and different site categories below:

3.5.1 Network level (NT)

Any road segments with a 50m long were considered within the network level.

3.5.2 Non – event site category (NE)

Non-event site categories were single or dual roadway segment without roundabouts, junctions, notable bends or gradients. Any roadway segments with a radius of curvature more than 500 m and a gradient less than 5% was considered within this site category.

3.5.3 Bends site category

The definition of this site category was based on the relation between the average number of accidents and the radius of curvature for 50m long roadway segments. Figures 3-4, 3-5, and 3-6 show the effects of radius of curvature on the number of accidents in each roadway segment in Norfolk, Oxfordshire, and Nottinghamshire networks.

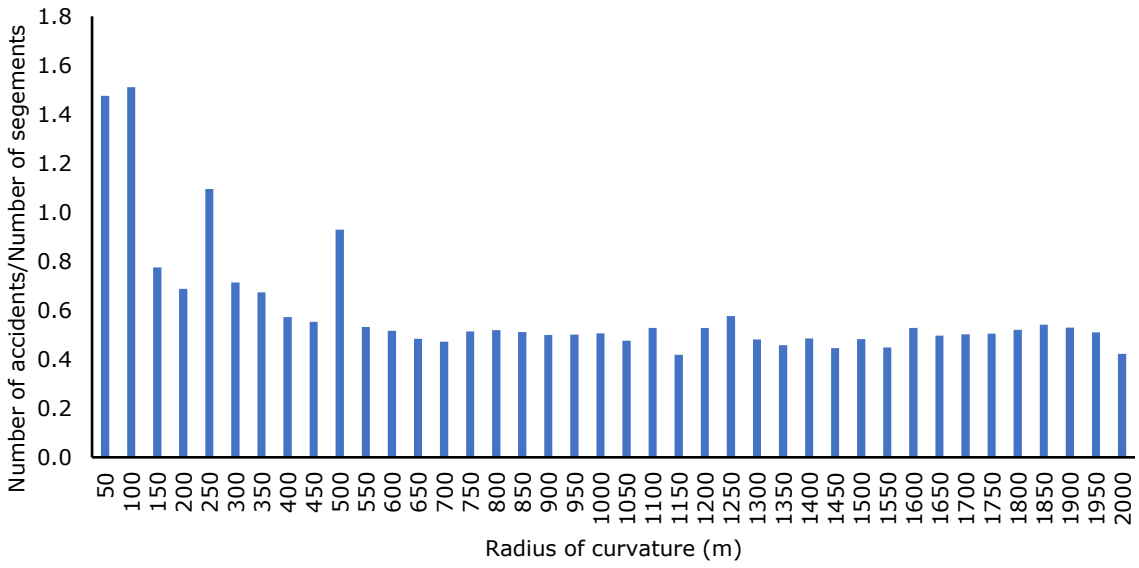


Figure 3-4: Average number of accidents in each radius of curvature bin on Norfolk A-roads network

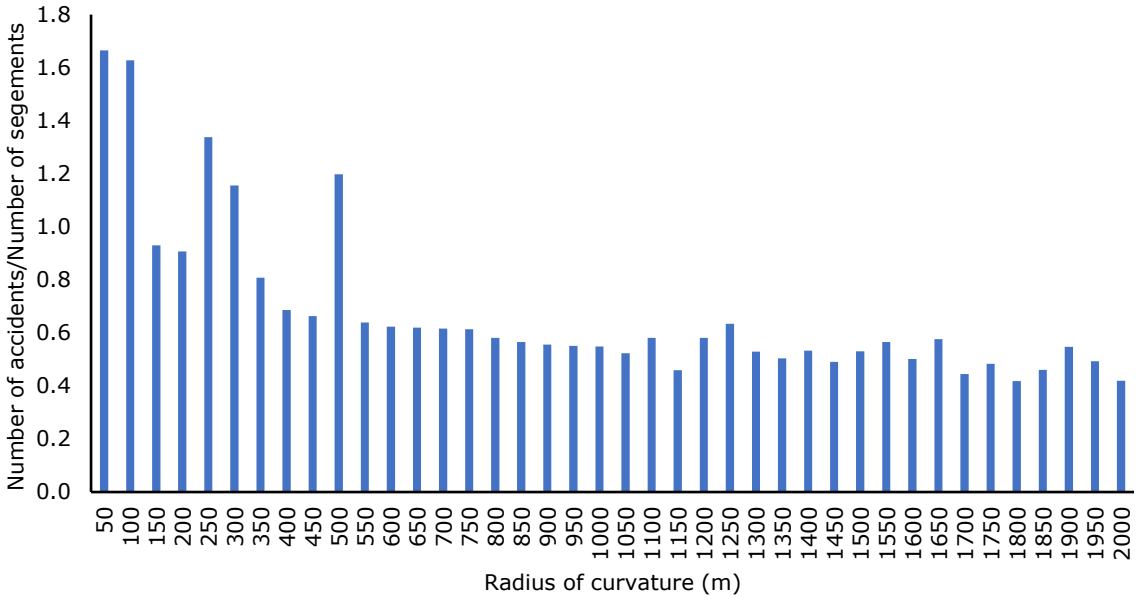


Figure 3-5: Average number of accidents in each radius of curvature bin on Oxfordshire A-roads network

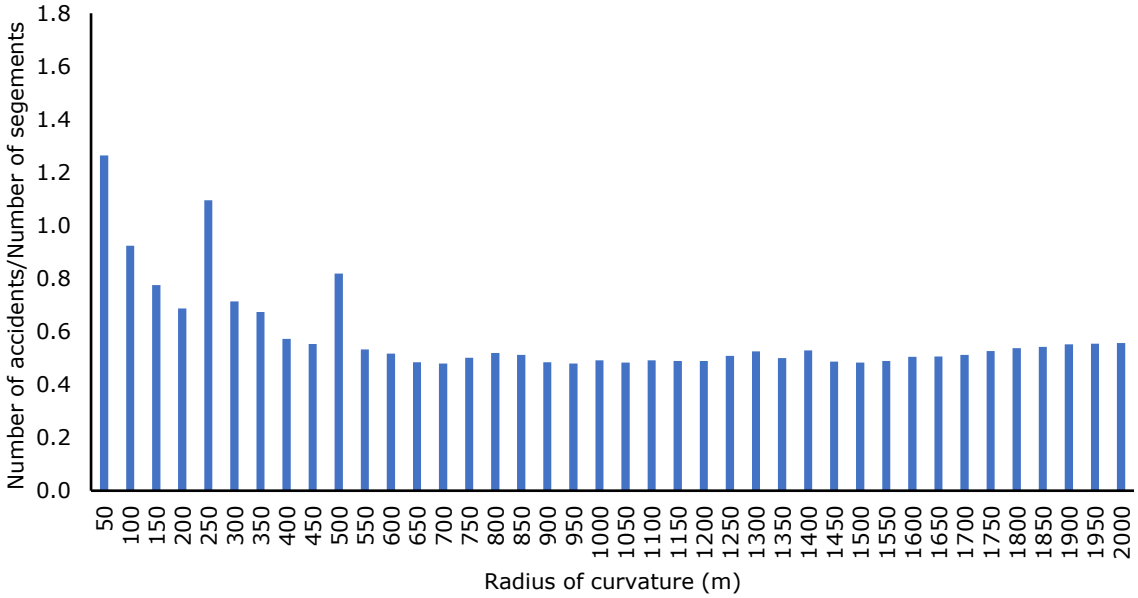


Figure 3-6: Average number of accidents in each radius of curvature bin on Nottinghamshire A-roads

There was a clear trend in decreasing numbers of accidents due to increasing radius of curvature. However, what is interesting is the effects of 250 and 500 m curvatures on accident numbers. A change in trend was clear through these two bins. Therefore,

the bend roadway segments were divided into two site categories: 1. Bends (any roadway segments with radius of curvature less than or equal to 250 m); 2. Bends (any roadway segments with radius of curvature greater than 250m and less than or equal to 500 m).

3.5.3.1 Bends site category (B1)

Any road segments with a radius of curvature less than or equal to 250m were considered within this site category.

3.5.3.2 Bends site category (B2)

Any road segments with radius of curvature greater than 250m and less than or equal to 500m were considered to be under this site category.

3.5.4 Roundabout site category (RA)

According to layout of accidents in the network of Norfolk, Oxfordshire, and Nottinghamshire counties, roundabouts were considered to be accident hotspot locations. In order to determine the effective buffer zone of each roundabout, the distance of each accident to the outer edge of nearest roundabouts is calculated with the help of the (Near tool) within the subsection of proximity tool of analysis toolbox of ArcGIS. The near tool determines the Euclidean or straight-line distance between accidents in one layer and the nearest feature (roundabout) in another. Figures 3-7, 3-8 and 3-9 show the effective buffer zone of roundabout on traffic accidents. According to these figures number of accidents are decreased while getting away from the nearest roundabouts; the majority of accidents are located between 0-50m. Therefore, roundabouts site category as shown in Figure 3-10 can be defined as any roadway segments across roundabout and any roadway segments that located within 50m from the outer edge of the roundabout in all directions.

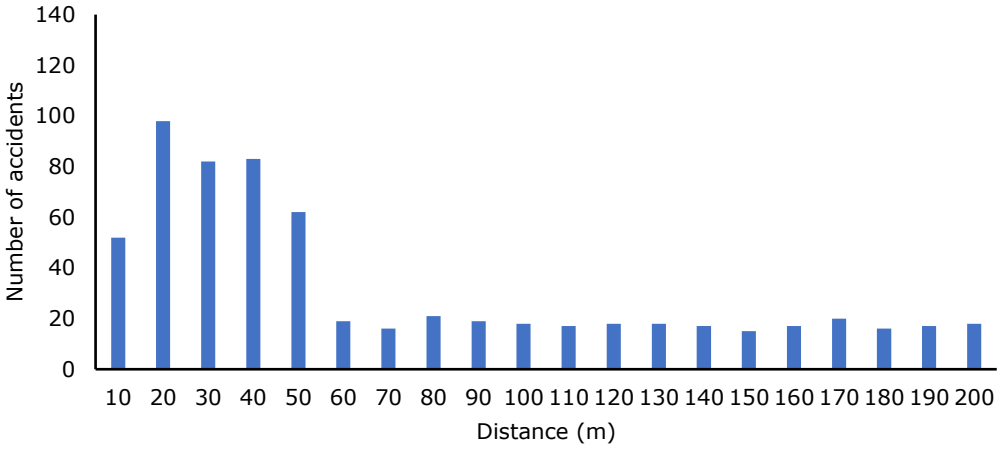


Figure 3-7: The relationship between accident numbers and their distance to the nearest roundabout on Norfolk A-roads network

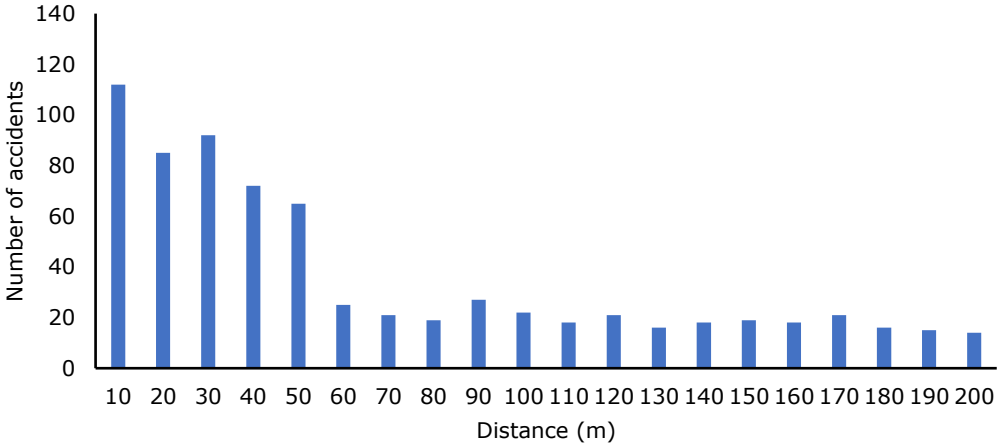


Figure 3-8: The relationship between accident numbers and their distance to the nearest roundabout on Oxfordshire A-roads network

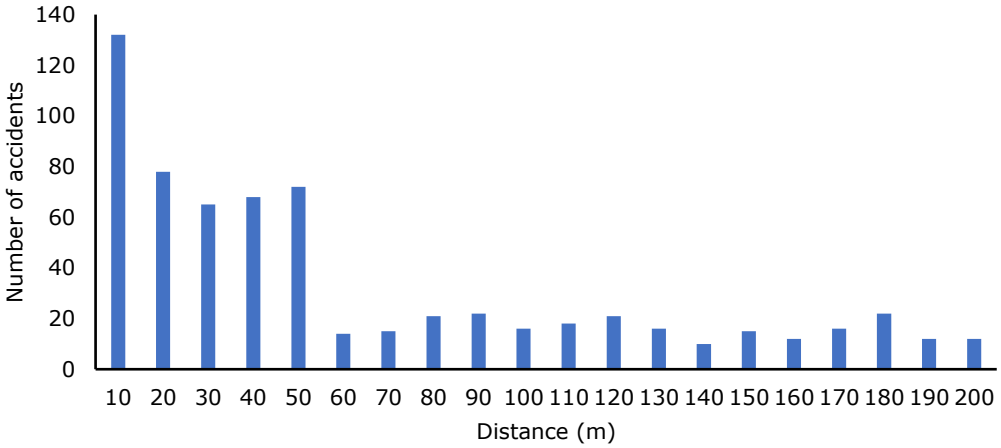


Figure 3-9: The relationship between accident numbers and their distance to the nearest roundabout on Nottinghamshire A-roads network

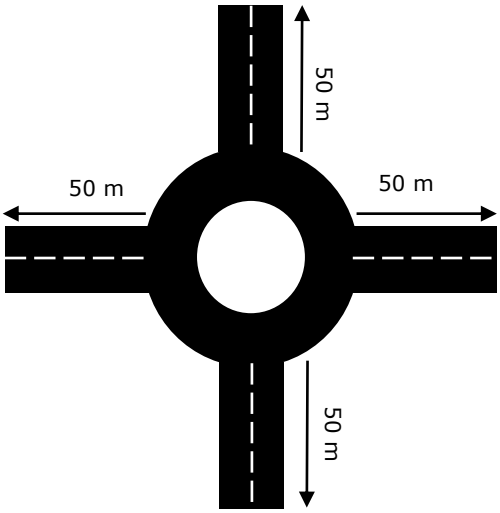


Figure 3-10: Roundabouts site category

3.5.5 Junctions site category (JN)

According to layout of accidents in the network of Norfolk, Oxfordshire, and Nottinghamshire counties, major and minor junctions were considered to be accident hotspot locations. In order to determine the effective buffer zone of each junction, the distance of each accident to the nearest junction boundary is calculated with the help of the near tool which is defined in section 3.5.4. After the near distances are calculated, Figures 3-11, 3-12 and 3-13 show the relationship between distance and number of accidents at junctions.

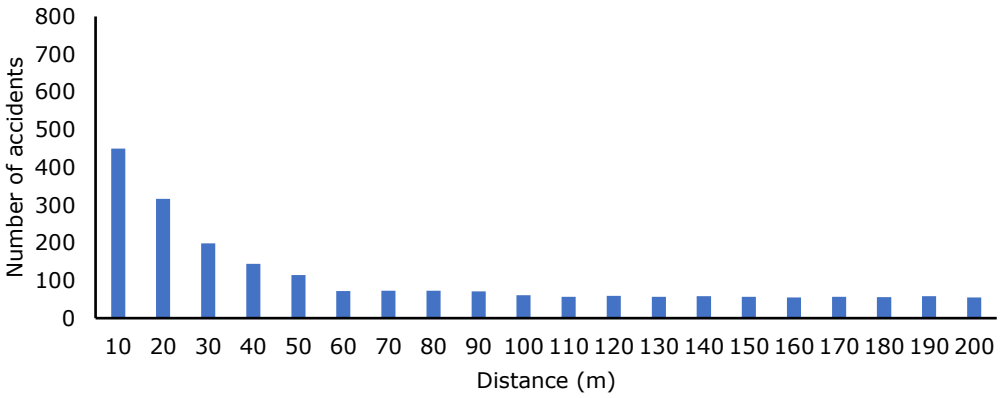


Figure 3-11: The relationship between accident numbers and their distance to the nearest junction on Norfolk A-roads network

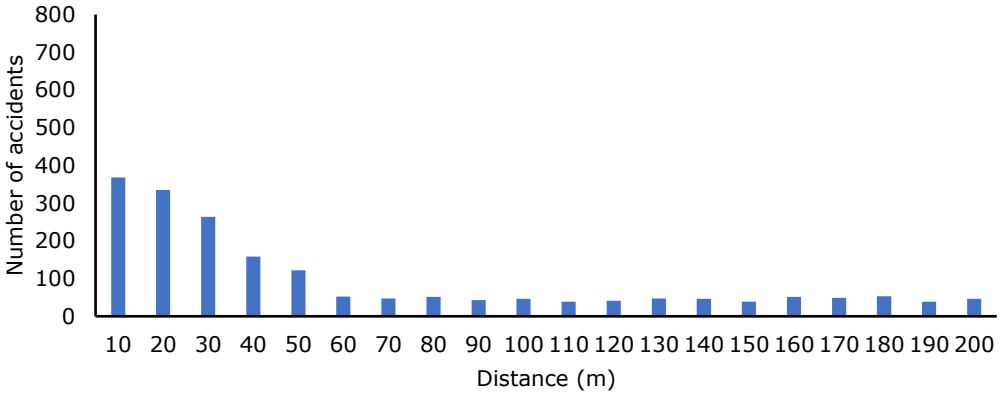


Figure 3- 12: The relationship between accident numbers and their distance to the nearest junction on Oxfordshire A-roads network

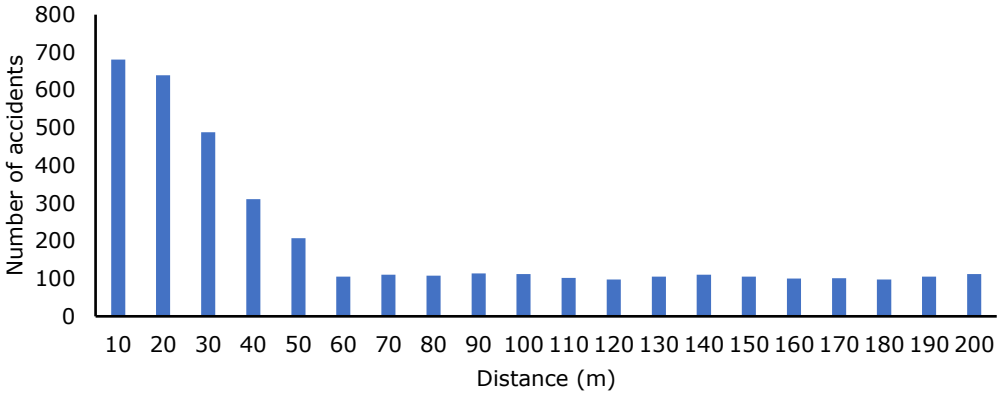


Figure 3-13: The relationship between accident numbers and their distance to the nearest junction on Nottinghamshire A-roads network

From the data in Figures 3-8, 3-9, and 3-10, it is apparent that the effective buffer zone of junction on accidents will be 50m in all direction. Therefore, junctions site category as shown in Figure 3-14 can be defined as any roadway segments across junction and any roadway segments that located within 50m from the junction boundary in all directions.

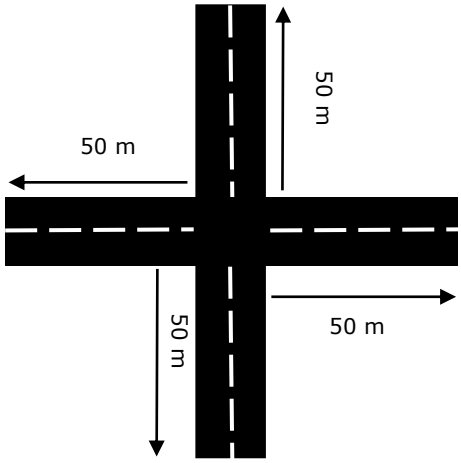


Figure 3-14: Junctions site category

3.5.6 Gradient site category (GR)

The definition of this site category was based on the relation between the average number of accidents and the gradient of roadway segments. Figures 3-15, 3-16 and 3-17 represent the effects of gradients on the number of accidents in each roadway segment on the Norfolk, Oxfordshire, and Nottinghamshire networks.

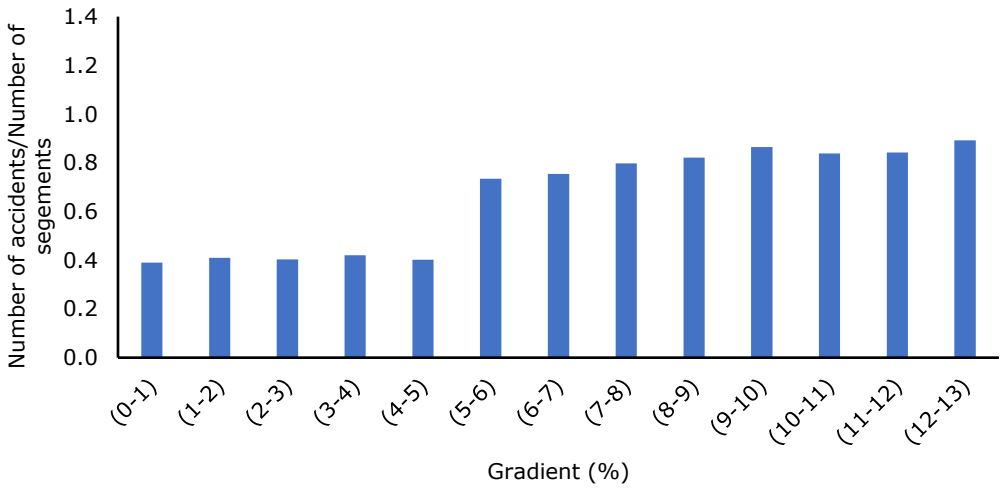


Figure 3-15: Average accidents in each gradient bin on Norfolk A – roads network

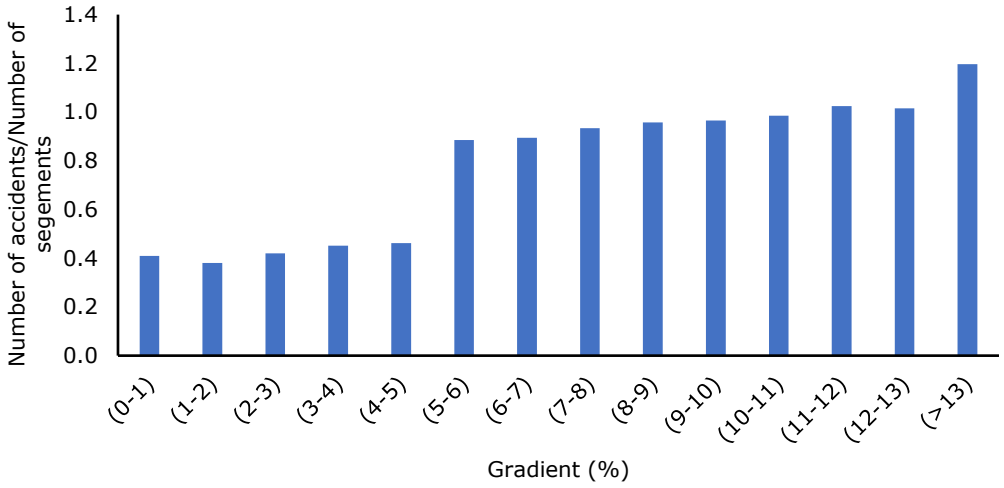


Figure 3- 16: Average accidents in each gradient bin on Oxfordshire A – roads network

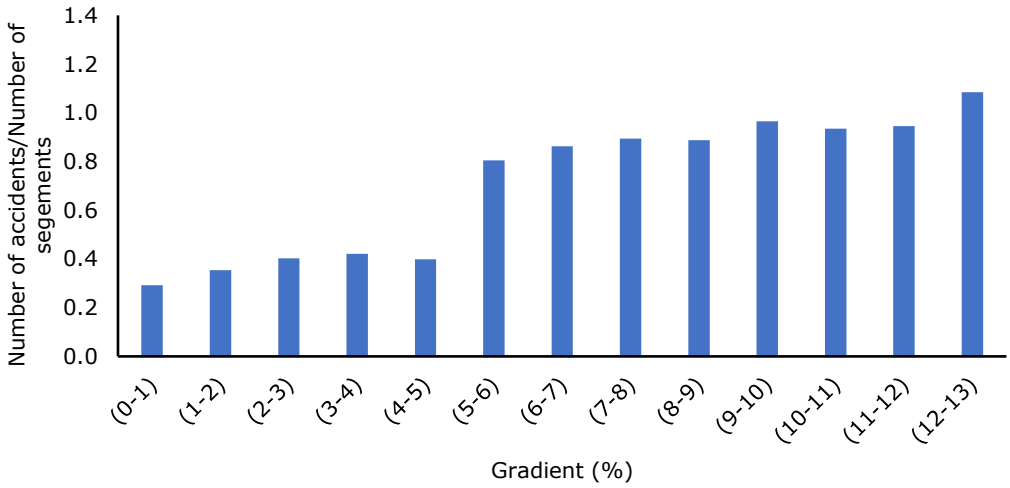


Figure 3- 17: Average accidents in each gradient bin on Nottinghamshire A – roads network

In Figures 3-15, 3-16 and 3-17, there was a clear trend towards increasing accidents for roadway segments with gradients equal or greater than 5%. Therefore, any roadway segments with gradients of more than 5% were considered in this site category.

3.6 Definition of variables

The section describes the dependent and independent variables used in the frequency and rate models. Tables 3-11 and 3-12 show the dependent and independent variables used for modelling the total, dry, wet, slight, and serious and fatal accident frequencies and rate accident that will be presented in Chapters five and six,

respectively. It provides a description for each variable for the six years' (2005 – 2010) data.

Table 3-11: Dependent variables for frequency and rate models

Variable	symbol	Description
Total accident frequencies	T	The total number of accidents for each roadway segment for six years (2005-2010) in each site categories
Dry accident frequencies	D	The total number of dry accidents for each roadway segment for six years (2005-2010) in each site categories
Wet accident frequencies	W	The total number of wet accidents for each roadway segment for six years (2005-2010) in each site categories
Slight accident frequencies	SL	The total number of slight accidents for each roadway segment for six years (2005-2010) in each site categories
Serious and fatal accident frequencies	SF	The total number of serious and fatal accidents for each roadway segment for six years (2005-2010) in each site categories
Total accident rates	TAR	The total accident rates per 10^8 million vehicles for each roadway segment for six years (2005-2010) in each site categories
Dry accident rates	DAR	The dry accident rates per 10^8 million vehicles for each roadway segment for six years (2005-2010) in each site categories
Wet accident rates	WAR	The wet accident rates per 10^8 million vehicles for each roadway segment for six years (2005-2010) in each site categories
Slight accident rates	SLAR	The slight accident rates per 10^8 million vehicles for each roadway segment for six years (2005-2010) in each site categories
Serious and fatal accidents rates	SFAR	The slight and fatal accident rates per 10^8 million vehicles for each roadway segment for six years (2005-2010) in each site categories

Table 3-12: Independent variables for frequency and rate models

Variable	symbol	Description
Traffic characteristics		
Natural logarithm of annual average daily flow	Ln AADF	The average natural logarithm of annual average daily flow for each roadway segment for six years (2005-2010) in each site categories
Percentage of heavy vehicles	%HV	The average of heavy vehicles percentage for each roadway segment for six years (2005-2010) in each site categories
Speed limit	SPL	Speed limit value for each roadway segment for six years (2005-2010) in each site categories
Geometric characteristics		
Radius of curvature	RC	The average value of radius of curvature for each roadway segment (50m long) measured for each 10m for six years (2005-2010) in each site categories
Gradient	% G	The average value of gradient for each roadway segment (50m long) measured for each 10m for six years (2005-2010) in each site categories
Number of lanes	NL	The total number of lanes in each direction for each roadway segment
Number of minor access	NMA	The total number of minor access points in each direction for each roadway segment
Pavement characteristics		
Skid resistance	SR	The average value of skid resistance in term of SCRIM value for each roadway segment (50m long) measured for each 10 m for six years (2005-2010) in each site categories
Rut depth	RD	The average value of rut depth for each roadway segment (50m long) measured for each 10 m for six years (2005-2010) in each site categories
Texture depth	TX	The average value of texture depth for each roadway segment (50m long) measured for each 10 m for six years (2005-2010) in each site categories

3.7 Definition of roadway segment length

The networks and other site categories were divided into fixed length roadway segment lengths of 50 m. Short length segments are preferred. As this length highlights the effect of pavement characteristics (skid resistance, rut depth and

texture depth) on both accident frequencies and rates, because pavement characteristics of short segments tend to be more homogeneous, than longer segments. A summary of roadway segments in each site category is given in Table 3-13.

Table 3-13: Number of 50m roadway segments and length in each site category

County	Site category	Number of roadway segment	Total length (km)
Norfolk	NT	14843	742
	NE	9511	476
	B1	1405	70
	B2	1947	97
	RA	351	18
	JN	1474	74
	GR	344	17
Oxfordshire	NT	11631	582
	NE	6510	326
	B1	1065	53
	B2	1644	82
	RA	580	29
	JN	1130	57
	GR	1107	55
Nottinghamshire	NT	13864	693
	NE	8059	403
	B1	1308	65
	B2	1595	80
	RA	672	34
	JN	1575	79
	GR	853	43

3.8 Modelling strategy

This section describes the main steps required to build and select the best models presented in Chapters 5 (frequency models) and Chapter 6 (rate models).

3.8.1 Variance Inflation Factor (VIF)

To check how independent variables are related to each other, collinearity tests were performed before building the model. Collinearity is defined as a linear association between two variables. Collinearity happens if there is a strong correlation between two variables in a model (O'Brien, 2007). When collinearity occurs, it increases the variance of the independent variables estimated to build a model. In the case of collinearity, the estimated dependent variable is usually unstable because of high standard errors, and a reliable and significant regression coefficient for the estimated variable is difficult to obtain (Washington *et al.*, 2010) . 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) which defined as the ratio of variance for the multiple factors model, divided by the variance for model with one factor are used to establish the degree of collinearity between independent variables. A maximum acceptable value of 5, as proposed by (Kutner *et al.*, 2004), has been adopted for this study. Equation (3-5) is used to estimate VIF (Chatterjee *et al.*, 2006):

$$VIF(\beta_j) = \frac{1}{(1 - R_j^2)} \qquad (3 - 5)$$

Where j =1, 2, 3,……, k and R_j^2 is the multiple correlation coefficient of X_j on the other explanatory variables.

3.8.2 Akaike Information Criteria (AIC) and Bayesian Information Criterion (BIC)

The Akaike's information criterion (AIC) and Bayesian Information Criterion (BIC) which are defined as (indicators to measure the quality of the statistical models for a given set of data) both are employed in the determining the process that should be used with respect to the subset of independent variables traffic, geometric and pavement characteristics. Thus, AIC and BIC distinguish the most suitable model

among others that exhibit different parameters. Washington *et al.* (2010) defines AIC and BIC by using Equations (3-6) and (3-7):

$$AIC = -2LL(\beta) + 2k \quad (3-6)$$

$$BIC = -2LL(\beta) + k(\ln(n)) \quad (3-7)$$

Where: LL (β) denotes the log likelihood at convergence, k denotes the number of the predicted variables including constant, and n denotes the number of observations.

The procedure for the selection of variables is repeated until the minimum possible AIC and BIC values are obtained. In order to determine the statistical significance of the difference between the two models (importance of the independent variables), Hilbe's AIC and Raftery's BIC rule-of-thumb criteria are adopted in the study (Raftery, 1995; Hilbe, 2011). The significance levels for both criteria are shown in Table 3-14. The model with the lowest AIC and BIC becomes AIC_{min} and BIC_{min} with which all other model AIC's BIC's are compared. The importance of each independent variables measure using Equations (3-8) and (3-9), where the difference between AIC_i for each model and AIC_{min} yields a W_{AICi}, while the difference between BIC_i for each model and BIC_{min} yields a W_{BICi}.

$$W_{AIC\ i} = AIC_i - AIC_{min} \quad (3-8)$$

$$W_{BIC\ i} = BIC_i - BIC_{min} \quad (3-9)$$

Table 3-14: Significance levels for AIC and BIC (Hilbe 2011; Raftery 1995)

ΔAIC for models A and B	Result if A < B	ΔBIC for models A and B	Result if A < B
< 0.0 and ≤ 2.5	No difference	< 0.0 and ≤ 2.5	Weak difference
< 2.5 and ≤ 6.0	Prefer A if n > 256	< 2.5 and ≤ 6.0	Positive difference
< 6.0 and ≤ 9.0	Prefer A if n > 64	< 6.0 and ≤ 9.0	Strong difference
+10	Prefer A	+10	Strong difference

3.8.3 Accident frequency models

3.8.3.1 Fixed and random parameters Negative Binomial models

Typically, models including Poisson and Negative Binomial models are employed in the analysis of the frequency of accidents that possess a value that is nonnegative. A Poisson regression model is used in situations where the average value of the data is similar to the data variance ($E(n_i) = Var(n_i)$). Conversely, a Negative Binomial regression model is used in examples related to the over-dispersion of data ($E(n_i) < Var(n_i)$) that is observed in most accident frequency data. In order to derive the Negative Binomial model, the error term is considered as follows:

$$\lambda_{ij} = exp\left(\beta X_{ij} + \varepsilon_{ij}\right) \qquad (3-10)$$

Where $exp(\varepsilon ij)$ denotes a gamma-distributed error term with mean l and variances α and β denote the estimated parameters. The error structure is incorporated, and the marginal distribution in form of Negative Binomial distribution is derived as follows:

$$P\left(n_{ij}/\lambda_{ij}, \alpha\right) = \frac{\Gamma\left((1/\alpha) + n_{ij}\right)}{\Gamma(1/\alpha)\, n_{ij}!} \left(\frac{1/\alpha}{(1/\alpha) + \lambda_{ij}}\right)^{(1/\alpha)} \left(\frac{\lambda_{ij}}{(1/\alpha) + \lambda_{ij}}\right)^{n_{ij}} \qquad (3-11)$$

Where α denotes the dispersion parameter. Equation (3-12) is used, and the variance of observations is permitted to vary from the mean as follows:

$$Var\left[n_{ij}\right] = E\left[n_{ij}\right]\left[1 + \alpha E\left[n_{ij}\right]\right] = E\left[n_{ij}\right] + \alpha E\left[n_{ij}\right]^2 \qquad (3-12)$$

Specifically, the Negative Binominal model is perceived as an extended model of the Poisson regression model when statistical variance between α and 0 is absent. Thus, the Negative Binominal model is more appropriate when compared to the Poisson regression model in examples where α that is statistically significantly varies from 0, (Washington *et al.*, 2010). Nevertheless, in its traditional form, the Poisson/Negative Binomial model functions based on the assumption of fixed parameters across all observations. In order to mitigate the challenge, Greene (2003) established a technique that includes random parameters in count models and parameters that permit for random parameters; and this is then expressed as follows:

$$\beta_i = \beta + \varphi_i \qquad (3 - 13)$$

Where φi denotes a randomly distributed term. For example, it can exhibit a normal distribution with mean equal to zero while variance corresponds to one (Anastasopoulos and Mannering, 2009). Additionally, a parameter in the random parameters model is considered as a variable when the standard deviation of the parameter distribution statistically varies from zero, and otherwise, it remains fixed across the observations. In the case, the random parameters model comprises of a combination of random and fixed parameters across the observations. With respect to Equation 3-7, the Poisson model is as follows: (λi | φi = *exp*(βXi). With respect to the Negative Binomial model it is as follows: λi| φi = *exp* (βXi + εi)). Thus, the log-likelihood is as follows:

$$LL = \sum_{\forall_i} ln \int_{\varphi_i} g(\varphi_i)\, P(n_i/\varphi_i) d\varphi_i \qquad (3 - 14)$$

Where $g(\varphi_i)$ denotes the probability density function of φi. Given the reality that a statistical challenge involves assimilating the count models with a random parameter distribution, a maximum likelihood model based on simulation is used. This maximises the simulation log-likelihood function. Thus, prior studies concluded that the Halton draw method can be employed while estimating empirical parameters (Bhat, 2003; Milton *et al.*, 2008).

3.8.3.2 Data for frequency models

Accident data from A roads network in the three counties (3C) (Norfolk, Oxfordshire and Nottinghamshire) were collected over a six-year period (2005-2010) to investigate the effects of traffic characteristics (Ln AADF, heavy vehicles percentage, and speed limit), geometric characteristics (radius of curvature, gradient, number of lanes and number of minor access), and pavement characteristics (skid resistance, rut depth and texture depth) on total, dry, wet, slight and serious and fatal accident frequencies.

Accident counts (i.e. accident frequency) per segment, per six years were obtained. Traffic, geometrics and pavement characteristics data were aggregated at a road segment level. As mentioned in section 3.3, the A roads network was divided into different site categories and in addition each site category was divided into fixed length segment of 50 m length. A total of 40338, 24080, 3778, 5186, 1603, 4179 and 2304 roadway segments were defined for NT, NE, B1, B2, RA, JN and GR site category for 3C A road networks. The aggregate total, dry, wet, slight and serious and fatal accident frequency on each roadway segment over the six years period of analysis, was used as the dependent variable, were also defined. Tables 3-15 to 3-21 show the descriptive statistics for dependent and independent variables used in the estimation of FPNB and RPNB models for different site categories.

Table 3-15: Summary statistics of accident frequencies, traffic, geometric and pavement condition characteristics for NT roadway segments in 3C network

Variable	Min	Max	Mean	S.D.
T	0	41	0.491	1.620
D	0	29	0.305	1.152

W	0	17	0.178	0.675
SL	0	36	0.402	1.428
SF	0	10	0.090	0.378
Ln AADF	7.001	10.898	8.587	0.663
%HV	1	27	5.702	3.972
SPL (km/hr)	32	112	81.975	19.804
RC (m)	26	2000	1231.098	1037.074
%G	0.074	13.794	1.974	1.679
NL	2	8	2.333	0.740
NMA	0	8	0.230	0.542
SR (SCRIM value)	0.082	0.649	0.401	0.045
RD (mm)	0.488	90.118	6.893	2.566
TX (mm)	0.099	1.617	0.520	0.201
Number of observations	40338			

Table 3-16: Summary statistics of accident frequencies, traffic, geometric and pavement condition characteristics for NE roadway segments in 3C network

Variable	Min	Max	Mean	S.D.
T	0	40	0.298	1.1938
D	0	29	0.187	0.865
W	0	17	0.109	0.498
SL	0	36	0.245	1.054
SF	0	6	0.0523	0.27
Ln AADF	7.071	10.773	8.606	0.654
%HV	1	23	6.335	4.415
SPL (km/hr)	32	112	84.616	18.467
RC (m)	501	2000	1568.187	962.248
%G	0.114	4.975	1.559	1.058
NL	1	8	2.310	0.7321
NMA	0	6	0.197	0.491
SR (SCRIM value)	0.172	0.604	0.403	0.044
RD (mm)	0.538	69.166	6.891	2.260
TX (mm)	0.106	1.444	0.531	0.203
Number of observations	24080			

Table 3-17: Summary statistics of accident frequencies, traffic, geometric and pavement condition characteristics for B1 roadway segments in 3C network

Variable	Min	Max	Mean	S.D.
T	0	41	0.388	1.305
D	0	29	0.243	0.925

W	0	16	0.148	0.636
SL	0	36	0.318	1.162
SF	0	6	0.069	0.330
Ln AADF	7.071	10.898	8.402	0.728
%HV	1	23	4.515	2.750
SPL (km/hr)	32	112	76.757	21.042
RC (m)	501	2000	145.427	65.048
%G	0.114	4.975	2.412	1.911
NL	2	8	2.269	0.694
NMA	0	8	0.249	0.579
SR (SCRIM value)	0.172	0.649	0.391	0.046
RD (mm)	0.538	69.166	6.766	3.833
TX (mm)	0.106	1.617	0.505	0.195
Number of observations	3778			

Table 3- 18: Summary statistics of accident frequencies, traffic, geometric and pavement condition characteristics for B2 roadway segments in 3C network

Variable	Min	Max	Mean	S.D.
T	0	20	0.339	0.994
D	0	14	0.212	0.709
W	0	8	0.126	0.509
SL	0	20	0.278	0.862
SF	0	5	0.061	0.298
Ln AADF	7.077	10.898	8.463	0.627
%HV	1	19	4.960	2.909
SPL (km/hr)	32	112	79.544	20.589
RC (m)	250.2	500	379.069	72.983
%G	0	10.4	2.086	1.692
NL	2	7	2.208	0.631
NMA	0	4	0.238	0.540
SR (SCRIM value)	0.197	0.587	0.395	0.044
RD (mm)	0.988	86.166	6.853	2.818
TX (mm)	0.108	1.3016	0.509	0.201
Number of observations	5186			

Table 3-19: Summary statistics of accident frequencies, traffic, geometric and pavement condition characteristics for RA roadway segments in 3C network

Variable	Min	Max	Mean	S.D.
T	0	38	2.029	3.416

D	0	23	1.206	2.409
W	0	15	0.731	1.451
SL	0	35	1.651	3.093
SF	0	10	0.377	0.757
Ln AADF	7.227	10.658	9.010	0.610
%HV	1	20	5.153	3.284
SPL (km/hr)	32	112	79.018	20.528
RC (m)	33	2000	1040.628	1105.429
%G	0.147	10.835	2.130	1.654
NL	2	6	2.855	0.743
NMA	0	6	0.293	0.653
SR (SCRIM value)	0.128	0.627	0.401	0.048
RD (mm)	1.187	16.159	7.065	2.407
TX (mm)	0.116	1.2796	0.486	0.181
Number of observations	1603			

Table 3-20: Summary statistics of accident frequencies, traffic, geometric and pavement condition characteristics for JN roadway segments in 3C network

Variable	Min	Max	Mean	S.D.
T	0	36	1.331	2.613
D	0	25	0.829	1.916
W	0	13	0.455	1.009
SL	0	33	1.073	2.305
SF	0	6	0.258	0.626
Ln AADF	7.073	10.773	8.635	0.618
%HV	1	21	4.554	3.101
SPL (km/hr)	32	112	75.008	21.695
RC (m)	45	2000	1222.566	1069.083
%G	0.179	11.927	2.083	1.724
NL	2	7	2.477	0.832
NMA	0	6	0.385	0.690
SR (SCRIM value)	0.175	0.626	0.400	0.048
RD (mm)	0.583	18.388	6.784	2.296
TX (mm)	0.118	1.3016	0.513	0.198
Number of observations	4179			

Table 3-21: Summary statistics of accident frequencies, traffic, geometric and pavement condition characteristics for GR roadway segments in 3C network

Variable	Min	Max	Mean	S.D.
T	0	39	0.403	1.809

D	0	28	0.234	1.193
W	0	15	0.168	0.783
SL	0	33	0.339	1.621
SF	0	5	0.064	0.307
Ln AADF	7.074	10.386	8.601	0.659
%HV	1	23	4.882	2.824
SPL (km/hr)	32	112	83.679	19.481
RC (m)	115	2000	1723.743	1393.027
%G	5.088	13.794	6.635	1.497
NL	2	6	2.323	0.757
NMA	0	6	0.186	0.509
SR (SCRIM value)	0.241	0.639	0.406	0.042
RD (mm)	0.891	16.254	7.478	2.678
TX (mm)	0.126	1.0808	0.467	0.175
Number of observations	2304			

3.8.4 Accident rate models

3.8.4.1 Fixed and random parameters Tobit models

The Tobit model is a regression model that is the creation of Tobin (1958). It is a model where the dependent variable is either right- or left-censored. Specifically, it involves the notion of left-censored denotes data that is censored at a threshold that is low while right-censored denotes data censored at a high threshold. With respect to accident data, the data is left-censored with clustering at zero bases. This is performed with the realisation that it is impossible to observe accident frequencies on all or a few intersections during the time of observation. Thus, the construction of the Tobit model is performed as follows:

$$Y_i^* = \beta X_i + \varepsilon_i, \; i=1,2,3,\ldots\ldots,N$$
$$Y_i = Y_i^* \; if \; Y_i^* > 0 \qquad (3-15)$$
$$Y_i = 0 \; if \; Y_i^* \leq 0$$

Where, N denotes the number of observations, Yi denotes the dependent variable (severe injury accident rate), β denotes the vector of estimate parameters, Xi denotes independent variables (traffic, geometric and pavement characteristics), and

εi denotes a normally and independently distributed error term with mean (μ) equal to 0 and variance σ^2 equal to 1. Specifically, there is an index that is both stochastic and implicit (dormant variable) that is denoted as Y_i^* and is only observed in examples where the Yi value exceeds zero. Therefore, the Tobit model's likelihood positive and aforementioned zero observations is as follows (Greene, 2003):

$$log\ LL = \prod_0 \left[1 - \boldsymbol{\Phi}\left(\frac{\beta X}{\sigma}\right)\right] \prod_1 \sigma^{-1}\, \phi\left[\frac{(Y_i - \beta X)}{\sigma}\right] \qquad (3-16)$$

In Equation (3-16), $\boldsymbol{\Phi}$ denotes the standard normal distribution function, and ϕ denotes the standard normal density function, and this corresponds to a description of the Tobit in the traditional sense (fixed parameter). Nevertheless, a challenge in the model involves accounting for heterogeneity (factors that are not observed and could differ across observations). In order to ensure that heterogeneity is accounted for by using a random parameter, a simulated maximum likelihood estimation procedure was developed by (Greene, 2003). Estimable parameters that are permitted for random parameters are as follows:

$$\beta_i = \beta + \varphi_i, \quad i = 1,2,3,\ldots, N \qquad (3-17)$$

Where φi denotes a term that is randomly distributed (Poisson regression model: λi | φi = *exp* (βXi) and Negative Binomial regression model: λi | φi = *exp* (βXi + εi)). Thus, the log-likelihood is re-expressed as follows:

$$LL = \sum_{\forall_i} \ln \int_{\varphi_i} g(\varphi_i)\, P(n_i/\varphi_i) d\varphi_i \qquad (3-18)$$

Specifically, $g(\varphi_i)$ denotes the probability density function of φi. The estimation of the random parameters is performed by using a maximum likelihood based on a simulation that uses Halton draws.

3.8.4.2 Data for rate models

Over a six-year period (from 2005 to 2010), accident data collected for A-road networks in Oxfordshire, Norfolk, and Nottinghamshire with the aim of investigating

the effect of traffic characteristics (Ln AADF, heavy vehicles percentage, and speed limit), geometric characteristics (radius of curvature, gradient, number of lanes and number of minor access), and pavement characteristics (skid resistance, rut depth and texture depth) on total, dry, wet, slight and serious and fatal accident rates. As discussed in Section 3.3, the 3C network is divided into different site categories. Additionally, every site category is divided into fixed length segments with a length of 50 m each. The data is also divided into roadway segments. The type of information that defines the roadway includes traffic, geometric and pavement characteristics. A total of 40338, 24080, 3778, 5186, 1603, 4179, and 2304 roadway segments are defined for the NT, NE, B1, B2, RA, JN, and GR site categories for the 3C A – roads network. In the study, the total number of total, dry, wet, slight and serious and fatal accidents that occur in each roadway segment is analysed as the independent variable while the total numbers of total, dry, wet, slight and serious and fatal accident rates on each roadway segment over the six-year analysis period is used as the dependent variable and is computed as follows:

$$Accident\ rate_i = \frac{\sum_{yr=1}^{n} Accidents_{yr,i}}{\left[\sum_{yr=1}^{n} AADF_{yr,i} * L_i * 365\right]/100000000} \qquad (3-19)$$

Where Accident rate denotes accident numbers for every 100 million vehicles on roadway segment, *i*, yr denotes the year (from 1 to *n*), $Accidents_{yr,i}$ denotes accident numbers per year yr (year from 1 to *n*) on segment *i*, $AADF_{yr,i}$ denotes the average annual daily flow in year yr on segment *i*, and L_i denotes the length of roadway segment *i* in kilometres.

Tables 3-22 to 3-27 show the descriptive statistics for dependent and independent variables used in the estimation of fixed and random parameter Tobit models for different site categories.

Table 3-22: Summary statistics of accident rates, traffic, geometric and pavement condition characteristics for NT roadway segments in 3C network

Variable	Min	Max	Mean	S.D.
TAR	0	14557	75.165	273.684

DAR	0	10587	44.007	182.943
WAR	0	5153	29.926	148.767
SLAR	0	14557	60.511	242.518
SFAR	0	2647	14.718	73.006
Ln AADF	7.001	10.898	8.587	0.663
%HV	1	27	5.702	3.972
SPL (km/hr)	32	112	81.975	19.804
RC (m)	26	2000	1231.098	1037.074
%G	0.074	13.794	1.974	1.679
NL	2	8	2.333	0.740
NMA	0	8	0.230	0.542
SR (SCRIM value)	0.082	0.649	0.401	0.045
RD (mm)	0.488	90.118	6.893	2.566
TX (mm)	0.099	1.617	0.520	0.201
Number of observations	40338			

Table 3-23: Summary statistics of accident rates, traffic, geometric and pavement condition characteristics for NE roadway segments in 3C network

Variable	Min	Max	Mean	S.D.
TAR	0	11426	45.212	191.036
DAR	0	7770	27.028	127.878
WAR	0	3656	18.001	99.072
SLAR	0	9141	36.405	161.156
SFAR	0	2285	8.806	55.429
Ln AADF	7.071	10.898	8.606	0.654
%HV	1	23	6.335	4.415
SPL (km/hr)	32	112	84.616	18.467
RC (m)	501	2000	1568.187	962.248
%G	0.114	4.975	1.559	1.058
NL	2	8	2.310	0.7321
NMA	0	8	0.197	0.491
SR (SCRIM value)	0.172	0.649	0.403	0.044
RD (mm)	0.538	69.166	6.891	2.260
TX (mm)	0.106	1.617	0.531	0.203
Number of observations	24080			

Table 3-24: Summary statistics of accident rates, traffic, geometric and pavement condition characteristics for B1 roadway segments in 3C network

Variable	Min	Max	Mean	S.D.
TAR	0	5534	74.899	282.100
DAR	0	4570	43.553	172.166

WAR	0	5153	33.055	207.101
SLAR	0	5534	62.195	263.661
SFAR	0	1057	12.704	65.896
Ln AADF	7.074	10.228	8.402	0.728
%HV	1	27	4.515	2.750
SPL (km/hr)	32	112	76.757	21.042
RC (m)	45	250	145.427	65.048
%G	0.127	12.164	2.412	1.911
NL	2	7	2.269	0.694
NMA	0	6	0.249	0.579
SR (SCRIM value)	0.131	0.637	0.391	0.046
RD (mm)	0.728	90.118	6.766	3.833
TX (mm)	0.106	1.242	0.505	0.195
Number of observations	3778			

Table 3-25: Summary statistics of accident rates, traffic, geometric and pavement condition characteristics for B2 roadway segments in 3C network

Variable	Min	Max	Mean	S.D.
TAR	0	4122	58.601	186.159
DAR	0	2202	34.613	119.001
WAR	0	4122	23.719	127.822
SLAR	0	4122	47.952	166.003
SFAR	0	1101	10.646	57.595
Ln AADF	7.077	10.722	8.463	0.627
%HV	1	22	4.960	2.909
SPL (km/hr)	32	112	79.544	20.589
RC (m)	250.2	500	379.069	72.983
%G	0.224	10.448	2.086	1.692
NL	2	7	2.208	0.631
NMA	0	4	0.238	0.540
SR (SCRIM value)	0.197	0.587	0.395	0.044
RD (mm)	0.988	86.166	6.853	2.818
TX (mm)	0.108	1.3016	0.509	0.201
Number of observations	5186			

Table 3-26: Summary statistics of accident rates, traffic, geometric and pavement condition characteristics for RA roadway segments in 3C network

Variable	Min	Max	Mean	S.D.
TAR	0	5153	241.846	437.152
DAR	0	3057	132.544	270.511

WAR	0	5153	96.836	283.714
SLAR	0	5153	195.429	401.140
SFAR	0	1323	46.410	110.008
Ln AADF	7.227	10.658	9.010	0.610
%HV	1	20	5.153	3.284
SPL (km/hr)	32	112	79.018	20.528
RC (m)	33	2000	1040.628	1105.429
%G	0.147	10.835	2.130	1.654
NL	2	6	2.855	0.743
NMA	0	6	0.293	0.653
SR (SCRIM value)	0.128	0.627	0.401	0.048
RD (mm)	1.187	16.159	7.065	2.407
TX (mm)	0.116	1.2796	0.486	0.181
Number of observations	1603			

Table 3-27: Summary statistics of accident rates, traffic, geometric and pavement condition characteristics for JN roadway segments in 3C network

Variable	Min	Max	Mean	S.D.
TAR	0	14557	208.601	497.254
DAR	0	10587	123.562	353.240
WAR	0	3970	77.539	218.120
SLAR	0	14557	163.042	432.149
SFAR	0	2647	45.559	135.443
Ln AADF	7.073	10.773	8.635	0.618
%HV	1	21	4.554	3.101
SPL (km/hr)	32	112	75.008	21.695
RC (m)	45	2000	1222.566	1069.083
%G	0.179	11.927	2.083	1.724
NL	2	7	2.477	0.832
NMA	0	6	0.385	0.690
SR (SCRIM value)	0.175	0.626	0.400	0.048
RD (mm)	0.583	18.388	6.784	2.296
TX (mm)	0.118	1.3016	0.513	0.198
Number of observations	4179			

Table 3-28: Summary statistics of accident rates, traffic, geometric and pavement condition characteristics for GR roadway segments in 3C network

Variable	Min	Max	Mean	S.D.
TAR	0	4122	62.719	258.277

DAR	0	2689	32.622	151.526
WAR	0	3607	29.960	179.060
SLAR	0	4122	53.919	242.211
SFAR	0	574	8.794	44.728
Ln AADF	7.074	10.386	8.601	0.659
%HV	1	23	4.882	2.824
SPL (km/hr)	32	112	83.679	19.481
RC (m)	115	2000	1723.743	1393.027
%G	5.088	13.794	6.635	1.497
NL	2	6	2.323	0.757
NMA	0	6	0.186	0.509
SR (SCRIM value)	0.241	0.639	0.406	0.042
RD (mm)	0.891	16.254	7.478	2.678
TX (mm)	0.126	1.0808	0.467	0.175
Number of observations	2304			

3.8.5 Halton draw

From statistical point of view, Halton draws which is proposed by Halton in 1960, are sequences used to create points in space for used in numerical methods. The Halton draw is constructed according to a deterministic method that uses coprime numbers as its bases. Halton sequences are best understood through an example. Start with a number that defines the draw. For illustration, consider the number 3. A Halton sequence for number 3 is constructed as follows. Take the unit interval (0,1) and divide it into 3 parts. The dividing points become the first two elements of the Halton sequence: 1/3 and 2/3. Now take each of the three parts and divide them into 3 parts. The dividing points constitute the next elements in the Halton sequence: 1/9, 4/9 (which is 1/9 above 1/3), 7/9 (which is 1/9 above 2/3), and 2/9, 5/9 (which is 2/9 above 2/3), and 8/9 (which is 2/9 above 2/3). The unit interval has now been divided into nine parts. Divide each of these nine parts into thirds. The dividing points are 1/27, 10/27, 19/27, 4/27, 13/27, 22/27, 7/27, 16/27, 25/27 (which are 1/9 added to zero and the previous numbers) and 2/27, 11/27, 20/27, 5/27, 14/27, 23/27, 8/27, 17/27, 26/27 (which are 2/9 added to zero and the previous numbers.) Each of the 27 spaces are then divided into three parts, and so on for as many numbers as needed in the draw. Similar draws are defined for other numbers, such as 2 (1/2, 1/4, 3/4, 1/8, 5/8, 3/8, ...) and 5 (1/5, 2/5, 3/5, 4/5, 1/25, 6/25, 11/25).

The simulation of the maximum likelihood, in the majority of studies that conducted in the area of transportation analysis for accident frequency and rate using random parameters approach, has been conducted using Halton draws (Lord and Mannering, 2010). The simulated maximum likelihood estimation is employed with standard Halton draws for purposes of evaluating the integral demonstrated in Equation (3-8) for RPNB model; and Equation (3-11) for RPT model. It achieves this by generating a Halton matrix Y of size G*K., where Y: Halton matrix, G=R*Q (R: number of independent variables in the predicted model; Q: number of observations), K: number of random parameters in the predicted model) (Bhat, 2001).

In terms of, simulation method the literatures reviewed in Chapter 2 (section 2.7) highlighted that Halton draw approach is one of the best ways to draw values of the parameter estimation coefficient for independent variables. Moreover, a 200 Halton draws is usually used for accurate parameter estimation (this number of Halton draws will be used in both random parameters Negative Binomial and random parameters Tobit models estimations).

Therefore; draws for both random parameters Negative Binomial models and random parameters Tobit models mixed logit estimation are created as follows. Using 200 as prime number, create a Halton sequence for each dimension of the mixing distribution. For example, if the mixing distribution describes the distribution of three random terms, create three Halton sequences.

3.8.6 Random and fixed parameters

After building a fixed parameters model (as discussed in section 3.8.2), the independent variables: traffic characteristics (Ln AADF, heavy vehicles percentage, and speed limit), geometric characteristics (radius of curvature, gradient, number of lanes and number of minor access), and pavement characteristics (skid resistance, rut depth and texture depth) are included in random parameters model as fixed or random parameter based on the significant of the coefficient mean and standard deviation of the independent parameters estimation which indicated by the t-statistic

(the ratio between the difference of estimated value of parameter from its actual value to its standard error).

Three t-statistic are available for testing the significance of the independent variables (1.65, 1.96, and 2.58 for 90%, 95%, and 99% significance level (Washington et al., 2011). As shown in Table 3-29 the independent variable is considered as random parameter that normally distributed with mean =0, and standard deviation =1, if the standard deviation of the parameter distribution is statistically different from zero (t-statistics≥1.65).

Table 3-29: Fixed and random parameter criteria for RPNB and RPT models

Mean	Standard deviation (Std.)	Random (R) parameter	Fixed (F) parameter	Note
t≥1.65	t≥1.65	✓		The variable considers to be random parameter
t≥1.65	t<1.65		✓	The variable considers to be fixed parameter
t<1.65	t≥1.65	✓		The variable considers to be random parameter
t<1.65	t<1.65			Remove the variable from the model

3.8.7 Positive effect of random parameter

In order to understand the effect of each random parameter on both RPNB and RPT model results, the positive percentage of the density of normal distribution of each random parameter (area under normal distribution curve) is calculated using Equation (3-20):

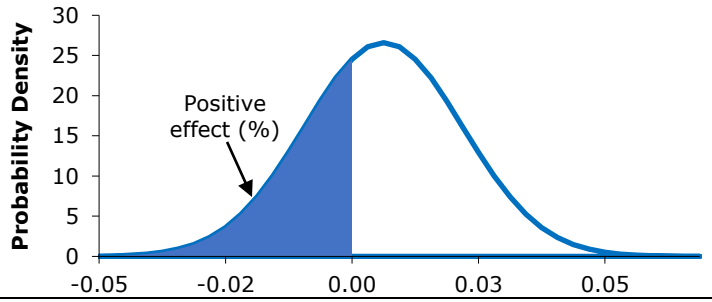
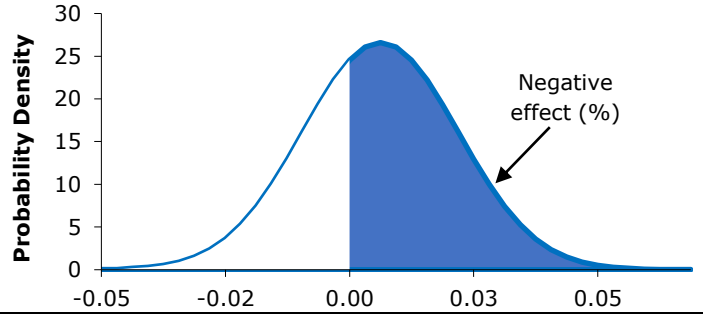
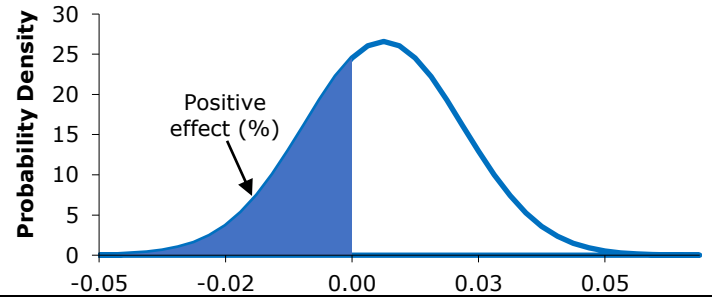
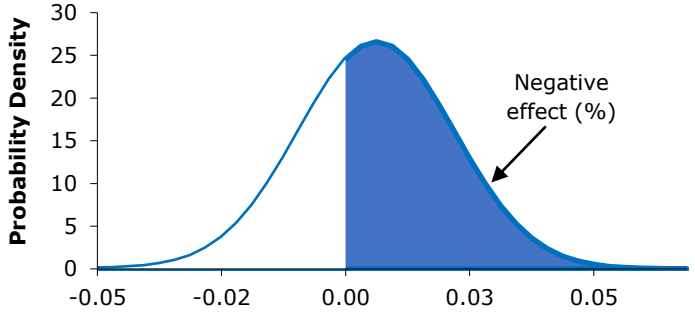
$$Z = \frac{x - \mu}{\sigma} \qquad (3 - 20)$$

Where

x: the mean of the estimated random parameter coefficient; μ: the mean of normal distribution (μ=0), and σ: the mean of the estimated standard deviation for random parameter coefficient.

Table 3-30 provides an overview of how to calculate the positive effect for random parameter, the positive effect presents the percentage of roadway segments where increase the independent variable leads to increase accident frequency or rate in RPNB and RPT models.

Table 3-30: Positive and negative effect of fixed and random parameters

Variable sign	Fixed (F) or Random (R)	Positive effect %	Negative effect %
Positive (+)	F	100%	0%
Negative (-)	F	0%	100%
Positive (+)	R	Positive effect (%) = area under normal distribution with mean = 0 and standard deviation = 1, which correspond to z value which calculated using equation $z = \frac{x - \mu}{\sigma}$ Where: x= the coefficient of parameter, μ= mean=0, σ=standard deviation=1. 	Negative effect (%) = 1- Positive effect (%) 
Positive (+)	R	Positive effect (%) = area under normal distribution with mean = 0 and standard deviation = 1, which correspond to z value which calculated using equation $z = \frac{x - \mu}{\sigma}$ 	Negative effect (%) = 1- Positive effect (%) 

3.8.8 Elasticity effects for frequency and rate models

The comparative significance of the variables was confirmed when the frequency and rate accident model parameter coefficients are computed. This was performed by using the elasticity value to measure the comparative influence of the variable on the frequency and rate of accidents (Shankar *et al.*, 1995). Approximately, elasticity is considered to denote the percentage change in the mean accident frequency and rate owing to a specific value percentage change within the independent variable. Elasticity effects is computed as follows:

$$E_{X_{ik}}^{\lambda_i} = \frac{\partial \lambda_i}{\lambda_i} * \frac{X_{ik}}{\partial X_{ik}} \qquad (3 - 21)$$

Equation (3-21) refers to the elasticity of the accident frequency and rate based on the kth independent variable for observation i.

3.8.9 Procedure of Fixed and random parameters models

The FPNB, RPNB, FPT and RPT models were applied to the dependent variables (total, dry, wet, slight and serious and fatal accident frequencies and rates) using NLOGIT5 software, which is an econometric and statistical software package that provides a programming language to specify, estimate and analyse FPNB, RPNB, FPT and RPT. This section describes the command statement used to both total, dry, wet, slight and serious and fatal accident frequencies and rates for NT level, NE, B1, B2, RA, JN and GR site categories. Halton draw and elasticity effects used in the statement are explained, and all the parameters used in the NLOGIT5 program are described. A more detailed description of the commands and statements illustrated in this section is given by Greene (2007).

3.8.9.1 Fixed parameters Negative Binomial (FPNB) model command

To predict total, dry, wet, slight and serious and fatal accident frequency for NT level, NE, B1, B2, RA, JN and GR site categories. The FPNB model can be written as

--> negbin; lhs = T; rhs = one,Ln AADF, %HV, SPL, RC, %G, NL, NMA, SC, RD, TX; ;rpm;pts = 200;halton; marginal effects$

3.8.9.2 Random parameters Negative Binomial (RPNB) model command

--> negbin; lhs = T; rhs = one,Ln AADF, %HV, SPL, RC, %G, NL, NMA, SC, RD, TX; ;rpm;pts = 200;halton; fcn= %HV(n); marginal effects$

3.8.9.3 Fixed parameters Tobit (FPT) model command

To predict total, dry, wet, slight and serious and fatal accident frequency for NT level, NE, B1, B2, RA, JN and GR site categories. The FPNB model can be written as

--> tobit; lhs = T; rhs = one,Ln AADF, %HV, SPL, RC, %G, NL, NMA, SC, RD, TX; ;rpm;pts = 200;halton; marginal effects$

3.8.9.4 Random parameters Tobit (RPT) model command

--> tobit; lhs = T; rhs = one,Ln AADF, %HV, SPL, RC, %G, NL, NMA, SC, RD, TX; ;rpm;pts = 200;halton; fcn= %HV(n); marginal effects$

Where:

negbin = specification for Negative Binomial model.

tobit = specification for Tobit model.

Lhs = specification for dependent variable (T= total accident frequency, D= dry accident frequency, W= wet accident frequency, SL= slight accident frequency, SF= serious and fatal accident frequency) based on the model to be developed.

rhs = specification for independent variables (one= is used for the constant term, Ln AADF = Natural logarithm for annual average daily flow, %HV= heavy vehicles percentage, SPL= speed limit, RC= radius of curvature, %G= gradient, NL= number of lanes, NMA= number of minor access, SC= skid resistance, RD= rut depth and TX= texture depth).

rpm: description of the random parameters models

Pts = the number of replications (draws) for the estimated simulation.

Halton = specification of Halton sequences or draws for simulation-based estimators

fcn = the specification of the random parameters. In the random-parameters model statement shown, in the fcn statement, for instance %Hv (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(Anasatasopoulas and Mannering, 2009).

Marginal effect = displays estimated elasticity effects.

3.8.9.5 The procedure for getting a random parameters

1. Firstly check all the variables to get a good FPNB or FPT models, any variables that are insignificant will be removed from the model. A good FPNB or FPT models are 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 FPNB or FPT models, 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 standard deviation of the parameter distribution is statistically different from zero; if the estimated standard deviation of the parameter distribution is not statistically different from zero then the parameter is fixed across the NT, NE, B1, B2, RA, JN and GR roadway segments.

3. Note that when a given variable's:

- Mean and standard deviation are insignificant; it is removed from the model. Note that the significance of the parameter is indicated by the t-statistic value. Usually, a t-statistic value is used to test the significance of the coefficients; three t statistic value 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)).

Table 3-31: Random parameter with insignificant mean and standard deviation

Variable	Coefficient	t statistic value	
Non-random parameters			
Constant	- 5.694	-30.21	
Ln AADF	0.640	37.63	
SPL	-0.009	-17.19	
RC	$-0.2768*10^{-4}$	-2.66	
%G	0.039	5.58	
NL	- 0.291	-20.45	
NMA	0.389	19.22	
SC	-1.405	-5.96	
RD	0.012	2.49	
TX	- 0.139	-2.34	
Means for random parameters			
%HV	0.072	***0.68***	Mean insignificant
Standard deviation for random parameters			
%HV	0.046	***1.02***	Standard deviation insignificant

- Mean is significant, and standard deviation is insignificant (not statistically different from zero), the variable is fixed across the observation.

Table 3-32: Random parameter with significant mean and insignificant standard deviation

Variable	Coefficient	t statistic value	
Non-random parameters			
Constant	- 5.694	-30.21	
Ln AADF	0.640	37.63	
SPL	-0.009	-17.19	
RC	$-0.2768*10^{-4}$	-2.66	
%G	0.039	5.58	
NL	- 0.291	-20.45	
NMA	0.389	19.22	
SC	-1.405	-5.96	
RD	0.012	2.49	
TX	- 0.139	-2.34	
Means for random parameters			
%HV	0.072	***2.68***	Mean significant
Standard deviation for random parameters			
%HV	0.046	***1.02***	Standard deviation insignificant

- Mean is statistically not insignificant and standard deviation is significant (statistically different from zero) the variable is considered random across the observations.

Table 3-33: Random parameter with insignificant mean and significant standard deviation

Variable	Coefficient	t statistic value	
Non-random parameters			
Constant	- 5.694	-30.21	
Ln AADF	0.640	37.63	
SPL	-0.009	-17.19	
RC	$-0.2768*10^{-4}$	-2.66	
%G	0.039	5.58	
NL	- 0.291	-20.45	
NMA	0.389	19.22	
SC	-1.405	-5.96	
RD	0.012	2.49	
TX	- 0.139	-2.34	
Means for random parameters			
%HV	0.072	***0.68***	Mean insignificant
Standard deviation for random parameters			
%HV	0.046	***3.02***	Standard deviation significant

- Mean and standard deviation are both significant, the variable is considered random across the observations.

Table 3-34: Random parameter with significant mean and standard deviation

Variable	Coefficient	t statistic value	
Non-random parameters			
Constant	- 5.694	-30.21	
Ln AADF	0.640	37.63	
SPL	-0.009	-17.19	
RC	$-0.2768*10^{-4}$	-2.66	
%G	0.039	5.58	
NL	- 0.291	-20.45	
NMA	0.389	19.22	
SC	-1.405	-5.96	
RD	0.012	2.49	
TX	- 0.139	-2.34	
Means for random parameters			
%HV	0.072	***2.68***	Mean significant
Standard deviation for random parameters			
%HV	0.046	***3.02***	Standard deviation significant

4. The same procedure (steps 1, 2 and 3) was used to estimate models for dry, wet, slight, serious, and fatal accident frequency and rate for NT, NE, B1, B2, RA, JN and GR roadway segments.

3.8.10 Log-Likelihood ratio test

The process of evaluating the statistical superiority of the substitute model specifications, FPNB vs RPNB, and FPT vs RPT are achieved via the likelihood test (Washington et al., 2010) for models representing accident frequency and rate models as follows:

$$\chi^2 = -2[LL(\beta_{FPNB}) - LL(\beta_{RPNB})]$$
$$\chi^2 = -2[LL(\beta_{FPT}) - LL(\beta_{RPT})] \quad (3 - 22)$$

Where:

$LL(\beta_{FPNB})$ denotes the log-likelihood at convergence of the FPNB model.

$LL(\beta_{RPNB})$ denotes the log-likelihood at convergence of the RPNB model.

$LL(\beta_{FPT})$ denotes the log-likelihood at convergence of the FPT model.

$LL(\beta_{RPT})$ denotes the log-likelihood at convergence of the RPT model.

The assumption in the null hypothesis is that both random and fixed parameters model statistically exhibit similar performance. Conversely, the alternate hypothesis operates based on the assumption that the random parameters model is statistically superior when compared to the fixed parameters model. The null hypothesis is rejected in the event when the computed chi-square from Equations 3-23 exceeds that tabled chi square with degrees of freedom equal to the number of random parameters in the random parameters model.

3.8.11 Transferability test

The transferability test using the log-likelihood ratio test was performed to check the significance of the following:

- The combined model for all total, dry, wet, slight and serious and fatal accident frequencies in all site categories in the three counties (3C) vs the

three separate models in each county (Norfolk, Oxfordshire and Nottinghamshire).

- The combined model for all total, dry, wet, slight and serious and fatal accident rates in all site category in the three counties (3C) vs the three separate models in each county (Norfolk, Oxfordshire and Nottinghamshire).

A likelihood ratio test is performed (Washington et al., 2010):

$$\chi^2 = -2[LL(\beta_{3C}) - LL(\beta_{NOR.}) - LL(\beta_{OXF.}) - LL(\beta_{NOT.})] \quad (3 - 23)$$

Where:

$LL(\beta_{3C})$ denotes the log-likelihood at convergence of the model estimated with the data from all counties (3C), $LL(\beta_{NOR.})$ denotes the log-likelihood at convergence of the model estimated with the data from Norfolk; $LL(\beta_{OXF.})$ denotes the log-likelihood at convergence of the model estimated with the data from Oxfordshire, and $LL(\beta_{NOT.})$ denotes the log-likelihood at convergence of the model estimated with the data from Nottinghamshire.

The null hypothesis is based on the assumption that there is no significant variance in parameter values for independent variables between the full data model (3C) and distinct models (Oxfordshire, Norfolk, and Nottinghamshire). The null hypothesis is rejected in the event that the computed chi-squire from Equation 3-24 exceeds the tabled chi-square with the degrees of freedom corresponding to the difference between the number of parameters of all data (3C) model and the aggregate of parameters in Oxfordshire, Norfolk, and Nottinghamshire models.

3.9 Skid resistance threshold

The second aim of this thesis is to present a methodology for the establishment of skid threshold values for different site categories, based on traffic accident models (frequency and rate). The proposed methodology can be applied in two stages (Figure 3-40). These stages consist of:

- Stage 1 evaluates the influence of skid resistance on the expected accident frequency and rate obtained from the developed models, by analysing coefficients associated with the other explanatory variables (traffic, geometrics and pavement characteristics).
- Stage 2 skid resistance data were divided into intervals (bins) with increments of 0.05 skid resistance units (SCRIM) (Table 3-35). The expected total, dry, wet, slight and serious and fatal accident frequencies and rates, obtained from RPNB and RPT models, for each skid resistance bin, were determined for different site categories. The analysis of the expected total, dry, wet, slight and serious and fatal accident frequencies and rates for different site categories as a function of skid resistance enables the definition of skid resistance thresholds.

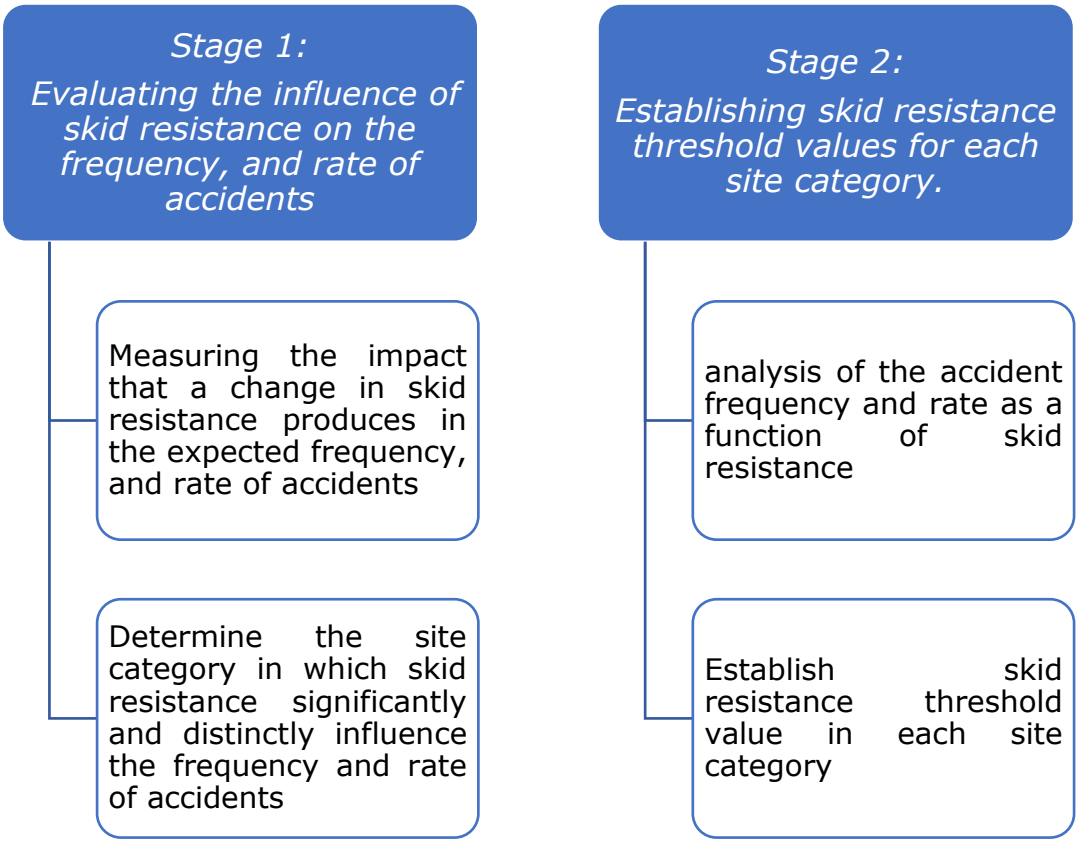


Figure 3-18: Skid resistance threshold methodology

Table 3-35: Categorized skid resistance data

Site category	Skid resistance (Bin)	Upper limit of skid resistance	Expected accidents frequency					Expected accidents rate				
			T	D	W	SL	SF	TAR	DAR	WAR	SLAR	SFAR
NT NE B1 B2 RA JN GR	SR <=0.2	0.20										
	0.2<SR<=0.25	0.25										
	0.25<SR<=0.3	0.30										
	0.3<SR<=0.35	0.35										
	0.35<SR<=0.4	0.40										
	0.4<SR<=0.45	0.45										
	0.45<SR<=0.5	0.50										
	0.5<SR<=0.55	0.55										
	0.55<SR<=0.6	0.60										
	SR>0.65	0.65										

3.10 Summary

This chapter discusses the methodology that is employed in the thesis. It includes details on the design of the study, site categories, dependent and independent variables definitions, statistical methods, and data to model accident rates and frequency. It also establishes thresholds for speed resistance for applications with respect to rates and frequencies of traffic accidents. The first part of the chapter clarifies as to how each of the networks in Oxfordshire, Norfolk, and Nottinghamshire are divided into distinct site categories based on the accident layout with respect to diverse features of the highway (junctions and roundabouts) and the relationship that exists between roadway segments geometric characteristics such as gradient, curvature radius, and accidents. In the second part of the chapter, a description of the model strategy followed in the thesis to construct the models (rate and frequency) is detailed. The FPNB and RPNB models are selected to model accident frequency while FTP and RPT models are selected for the accident rate modelling. The chapter finally delivers a description of the method employed to establish thresholds for skid resistance by using the outcome of the rate and frequency models.

CHAPTER FOUR

MODEL DEVELOPMENT AND SELECTION

CHAPTER FOUR: MODEL DEVELOPMENT AND SELECTION

4.1 Overview

There are many ways to assess the performance of a statistical model. Each method is informative, but none are definitive. Rather, they can be used together to gain a balanced view of model performance, and hence guide selection of a preferred model (Memon, 2012). The main objectives of model development and selection were to achieve models that related variations in T, D, W, SL and SF accident frequencies and rates, to explanatory variables (traffic, geometrics and pavement characteristics) in a way that represented a substantial proportion of observed variation, whilst respecting data variability. Explanatory variables should have clear interpretation and they should have a good degree of mutual independence.

This chapter is organised as follows:

- In the first, collinearity test results are performed for independent variables by using the VIF is presented.
- The process of selecting the subset of independent variables is incorporated into the frequency and rate estimation models for each site category using BIC and AIC and is explained in the second section.
- Section three presents the log-likelihood ratio test results that are performed with the aim of evaluating whether the random-parameter models are more statistically superior when compared to their matching fixed parameter models.
- The forth section details the results of the log-likelihood ratio tests performed to ascertain the statistical significance of the three distinct models (Oxfordshire, Norfolk, and Nottinghamshire) as opposed to the all-data model (combined 3C data).
- The final section delivers a summary of the results and obtained findings.

4.2 Correlation analysis

Collinearity tests are conducted by using VIF as the collinearity indicator to distinguish any correlation between independent variables (traffic, geometric and pavement characteristics) used in creating the models for total, dry, wet, slight and serious and fatal accident frequencies and rates for 3C site categories (refer to section 3.8.1, Equation 3-1). Table 4-1 shows a representation of the correlation between all traffic, geometric and pavement characteristics variables that were tested in the process of constructing the models for NT, NE, B1, B2, RA, JN, and GR site categories for 3C models. As elucidated in Section 3.8.1, in the event when VIF ≥ 5 between two variables that are independent, one of the variables should not be included in the model. This is because the collinearity between two variables leads to high standard errors and makes the independent variable appear insignificant even in cases where it is actually statistically significant. Using the results presented in Table 4-1, it is noted from the collinearity test that all VIF values between independent variables (traffic, geometric and pavement characteristics) for all site categories are below 5. Hence, there is no evidence that a collinearity problem exists.

Table 4-1: VIF results of correlation between independent variables for 3C at different site categories

S. C.	Var.	Ln AADF	%HV	SPL	RC	%G	NL	NMA	SR	RD	TX
NT	Ln AADF										
	%HV	1.214									
	SPL	1.132	1.043								
	RC	1.039	1.037	1.026							
	%G	1.023	1.021	1.023	1.012						
	NL	1.062	1.000	1.000	1.011	1.072					
	NMA	1.016	1.017	1.016	1.015	1.000	1.099				
	SR	1.034	1.035	1.012	1.013	1.017	1.014	1.016			
	RD	1.020	1.027	1.026	1.011	1.010	1.017	1.012	1.003		
	TX	1.051	1.012	1.019	1.012	1.015	1.000	1.000	1.007	1.000	
NE	Ln AADF										
	%HV	1.244									
	SPL	1.112	1.043								
	RC	1.029	1.027	1.026							
	%G	1.023	1.011	1.013	1.012						
	NL	1.132	1.016	1.016	1.015	1.012					
	NMA	1.016	1.017	1.016	1.019	1.019	1.000				
	SR	1.034	1.035	1.012	1.013	1.011	1.019	1.013			
	RD	1.050	1.027	1.046	1.031	1.021	1.027	1.016	1.013		
	TX	1.041	1.022	1.019	1.012	1.015	1.014	1.013	1.011	1.008	

Table 4-1: Continued

S. C.	Var.	Ln AADF	%HV	SPL	RC	%G	NL	NMA	SR	RD	TX
B1	Ln AADF										
	%HV	1.235									
	SPL	1.105	1.026								
	RC	1.025	1.026	1.024							
	%G	1.027	1.018	1.018	1.017						
	NL	1.056	1.031	1.038	1.028	1.027					
	NMA	1.014	1.011	1.013	1.017	1.029	1.001				
	SR	1.041	1.035	1.023	1.028	1.025	1.012	1.005			
	RD	1.017	1.015	1.015	1.011	1.012	1.018	1.000	1.000		
	TX	1.133	1.013	1.014	1.012	1.011	1.004	1.003	0.999	1.004	
B2	Ln AADF										
	%HV	1.226									
	SPL	1.131	1.031								
	RC	1.014	1.018	1.002							
	%G	1.013	1.014	1.019	1.011						
	NL	1.012	1.017	1.012	1.013	1.000					
	NMA	1.022	1.022	1.019	1.002	1.004	1.019				
	SR	1.030	1.028	1.013	1.019	1.012	1.018	0.998			
	RD	1.034	1.025	1.025	1.024	1.028	1.013	1.018	0.998		
	TX	1.112	1.017	1.013	1.017	1.001	1.003	1.007	1.008	1.000	
RA	Ln AADF										
	%HV	1.158									
	SPL	1.131	1.020								
	RC	1.117	1.116	1.109							
	%G	1.062	1.049	1.042	1.010						
	NL	1.111	1.108	1.106	1.097	1.090					
	NMA	1.023	1.023	1.013	1.019	1.011	1.019				
	SR	1.013	1.010	1.016	1.003	1.009	1.000	0.999			
	RD	1.134	1.137	1.130	1.102	1.105	1.014	1.000	1.000		
	TX	1.048	1.023	1.023	1.017	1.011	1.011	1.108	1.001	0.998	
JN	Ln AADF										
	%HV	1.249									
	SPL	1.224	1.083								
	RC	1.034	1.035	1.020							
	%G	1.034	1.026	1.022	1.013						
	NL	1.033	1.038	1.018	1.012	1.003					
	NMA	1.027	1.014	1.005	1.006	1.008	1.000				
	SR	1.030	1.038	1.020	1.012	1.019	1.015	1.014			
	RD	1.037	1.024	1.022	1.021	1.012	1.017	1.012	0.998		
	TX	1.091	1.045	1.013	1.018	1.000	1.002	1.000	1.001	1.014	
GR	Ln AADF										
	%HV	1.154									
	SPL	1.131	1.074								
	RC	1.025	1.024	1.029							
	%G	1.039	1.038	1.022	1.027						
	NL	1.068	1.045	1.013	1.016	1.017					
	NMA	1.014	1.018	1.013	1.012	1.013	1.010				
	SR	1.062	1.050	1.044	1.035	1.037	1.038	1.048			
	RD	1.073	1.070	1.066	1.060	1.068	1.053	1.036	1.003		
	TX	1.062	11.03	1.033	1.026	1.049	1.011	1.011	1.006	0.998	

4.3 Selection of independent variables

Section 3.8.2 indicated that two information AIC and BIC criteria are used in the selection of the subset of independent variables that should be included in total, dry, wet, slight and serious and fatal accident frequency and rate estimation models for each site category. The model indicating the minimum AIC and BIC value was considered as the most effective model that delivered a fit that is superior and reflected the parameter estimates that exhibit a close convergence to the true parameters of the model (Naderan and Babaei, 2011; Cummings, 2009; Greene, 2008). Several FPNB and FPT models are created used a varying range of independent variables using forward selection method (which involves starting with constant model, testing the addition of each variable using a chosen model fit criterion (AIC, BIC)), this process will be repeating until none improves the model to a statistically significant extent) which involves in the process of setting up the base models for total, dry, wet, slight and serious and fatal accident frequencies and rates for each site category (Refer to Table 4-2).

Table 4-2: Framework of frequency and rate model development

Model	Description
1	Constant
2	Constant + Ln AADF
3	Constant + Ln AADF + %HV
4	Constant + Ln AADF + %HV + SPL
5	Constant + Ln AADF + %HV + SPL + RC
6	Constant + Ln AADF + %HV + SPL + RC + %G
7	Constant + Ln AADF + %HV + SPL + RC + %G + NL
8	Constant + Ln AADF + %HV + SPL + RC + %G + NL + NMA
9	Constant + Ln AADF + %HV + SPL + RC + %G + NL + NMA + SR
10	Constant + Ln AADF + %HV + SPL + RC + %G + NL + NMA + SR + RD
11	Constant + Ln AADF + %HV + SPL + RC + %G + NL + NMA + SR + RD + TX

Tables 4-3 and 4-4 show the AIC and BIC results for total, dry, wet, slight and serious and fatal accident frequency and rate models, for 3C, at different site categories. The process of evaluating the model is performed through an analysis of AIC and BIC values with the obtained results indicating that model number 11 (FPNB) for total, dry, wet, slight and serious and fatal accident frequencies; and model number 11 (FPT) total, dry, wet, slight and serious and fatal accident rates for all site categories exhibit lower AIC and BIC values when compared with other models (see Tables 4-2 and 4-3). In addition, the importance of each independent variables measure using Equations (3-8) and (3-9). Tables 4-4 and 4-5 show the rank of each independent variable for total, dry, wet, slight and serious and fatal accident frequencies and rates for NT level, NE, B1, B2, RA, JN and GR site categories.

Table 4-3: AIC and BIC Results for T, D, W, SL and SF accident frequency models for 3C at different site categories

AC TYPE	MODEL	Site category													
		NT		NE		B1		B2		RA		JN		GR	
		AIC	BIC	AIC	BIC	AIC	BIC	AIC	BIC	AIC	BIC	AIC	BIC	AIC	BIC
T	1	68573.4	68582.0	30510.8	30518.9	5717.2	5723.4	7391.8	7398.4	6124.8	6130.2	12891.0	12897.3	2223.2	2228.9
	2	67145.0	67162.2	29905.8	29922.0	5624.8	5637.3	7226.8	7239.9	6083.4	6094.2	12680.6	12693.3	2211.2	2222.7
	3	66518.2	66544.0	29899.8	29924.1	5613.8	5632.5	7207.8	7227.5	6065.4	6081.5	12625.2	12644.2	2199.6	2216.8
	4	66257.8	66292.2	29887.2	29919.6	5594.4	5619.3	7188.8	7215.0	6048.4	6069.9	12607.8	12633.2	2171.4	2194.4
	5	66252.2	66295.2	29779.2	29819.6	5571.4	5602.6	7177.8	7210.6	6035.8	6062.7	12597.0	12628.7	2160.6	2189.3
	6	66206.4	66258.0	29752.8	29801.3	5547.8	5585.2	7163.8	7203.1	6022.2	6054.5	12579.6	12617.6	2150.2	2184.7
	7	65902.2	65962.4	29669.6	29726.2	5524.4	5568.1	7153.8	7199.7	6009.2	6046.9	12537.8	12582.2	2123.0	2163.2
	8	65552.8	65621.6	29479.0	29543.7	5503.4	5553.3	7141.0	7193.4	5998.2	6041.2	12499.0	12549.7	2110.8	2156.7
	9	65526.6	65604.0	29414.8	29487.6	5482.2	5538.3	7131.4	7190.4	5987.0	6035.4	12481.0	12538.0	2100.2	2151.9
	10	65510.2	65596.3	29318.4	29399.3	5459.6	5522.0	7120.8	7186.3	5974.2	6028.0	12464.6	12528.0	2088.2	2145.6
	11	65493.6	65588.3	29300.4	29389.4	5435.4	5504.0	7106.6	7178.7	5962.8	6022.0	12453.6	12523.3	2079.4	2142.6
D	1	50894.8	50903.4	22596.2	22604.3	4312.8	4319.0	5491.6	5498.2	4673.4	4678.8	9923.8	9930.1	1646.6	1652.3
	2	49481.6	49498.8	22076.6	22092.8	4234.4	4246.9	5332.4	5345.5	4621.4	4632.2	9785.8	9798.5	1577.6	1589.1
	3	48931.6	48957.4	21817.4	21841.7	4188.8	4207.5	5320.6	5340.3	4611.4	4627.5	9772.8	9791.8	1561.4	1578.6
	4	48599.4	48633.8	21799.2	21831.6	4146.8	4171.7	5310.8	5337.0	4598.6	4620.1	9756.8	9782.2	1552.4	1575.4
	5	48584.2	48627.2	21779.6	21820.0	4121.4	4152.6	5298.8	5331.6	4578.6	4605.5	9538.2	9569.9	1523.4	1552.1
	6	48573.0	48624.6	21766.2	21814.7	4103.4	4140.8	5287.8	5327.1	4556.2	4588.5	9519.8	9557.8	1510.8	1545.3
	7	48433.8	48494.0	21691.6	21748.2	4085.0	4128.7	5274.4	5320.3	4542.6	4580.3	9494.4	9538.8	1494.6	1534.8
	8	48048.0	48116.8	21669.4	21734.1	4072.6	4122.5	5261.2	5313.6	4532.2	4575.2	9472.6	9523.3	1479.8	1525.7
	9	47994.6	48072.0	21643.4	21716.2	4058.6	4114.7	5246.2	5305.2	4524.2	4572.6	9460.4	9517.4	1461.6	1513.3
	10	47980.4	48066.5	21620.6	21701.5	4049.2	4111.6	5235.6	5301.1	4509.0	4562.8	9450.4	9513.8	1451.0	1508.4
	11	47962.4	48057.1	21607.4	21696.4	4035.4	4104.0	5223.0	5295.1	4497.2	4556.4	9441.4	9511.1	1439.2	1502.4
W	1	37362.4	37371.0	16081.0	16089.1	3028.6	3034.8	3874.2	3880.8	3733.6	3739.0	7375.6	7381.9	1397.2	1402.9
	2	36931.4	36948.6	15905.2	15921.4	3016.8	3029.3	3856.6	3869.7	3649.0	3659.8	7320.2	7332.9	1342.4	1353.9
	3	36558.4	36584.2	15880.2	15904.5	3007.0	3025.7	3840.4	3860.1	3636.8	3652.9	7267.0	7286.0	1329.2	1346.4
	4	36498.8	36533.2	15823.4	15855.8	2992.4	3017.3	3829.4	3855.6	3622.6	3644.1	7249.4	7274.8	1320.6	1343.6
	5	36477.0	36520.0	15796.4	15836.8	2971.8	3003.0	3818.6	3851.4	3611.4	3638.3	7233.2	7264.9	1306.2	1334.9
	6	36457.2	36508.8	15786.4	15834.9	2957.2	2994.6	3809.0	3848.3	3600.4	3632.7	7215.6	7253.6	1290.4	1324.9
	7	36439.6	36499.8	15761.2	15817.8	2939.8	2983.5	3799.6	3845.5	3587.4	3625.1	7191.4	7235.8	1280.2	1320.4
	8	36390.4	36459.2	15730.4	15795.1	2918.6	2968.5	3784.6	3837.0	3576.8	3619.8	7178.8	7229.5	1269.2	1315.1
	9	36364.0	36441.4	15702.4	15775.2	2874.4	2930.5	3768.4	3827.4	3564.8	3613.2	7157.4	7214.4	1259.2	1310.9
	10	36064.2	36150.3	15678.4	15759.3	2857.0	2919.4	3757.8	3823.3	3554.6	3608.4	7142.8	7206.2	1239.2	1296.6
	11	36046.2	36140.9	15656.6	15745.6	2837.4	2906.0	3744.6	3816.7	3542.2	3601.4	7119.8	7189.5	1222.4	1285.6

Table 4-3: Continued

AC TYPE	MODEL	Site category													
		NT		NE		B1		B2		RA		JN		GR	
		AIC	BIC	AIC	BIC	AIC	BIC	AIC	BIC	AIC	BIC	AIC	BIC	AIC	BIC
SL	1	60347.8	60356.4	26882.4	26890.5	4489.4	4495.6	6542.2	6548.8	5490.4	5495.8	11472.2	11478.5	2171.6	2177.3
	2	58985.8	59003.0	26274.4	26290.6	4415.4	4427.9	6392.2	6405.3	5456.1	5466.9	11247.0	11259.7	1992.2	2003.7
	3	58858.4	58884.2	26211.2	26235.5	4402.6	4421.3	6370.8	6390.5	5441.6	5457.8	11158.6	11177.6	1980.4	1997.6
	4	58105.2	58139.6	26179.6	26212.0	4389.6	4414.5	6347.8	6374.0	5431.2	5452.7	11137.6	11163.0	1971.8	1994.8
	5	58080.6	58123.6	26133.8	26174.2	4369.2	4400.4	6330.4	6363.2	5418.4	5445.3	11113.6	11145.3	1962.2	1990.9
	6	58049.0	58100.6	26055.8	26104.3	4353.2	4390.6	6309.8	6349.1	5408.6	5440.9	11096.2	11134.2	1943.2	1977.7
	7	57740.6	57800.8	26035.8	26092.4	4330.4	4374.1	6294.4	6340.3	5398.2	5435.9	11085.0	11129.4	1923.8	1964.0
	8	57426.8	57495.6	25882.6	25947.3	4317.4	4367.3	6271.6	6324.0	5384.8	5427.8	11070.8	11121.5	1904.4	1950.3
	9	57406.4	57483.8	25869.8	25942.6	4301.2	4357.3	6258.2	6317.2	5365.4	5413.8	11058.8	11115.8	1878.8	1930.5
	10	57385.2	57471.3	25854.8	25935.7	4268.4	4330.8	6247.4	6312.9	5350.4	5404.2	11043.6	11107.0	1872.6	1930.0
	11	57369.2	57463.9	25846.6	25918.6	4247.2	4315.8	6235.2	6307.3	5339.4	5398.6	11031.8	11101.5	1859.6	1922.8
SF	1	24152.6	24161.2	9724.4	9732.5	1875.8	1882.0	2365.2	2371.8	2909.2	2914.6	5288.2	5294.5	794.4	800.1
	2	23889.2	23906.4	9642.8	9659.0	1856.4	1868.9	2333.0	2346.1	2708.2	2719.0	5267.6	5280.3	755.6	767.1
	3	23869.4	23895.2	9561.2	9585.5	1846.2	1864.9	2319.2	2338.9	2694.4	2710.5	5248.6	5267.6	746.4	763.6
	4	23815.8	23850.2	9538.4	9570.8	1830.6	1855.5	2306.4	2332.6	2682.8	2704.3	5236.6	5262.0	738.2	761.2
	5	23745.6	23788.6	9521.8	9562.2	1816.2	1847.4	2295.4	2328.2	2671.2	2698.1	5219.8	5251.5	725.4	754.1
	6	23721.6	23773.2	9502.4	9550.9	1802.8	1840.2	2282.2	2321.5	2656.6	2688.9	5189.4	5227.4	695.4	729.9
	7	23671.8	23732.0	9483.0	9539.6	1789.2	1832.9	2268.8	2314.7	2643.4	2681.1	5137.6	5182.0	680.2	720.4
	8	23473.8	23542.6	9463.8	9528.5	1778.8	1828.7	2255.8	2308.2	2625.2	2668.2	5125.2	5175.9	671.6	717.5
	9	23455.4	23532.8	9440.4	9513.2	1767.2	1823.3	2245.0	2304.0	2610.8	2659.2	5107.2	5164.2	654.2	705.9
	10	23426.6	23512.7	9423.6	9504.5	1758.2	1820.6	2226.8	2292.3	2600.8	2654.6	5048.8	5112.2	629.6	687.0
	11	23408.8	23503.5	9403.0	9492.0	1742.4	1811.0	2212.8	2284.9	2582.6	2641.8	5026.6	5096.3	619.2	682.4

Table 4-4: AIC and BIC Results for TAR, DAR, WAR, SLAR and SFAR accident rate models for 3C at different site categories

AC TYPE	MODEL	Site category													
		NT		NE		B1		B2		RA		JN		GR	
		AIC	BIC	AIC	BIC	AIC	BIC	AIC	BIC	AIC	BIC	AIC	BIC	AIC	BIC
TAR	1	190226.6	190235.2	72498.6	72506.7	17371.0	17377.2	18400.6	18407.2	12424.2	12429.6	36706.8	36713.1	5209.4	5215.1
	2	176615.2	176632.4	72393.0	72409.2	17350.2	17362.7	18336.8	18349.9	12213.6	12224.4	36577.8	36590.5	5199.8	5211.3
	3	173409.0	173434.8	72383.2	72407.5	17321.6	17340.3	18326.4	18346.1	12202.8	12218.9	36563.8	36582.8	5188.8	5206.0
	4	169050.0	169084.4	72368.8	72401.2	14432.8	14457.7	18303.6	18329.8	12190.2	12211.7	36550.8	36576.2	5174.6	5197.6
	5	165066.8	165109.8	72332.4	72372.8	14410.8	14442.0	18291.2	18324.0	12173.4	12200.3	36529.4	36561.1	5165.8	5194.5
	6	165030.4	165082.0	72317.8	72366.3	14399.8	14437.2	18281.2	18320.5	12154.4	12186.7	36507.4	36545.4	5135.8	5170.3
	7	164795.8	164856.0	72301.4	72358.0	14373.8	14417.5	18269.0	18314.9	12136.4	12174.1	36483.2	36527.6	5122.2	5162.4
	8	164453.8	164522.6	72273.8	72338.5	14357.2	14407.1	18244.2	18296.6	12122.2	12165.2	36473.0	36523.7	5106.6	5152.5
	9	164415.2	164492.6	72190.4	72263.2	14344.8	14400.9	18233.4	18292.4	12111.4	12159.8	36449.0	36506.0	5095.8	5147.5
	10	164402.8	164488.9	72172.4	72253.3	14326.6	14389.0	18211.0	18276.5	12098.6	12152.4	36436.2	36499.6	5086.2	5143.6
	11	164389.0	164483.7	72157.8	72246.8	14314.6	14383.2	18172.4	18244.5	12084.4	12143.6	36423.4	36493.1	5077.2	5140.4
DAR	1	116984.6	116993.2	51987.2	51995.3	14018.2	14024.4	13084.6	13091.2	7563.2	7568.6	29052.4	29058.7	3685.4	3691.1
	2	116829.0	116846.2	51808.6	51824.8	10626.8	10639.3	13019.6	13032.7	7523.4	7534.2	28469.6	28482.3	3587.0	3598.5
	3	116816.2	116842.0	51668.4	51692.7	10464.2	10482.9	13003.4	13023.1	7499.0	7515.1	28304.6	28323.6	3575.8	3593.0
	4	116798.2	116832.6	51497.6	51530.0	10448.8	10473.7	12983.4	13009.6	7484.2	7505.7	28141.2	28166.6	3538.8	3561.8
	5	116779.4	116822.4	51481.8	51522.2	10436.4	10467.6	12963.8	12996.6	7460.6	7487.5	27703.6	27735.3	3530.6	3559.3
	6	116765.4	116817.0	51463.4	51511.9	10418.4	10455.8	12953.6	12992.9	7444.2	7476.5	27492.6	27530.6	3520.4	3554.9
	7	116685.0	116745.2	51445.6	51502.2	10407.6	10451.3	12922.8	12968.7	7431.0	7468.7	27463.0	27507.4	3512.2	3552.4
	8	116348.2	116417.0	51396.0	51460.7	10384.6	10434.5	12881.4	12933.8	7416.8	7459.8	26925.8	26976.5	3498.2	3544.1
	9	116280.4	116357.8	51343.2	51416.0	10365.8	10421.9	12869.4	12928.4	7407.8	7456.2	26914.2	26971.2	3473.0	3524.7
	10	116262.4	116348.5	51325.6	51406.5	10346.6	10409.0	12854.6	12920.1	7394.2	7448.0	26898.4	26961.8	3450.8	3508.2
	11	116244.2	116338.9	51309.6	51398.6	10325.8	10394.4	12844.8	12916.9	7385.6	7444.8	26883.8	26953.5	3436.6	3499.8
WAR	1	95296.2	95304.8	36697.2	36705.3	11161.2	11167.4	9806.2	9812.8	6226.1	6231.4	21219.8	21226.1	3189.6	3195.3
	2	93176.4	93193.6	36595.2	36611.4	7197.6	7210.1	9580.8	9593.9	6175.2	6186.0	21165.8	21178.5	3129.8	3141.3
	3	89801.8	89827.6	36485.8	36510.1	7175.6	7194.3	9536.4	9556.1	6161.6	6177.7	21114.2	21133.2	3074.2	3091.4
	4	89744.6	89779.0	36417.0	36449.4	7158.6	7183.5	9504.6	9530.8	4466.8	4488.3	21013.2	21038.6	3058.2	3081.2
	5	89694.6	89737.6	36405.8	36446.2	7144.2	7175.4	9465.8	9498.6	4457.6	4484.5	21000.6	21032.3	3035.2	3063.9
	6	87313.6	87365.2	36392.2	36440.7	7133.8	7171.2	9407.8	9447.1	4447.0	4479.3	20978.8	21016.8	3022.6	3057.1
	7	87079.4	87139.6	36375.6	36432.2	7122.2	7165.9	9347.6	9393.5	4438.2	4475.9	20970.4	21014.8	3012.2	3052.4
	8	86976.2	87045.0	36357.6	36422.3	7111.2	7161.1	9285.8	9338.2	4428.6	4471.6	20953.4	21004.1	2999.8	3045.7
	9	86946.6	87024.0	36327.4	36400.2	7101.2	7157.3	9261.2	9320.2	4418.3	4466.7	20939.6	20996.6	2991.4	3043.1
	10	86931.0	87017.1	36305.0	36385.9	7086.2	7148.6	9221.4	9286.9	4396.5	4450.3	20927.4	20990.8	2980.6	3038.0
	11	86915.8	87010.5	48379.6	48468.6	7073.0	7141.6	9205.0	9277.1	4143.0	4202.1	20888.6	20958.3	2921.8	2858.6

Table 4-4: Continued

AC TYPE	MODEL	Site category													
		NT		NE		B1		B2		RA		JN		GR	
		AIC	BIC	AIC	BIC	AIC	BIC	AIC	BIC	AIC	BIC	AIC	BIC	AIC	BIC
SLAR	1	142551.0	142559.6	63011.4	63019.5	15769.4	15775.6	20658.0	20664.6	10199.4	10204.8	33979.8	33986.1	4646.2	4651.9
	2	142371.0	142388.2	62851.2	62867.4	15623.6	15636.1	18441.4	18454.5	10143.4	10154.2	32409.8	32422.5	4599.8	4611.3
	3	142353.0	142378.8	62692.2	62716.5	15474.4	15493.1	18406.2	18425.9	10135.4	10151.5	31882.4	31901.4	4575.0	4592.2
	4	142336.4	142370.8	62512.8	62545.2	12615.0	12639.9	18017.4	18043.6	10085.2	10106.7	31867.6	31893.0	4560.6	4583.6
	5	142315.0	142358.0	62501.8	62542.2	12601.8	12633.0	17880.2	17913.0	9989.6	10016.5	31846.2	31877.9	4549.8	4578.5
	6	142291.6	142343.2	62483.6	62532.1	12587.4	12624.8	17800.2	17839.5	9973.6	10005.9	31834.2	31872.2	4537.8	4572.3
	7	142085.2	142145.4	62450.8	62507.4	12574.4	12618.1	16436.2	16482.1	9947.4	9985.1	31820.6	31865.0	4522.2	4562.4
	8	141725.8	141794.6	62400.2	62464.9	12562.6	12612.5	16404.6	16457.0	9925.2	9968.2	31811.4	31862.1	4494.4	4540.3
	9	141700.6	141778.0	62335.6	62408.4	12549.4	12605.5	16378.6	16437.6	9910.6	9959.0	31781.2	31838.2	4473.8	4525.5
	10	141685.6	141771.7	62317.2	62398.1	12533.8	12596.2	16012.6	16078.1	9871.6	9925.4	31770.4	31833.8	4462.8	4520.2
	11	141668.6	141763.3	62298.4	62387.4	12518.2	12586.8	15969.6	16041.7	9848.0	9907.2	31759.8	31829.5	4443.8	4507.0
SFAR	1	55680.2	55688.8	21772.2	21780.3	4312.6	4318.8	5388.2	5394.8	5021.4	5026.8	13978.2	13984.5	1583.2	1588.9
	2	55583.2	55600.4	21752.2	21768.4	4301.0	4313.5	5368.6	5381.7	4980.8	4991.6	13901.2	13913.9	1571.2	1582.7
	3	55427.6	55453.4	21680.2	21704.5	4286.2	4304.9	5355.8	5375.5	4970.2	4986.3	13883.2	13902.2	1563.0	1580.2
	4	55375.6	55410.0	21660.6	21693.0	4276.2	4301.1	5341.8	5368.0	4962.2	4983.7	13859.0	13884.4	1548.6	1571.6
	5	55360.8	55403.8	21620.2	21660.6	4263.8	4295.0	5331.4	5364.2	4951.8	4978.7	13845.0	13876.7	1538.4	1567.1
	6	55340.4	55392.0	21608.2	21656.7	4253.6	4291.0	5313.0	5352.3	4939.8	4972.1	13831.8	13869.8	1521.4	1555.9
	7	55326.2	55386.4	21594.2	21650.8	4242.4	4286.1	5290.2	5336.1	4929.8	4967.5	13812.4	13856.8	1510.6	1550.8
	8	55221.0	55289.8	21578.6	21643.3	4232.2	4282.1	5259.4	5311.8	4921.2	4964.2	13801.8	13852.5	1478.4	1524.3
	9	55193.8	55271.2	21564.2	21637.0	4221.8	4277.9	5251.2	5310.2	4907.2	4955.6	13776.8	13833.8	1463.6	1515.3
	10	55175.4	55261.5	21546.2	21627.1	4211.8	4274.2	5237.0	5302.5	4882.8	4936.6	13728.4	13791.8	1451.4	1508.8
	11	55134.8	55229.5	21528.2	21617.2	4199.6	4268.2	5223.0	5295.1	4870.2	4929.4	13665.2	13734.9	1440.6	1503.8

Table 4-5: Importance of independent variables for frequency models

AC TYPE	Variable	Site category																			
		NT			NE			B1			B2			RA			JN			GR		
		W_{AICi}	W_{BICi}	Rank	W_{AICi}	W_{BICi}	Rank	W_{AICi}	W_{BICi}	Rank	W_{AICi}	W_{BICi}	Rank	W_{AICi}	W_{BICi}	Rank	W_{AICi}	W_{BICi}	Rank	W_{AICi}	W_{BICi}	Rank
T	Ln AADF	1651	1574	1	605	533	1	189	133	1	120	61	1	121	72	1	227	170	1	132	80	1
	%HV	1025	956	2	599	535	2	178	129	2	101	49	2	103	60	2	172	121	2	120	74	2
	SPL	764	704	3	587	530	3	159	115	3	82	36	3	86	48	3	154	110	3	92	52	3
	RC	759	707	4	479	430	4	136	99	4	71	32	4	73	41	4	143	105	4	81	47	4
	%G	713	670	5	452	412	5	112	81	5	57	24	5	59	33	5	126	94	5	71	42	5
	NL	409	374	6	369	337	6	89	64	6	47	21	6	46	25	6	84	59	6	44	21	6
	NMA	59	33	7	179	154	7	68	49	7	34	15	7	35	19	7	45	26	7	31	14	7
	SR	33	16	8	114	98	8	47	34	8	25	12	8	24	13	8	27	15	8	21	9	8
	RD	17	8	9	18	10	9	24	18	9	14	8	9	11	6	9	11	5	9	9	3	9
	TX	0	0	10	0	0	10	0	0	10	0	0	10	0	0	10	0	0	10	0	0	10
D	Ln AADF	1519	1442	1	469	396	1	199	143	1	109	50	1	124	76	1	344	287	1	138	87	1
	%HV	969	900	2	210	145	2	153	104	2	98	45	2	114	71	2	331	281	2	122	76	2
	SPL	637	577	3	192	135	3	111	68	3	88	42	3	101	64	3	315	271	3	113	73	3
	RC	622	570	4	172	124	4	86	49	4	76	37	4	81	49	4	97	59	4	84	50	4
	%G	611	568	5	159	118	5	68	37	5	65	32	5	59	32	5	78	47	5	72	43	5
	NL	471	437	6	84	52	6	50	25	6	51	25	6	45	24	6	53	28	6	55	32	6
	NMA	86	60	7	62	38	7	37	19	7	38	19	7	35	19	7	31	12	7	41	23	7
	SR	32	15	8	36	20	8	23	11	8	23	10	8	27	16	8	19	6	8	22	11	8
	RD	18	9	9	13	5	9	14	8	9	13	6	9	12	6	9	9	3	9	12	6	9
	TX	0	0	10	0	0	10	0	0	10	0	0	10	0	0	10	0	0	10	0	0	10
W	Ln AADF	885	808	1	249	176	1	179	123	1	112	53	1	107	58	1	200	143	1	120	68	1
	%HV	512	443	2	224	159	2	170	120	2	96	43	2	95	52	2	147	97	2	107	61	2
	SPL	453	392	3	167	110	3	155	111	3	85	39	3	80	43	3	130	85	3	98	58	3
	RC	431	379	4	140	91	4	134	97	4	74	35	4	69	37	4	113	75	4	84	49	4
	%G	411	368	5	130	89	5	120	89	5	64	32	5	58	31	5	96	64	5	68	39	5
	NL	393	359	6	105	72	6	102	78	6	55	29	6	45	24	6	72	46	6	58	35	6
	NMA	344	318	7	74	50	7	81	63	7	40	20	7	35	18	7	59	40	7	47	30	7
	SR	318	301	8	46	30	8	37	25	8	24	11	8	23	12	8	38	25	8	37	25	8
	RD	18	9	9	22	14	9	20	13	9	13	7	9	12	7	9	23	17	9	17	11	9
	TX	0	0	10	0	0	10	0	0	10	0	0	10	0	0	10	0	0	10	0	0	10

Table 4-5: Continued

AC TYPE	Variable	Site category																			
		NT			NE			B1			B2			RA			JN			GR		
		W_{AICi}	W_{BICi}	Rank	W_{AICi}	W_{BICi}	Rank	W_{AICi}	W_{BICi}	Rank	W_{AICi}	W_{BICi}	Rank	W_{AICi}	W_{BICi}	Rank	W_{AICi}	W_{BICi}	Rank	W_{AICi}	W_{BICi}	Rank
SL	Ln AADF	1617	1539	1	428	372	1	168	112	1	157	98	1	117	68	1	215	158	1	133	81	1
	%HV	1489	1420	2	365	317	2	155	106	2	136	83	2	102	59	2	127	76	2	121	75	2
	SPL	736	676	3	333	293	3	142	99	3	113	67	3	92	54	3	106	62	3	112	72	3
	RC	711	660	4	287	256	4	122	85	4	95	56	4	79	47	4	82	44	4	103	68	4
	%G	680	637	5	209	186	5	106	75	5	75	42	5	69	42	5	64	33	5	84	55	5
	NL	371	337	6	189	174	6	83	58	6	59	33	6	59	37	6	53	28	6	64	41	6
	NMA	58	32	7	36	29	7	70	52	7	36	17	7	45	29	7	39	20	7	45	28	7
	SR	37	20	8	23	24	8	54	42	8	23	10	8	26	15	8	27	14	8	19	8	8
	RD	16	7	9	8	17	9	21	15	9	12	6	9	11	6	9	12	6	9	13	7	9
	TX	0	0	10	0	0	10	0	0	10	0	0	10	0	0	10	0	0	10	0	0	10
SF	Ln AADF	480	403	1	240	167	1	114	58	1	120	61	1	126	77	1	241	184	1	136	85	1
	%HV	461	392	2	158	94	2	104	54	2	106	54	2	112	69	2	222	171	2	127	81	2
	SPL	407	347	3	135	79	3	88	45	3	94	48	3	100	63	3	210	166	3	119	79	3
	RC	337	285	4	119	70	4	74	36	4	83	43	4	89	56	4	193	155	4	106	72	4
	%G	313	270	5	99	59	5	60	29	5	69	37	5	74	47	5	163	131	5	76	48	5
	NL	263	229	6	80	48	6	47	22	6	56	30	6	61	39	6	111	86	6	61	38	6
	NMA	65	39	7	61	37	7	36	18	7	43	23	7	43	26	7	99	80	7	52	35	7
	SR	47	29	8	37	21	8	25	12	8	32	19	8	28	17	8	81	68	8	35	24	8
	RD	18	9	9	21	13	9	16	10	9	14	7	9	18	13	9	22	16	9	10	5	9
	TX	0	0	10	0	0	10	0	0	10	0	0	10	0	0	10	0	0	10	0	0	10

Table 4-6: Importance of independent variables for rate models

AC TYPE	Variable	Site category																				
		NT			NE			B1			B2			RA			JN			GR		
		W_{AICi}	W_{BICi}	Rank	W_{AICi}	W_{BICi}	Rank	W_{AICi}	W_{BICi}	Rank	W_{AICi}	W_{BICi}	Rank	W_{AICi}	W_{BICi}	Rank	W_{AICi}	W_{BICi}	Rank	W_{AICi}	W_{BICi}	Rank
TAR	Ln AADF	12226	12149	1	235	162	1	3036	2980	1	164	105	1	129	81	1	154	97	1	123	71	1
	%HV	9020	8951	2	225	161	2	3007	2957	2	154	102	2	118	75	2	140	90	2	112	66	2
	SPL	4661	4601	3	211	154	3	118	75	3	131	85	3	106	68	3	127	83	3	97	57	3
	RC	678	626	4	175	126	4	96	59	4	119	80	4	89	57	4	106	68	4	89	54	4
	%G	641	598	5	160	120	5	85	54	5	109	76	5	70	43	5	84	52	5	59	30	5
	NL	407	372	6	144	111	6	59	34	6	97	70	6	52	31	6	60	35	6	45	22	6
	NMA	65	39	7	116	92	7	43	24	7	72	52	7	38	22	7	50	31	7	29	12	7
	SR	26	9	8	33	16	8	30	18	8	61	48	8	27	16	8	26	13	8	19	7	8
	RD	14	5	9	15	7	9	12	6	9	39	32	9	14	9	9	13	7	9	9	3	9
	TX	0	0	10	0	0	10	0	0	10	0	0	10	0	0	10	0	0	10	0	0	10
DAR	Ln AADF	585	507	1	499	426	1	301	245	1	175	116	1	138	89	1	1586	1529	1	150	99	1
	%HV	572	503	2	359	294	2	138	89	2	159	106	2	113	70	2	1421	1370	2	139	93	2
	SPL	554	494	3	188	131	3	123	79	3	139	93	3	99	61	3	1257	1213	3	102	62	3
	RC	535	484	4	172	124	4	111	73	4	119	80	4	75	43	4	820	782	4	94	60	4
	%G	521	478	5	154	113	5	93	61	5	109	76	5	59	32	5	609	577	5	84	55	5
	NL	441	406	6	136	104	6	82	57	6	78	52	6	45	24	6	579	554	6	76	53	6
	NMA	104	78	7	86	62	7	59	40	7	37	17	7	31	15	7	42	23	7	62	44	7
	SR	36	19	8	34	17	8	40	28	8	25	12	8	22	11	8	30	18	8	36	25	8
	RD	18	10	9	16	8	9	21	15	9	10	3	9	9	3	9	15	8	9	14	8	9
	TX	0	0	10	0	0	10	0	0	10	0	0	10	0	0	10	0	0	10	0	0	10
WAR	Ln AADF	6261	6183	1	499	426	1	125	69	1	376	317	1	2032	1984	1	277	220	1	208	283	1
	%HV	2886	2817	2	359	294	2	103	53	2	331	279	2	2019	1976	2	226	175	2	152	233	2
	SPL	2829	2769	3	188	131	3	86	42	3	300	254	3	324	286	3	125	80	3	136	223	3
	RC	2779	2727	4	172	124	4	71	34	4	261	222	4	315	282	4	112	74	4	113	205	4
	%G	398	355	5	154	113	5	61	30	5	203	170	5	304	277	5	90	59	5	101	199	5
	NL	164	129	6	136	104	6	49	24	6	143	116	6	295	274	6	82	57	6	90	194	6
	NMA	60	35	7	86	62	7	38	20	7	81	61	7	286	270	7	65	46	7	78	187	7
	SR	31	14	8	34	17	8	28	16	8	56	43	8	275	265	8	51	38	8	70	185	8
	RD	15	7	9	16	8	9	13	7	9	16	10	9	254	248	9	39	33	9	59	179	9
	TX	0	0	10	0	0	10	0	0	10	0	0	10	0	0	10	0	0	10	0	0	10

Table 4-6: Continued

AC TYPE	Variable	Site category																			
		NT			NE			B1			B2			RA			JN			GR		
		W_{AICi}	W_{BICi}	Rank	W_{AICi}	W_{BICi}	Rank	W_{AICi}	W_{BICi}	Rank	W_{AICi}	W_{BICi}	Rank	W_{AICi}	W_{BICi}	Rank	W_{AICi}	W_{BICi}	Rank	W_{AICi}	W_{BICi}	Rank
SLAR	Ln AADF	702	625	1	553	480	1	3105	3049	1	2472	2413	1	295	247	1	650	593	1	156	104	1
	%HV	684	616	2	394	329	2	2956	2906	2	2437	2384	2	287	244	2	123	72	2	131	85	2
	SPL	668	608	3	214	158	3	97	53	3	2048	2002	3	237	200	3	108	64	3	117	77	3
	RC	646	595	4	203	155	4	84	46	4	1911	1871	4	142	109	4	86	48	4	106	72	4
	%G	623	580	5	185	145	5	69	38	5	1831	1798	5	126	99	5	74	43	5	94	65	5
	NL	417	382	6	152	120	6	56	31	6	467	440	6	99	78	6	61	36	6	78	55	6
	NMA	57	31	7	102	78	7	44	26	7	435	415	7	77	61	7	52	33	7	51	33	7
	SR	32	15	8	37	21	8	31	19	8	409	396	8	63	52	8	21	9	8	30	19	8
	RD	17	8	9	19	11	9	16	9	9	43	36	9	24	18	9	11	4	9	19	13	9
	TX	0	0	10	0	0	10	0	0	10	0	0	10	0	0	10	0	0	10	0	0	10
SFAR	Ln AADF	448	371	1	224	151	1	101	45	1	146	87	1	111	62	1	236	179	1	131	79	1
	%HV	293	224	2	152	87	2	87	37	2	133	80	2	100	57	2	218	167	2	122	76	2
	SPL	241	181	3	132	76	3	77	33	3	119	73	3	92	54	3	194	150	3	108	68	3
	RC	226	174	4	92	43	4	64	27	4	108	69	4	82	49	4	180	142	4	98	63	4
	%G	206	163	5	80	40	5	54	23	5	90	57	5	70	43	5	167	135	5	81	52	5
	NL	191	157	6	66	34	6	43	18	6	67	41	6	60	38	6	147	122	6	70	47	6
	NMA	86	60	7	50	26	7	33	14	7	36	17	7	51	35	7	137	118	7	38	21	7
	SR	59	42	8	36	20	8	22	10	8	28	15	8	37	26	8	112	99	8	23	12	8
	RD	41	32	9	18	10	9	12	6	9	14	7	9	13	7	9	63	57	9	11	5	9
	TX	0	0	10	0	0	10	0	0	10	0	0	10	0	0	10	0	0	10	0	0	10

4.4 Model comparisons

As mentioned in section 3.8.9, to evaluate the statistical superiority of the random parameters models, a likelihood ratio test was performed to compare the results with the same specifications, estimated from the fixed parameters model. Table 4-7 shows the statistical superiority of RPNB models for 3C frequency models, for all types of accidents in all site categories, as indicated by the log-likelihood, chi square value and the confident level. Regarding the NT site category, Table 4-7 shows the log-likelihood at convergence for FPNB model was -32748.8 and the log-likelihood at convergence for RPNB model for T accidents was -31643.59. Therefore, the likelihood ratio statistic was (X^2 calculated) 2210.4 with 8 degrees of freedom (equal to the number of random parameters in RPNB model), which was larger than the χ^2 critical value of 7.81, for the 0.01 level of significance. This indicated that the RPNB model was statistically better than the FPNB model, in terms of goodness of fit, at a level of confidence interval of 99%. As shown in Table 4-7, the X^2 calculated > X^2 critical in all models thus, the null hypothesis that both FPNB and RPNB had the same statistical performances was rejected, whereas the alternative hypothesis was accepted, assuming that the RPNB model was statistically better than the FPNB model.

Similarly, Table 4-8 shows the statistical superiority of RPT models for 3C rate models, for all types of accidents, in all site categories, as indicated by the log-likelihood, chi square value and the confident level. Regarding the NT site category, Table 4-6 shows that the log-likelihood at convergence for the FPT model was -32748.8 and the log-likelihood at convergence for the RPT model, for total accidents, was -31643.59. Therefore, the likelihood ratio statistic was 2210.4 with 8 degrees of freedom (equal to the number of random parameters in the RPT model), which is larger than the χ^2 critical value of 7.81, for the 0.01 level of significance. This indicated that the RPT model was statistically better than the FPT model, in terms of goodness of fit, at a level of confidence interval of 99%. As shown in Table 4-8, the X^2 calculated > X^2 critical in all models thus the null hypothesis that both FPT and RPT models had the same statistical performance was rejected and accepted the

alternative hypothesis that assumed that RPT model were statistically better than the FPT model.

Table 4-7: Likelihood ratio test for 3C frequency models

Accident type	Site Category	Log-likehood for FPNB	Log-likehood for RPNB	X^2 calculated	DOF	X^2 critical	% confident
T	NT	-32748.8	-31643.59	2210.42	8	20.1	99%
	NE	-14649.2	-13778.45	1741.5	8	20.1	99%
	B1	-2776.68	-2630.82	291.72	6	16.8	99%
	B2	-3572.33	-3476.47	191.72	4	13.3	99%
	RA	-2996.27	-2850.92	290.7	6	16.8	99%
	JN	-6238.85	-6096.52	284.66	6	16.8	99%
	GR	-1048.72	-1192.03	113.38	3	11.3	99%
D	NT	-23988.2	-23277.83	1420.74	8	20.1	99%
	NE	-10862.5	-10229.20	1266.6	8	20.1	99%
	B1	-2056.68	-1950.84	211.68	6	16.8	99%
	B2	-2607.49	-2557.76	99.46	6	16.8	99%
	RA	-2268.01	-2219.35	97.32	6	16.8	99%
	JN	-4736.61	-4594.11	285	5	15.1	99%
	GR	-728.538	-855.38	146.316	3	11.3	99%
W	NT	-18019.1	-17458.30	1121.6	7	18.5	99%
	NE	-7929.23	-5949.34	3959.78	6	16.8	99%
	B1	-1511.62	-1388.74	245.76	3	11.3	99%
	B2	-1916.73	-1838.81	155.84	7	18.5	99%
	RA	-1843.4	-1765.22	156.36	6	16.8	99%
	JN	-3588.91	-3507.31	163.2	4	13.3	99%
	GR	-619.177	-672.59	53.174	2	9.2	99%
SL	NT	-28687.5	-27710.55	1953.9	8	20.1	99%
	NE	-13062.1	-12216.40	1691.4	8	20.1	99%
	B1	-2451.68	-2311.38	280.6	7	18.5	99%
	B2	-3155.57	-3063.71	183.72	5	15.1	99%
	RA	-2689.82	-2600.11	179.42	4	13.3	99%
	JN	-5504.81	-5379.35	250.92	5	15.1	99%
	GR	-928.798	-1050.97	155.656	4	13.3	99%
SF	NT	-11722.7	-11419.24	606.92	7	18.5	99%
	NE	-4740.45	-4627.53	225.84	6	16.8	99%
	B1	-910.509	-875.75	69.518	3	11.3	99%
	B2	-1143.32	-1120.27	46.1	3	11.3	99%
	RA	-1276.74	-1243.13	67.22	5	15.1	99%
	JN	-2612.23	-2578.51	67.44	1	6.6	99%
	GR	-331.644	-388.02	27.248	1	6.6	99%

Table 4-8: Likelihood ratio test for 3C rate models

Accident type	Site Category	Log-likehood for FPT	Log-likehood for RPT	X^2 calculated	DOF	X^2 critical	% confident
TAR	NT	-82183.5	-82113.4	140.3	7	18.5	99%
	NE	-36067.9	-36015.9	104.0	3	11.3	99%
	B1	-7146.3	-7127.3	38.0	6	16.8	99%
	B2	-9075.2	-9016.2	117.9	7	18.5	99%
	RA	-6031.2	-6016.4	29.6	5	15.1	99%
	JN	-18200.7	-17307.6	1786.2	2	9.2	99%
	GR	-2527.6	-2517.7	19.9	3	11.3	99%
DAR	NT	-58111.1	-58100.9	20.4	3	11.3	99%
	NE	-25643.8	-25637.9	11.7	2	9.2	99%
	B1	-5151.9	-5111.3	81.2	1	6.6	99%
	B2	-6411.4	-6367.0	88.8	7	18.5	99%
	RA	-3681.8	-3600.8	161.9	6	16.8	99%
	JN	-13430.9	-12773.0	1315.8	1	6.6	99%
	GR	-1707.3	-1681.3	52.0	7	18.5	99%
WAR	NT	-43446.9	-43386.7	120.4	5	15.1	99%
	NE	-24178.8	-18120.7	12116.2	5	15.1	99%
	B1	-3525.5	-3510.8	29.3	7	18.5	99%
	B2	-4591.5	-4572.9	37.2	7	18.5	99%
	RA	-2060.5	-2000.7	119.5	1	6.6	99%
	JN	-10433.3	-9660.8	1545.0	5	15.1	99%
	GR	-1471.9	-1457.0	29.9	8	20.1	99%
SLAR	NT	-70823.3	-70801.7	43.2	2	9.2	99%
	NE	-31138.2	-31122.3	31.7	1	6.6	99%
	B1	-6248.1	-6227.7	40.9	8	20.1	99%
	B2	-7973.8	-7954.7	38.2	1	6.6	99%
	RA	-4913.0	-4900.9	24.2	8	20.1	99%
	JN	-15868.9	-15855.3	27.2	7	18.5	99%
	GR	-2210.9	-2204.4	13.1	7	18.5	99%
SFAR	NT	-27556.4	-27541.4	30.0	6	16.8	99%
	NE	-10753.1	-10707.5	91.2	6	16.8	99%
	B1	-2088.8	-2077.3	23.1	7	18.5	99%
	B2	-2600.5	-2590.2	20.6	7	18.5	99%
	RA	-2424.1	-2410.6	27.0	7	18.5	99%
	JN	-6821.6	-6808.9	25.3	7	18.5	99%
	GR	-709.3	-700.5	17.5	2	9.2	99%

4.5 Transferability test

As mentioned in section 3.8.10, the transferability test was performed to check the suitability of separate models for Norfolk, Oxfordshire, and Nottinghamshire models over one aggregate model (3C). Table 4-9 presents the results for this transferability test (using log likelihood ratio tests as shown in Equation 3-15) for total, dry, wet, slight and serious and fatal accident frequency models, for all site categories. For all

models, the null hypothesis, which assumed there were no significant differences in the parameter values for the independent variables between the full data model (3C) and separate models (Norofolk, Oxfordshire and Nottinghamshire) was accepted with over 99.99% level of confidence, suggesting the estimation of separate models was statistically unnecessary. For example, for the total accident model at NT level, the likelihood ratio statistic (X^2 calculated) was 28.6 with 20 degrees of freedom (equal to the summation of the number of estimated parameters in 3C models (Norfolk, Oxfordshire and Nottinghamshire), minus the number of estimated parameters in each county model), which was less than the X^2 critical value of 37.6, for the 0.01 level of significance.

Similarly, Table 4-10 presents the results for transferability tests (using log likelihood ratio tests as shown in Equation 3-15) for total, dry, wet, slight and serious and fatal accident rate models, for all site categories. For all models, the null hypothesis, which assumed there were no significant difference in the parameter values for the independent variables between the full data model (3C) and separate models (Norfolk, Oxfordshire and Nottinghamshire), was accepted with over 99.99% level of confidence, suggesting the estimation of separate models was statistically unnecessary. For example, for the total accident model at NT level, the likelihood ratio statistic (X^2 calculated) was 25.4 with 20 degrees of freedom (equal to the summation of the number of estimated parameters in the 3C models (Norfolk, Oxfordshire and Nottinghamshire), minus the number of estimated parameters in each county model), which was less than the χ^2 critical value of 37.6, for the 0.01 level of significance.

Table 4-9: Likelihood ratio tests for parameter transferability for RPNB models

Ac. type	Site cat.	3C	NOR	OXF	NOT	χ^2 CaL	DOF	χ^2 Cri.	No. of Models
		Log-likehood for RPNB	Log-likehood for RPNB	Log-likehood for RPNB	Log-likehood for RPNB				
T	NT	-31643.6	-9460.4	-9218.0	-12951.0	28.6	20	37.6	1
	NE	-13778.5	-4334.9	-3836.8	-5590.8	31.8	20	37.6	1
	B1	-2630.8	-1043.7	-680.3	-902.7	8.2	20	37.6	1
	B2	-3476.5	-1272.1	-995.1	-1206.4	5.6	20	37.6	1
	RA	-2850.9	-565.9	-1054.4	-1225.9	9.4	20	37.6	1
	JN	-6096.5	-1783.8	-1685.6	-2620.4	13.5	20	37.6	1
	GR	-1000.0	-224.8	-303.5	-463.0	17.4	20	37.6	1
D	NT	-23277.8	-7031.0	-6103.9	-10128.3	29.4	20	37.6	1
	NE	-10229.2	-3215.7	-2381.2	-4615.7	33.3	20	37.6	1
	B1	-1950.8	-846.7	-410.4	-678.6	30.3	20	37.6	1
	B2	-2557.8	-1000.9	-640.2	-904.3	24.6	20	37.6	1
	RA	-2219.4	-447.4	-749.5	-1009.4	26.0	20	37.6	1
	JN	-4594.1	-1289.6	-1148.8	-2140.6	30.3	20	37.6	1
	GR	-687.4	-217.5	-240.1	-223.4	12.7	20	37.6	1
W	NT	-17458.3	-4353.1	-5783.0	-7306.4	31.7	20	37.6	1
	NE	-5949.3	-2067.9	-2130.1	-1746.4	9.9	20	37.6	1
	B1	-1388.7	-466.1	-398.7	-510.8	26.5	20	37.6	1
	B2	-1838.8	-591.4	-571.8	-662.7	26.0	20	37.6	1
	RA	-1745.7	-268.6	-728.5	-745.4	6.3	20	37.6	1
	JN	-3507.3	-824.0	-1126.7	-1543.8	25.6	20	37.6	1
	GR	-588.6	-105.4	-225.9	-245.2	24.2	20	37.6	1
SL	NT	-27710.6	-7982.9	-8123.9	-11594.6	18.5	20	37.6	1
	NE	-12216.4	-3695.6	-3181.5	-5326.6	25.4	20	37.6	1
	B1	-2065.4	-699.6	-605.7	-747.2	25.7	20	37.6	1
	B2	-3063.7	-1095.8	-883.8	-1076.4	15.4	20	37.6	1
	RA	-2600.1	-501.9	-963.5	-1122.3	24.6	20	37.6	1
	JN	-5379.4	-1490.9	-1493.8	-2388.4	12.4	20	37.6	1
	GR	-902.0	-197.1	-302.2	-397.8	9.7	20	37.6	1
SF	NT	-11419.2	-3621.6	-3117.1	-4678.8	3.7	20	37.6	1
	NE	-4627.5	-1419.3	-1152.8	-2043.5	23.8	20	37.6	1
	B1	-845.8	-344.5	-184.9	-302.0	28.8	20	37.6	1
	B2	-1082.3	-431.8	-280.2	-361.9	16.7	20	37.6	1
	RA	-1243.1	-322.1	-437.6	-472.1	22.6	20	37.6	1
	JN	-2490.5	-827.4	-711.2	-935.5	32.8	20	37.6	1
	GR	-288.0	-67.2	-95.2	-110.0	31.3	20	37.6	1

Table 4-10: Likelihood ratio tests for parameter transferability for RPT models

Ac. type	Site cat.	3C	NOR	OXF	NOT	χ^2 CaL	DOF	χ^2 Cri.	No. of Models
		Log-likehood for RPT	Log-likehood for RPT	Log-likehood for RPT	Log-likehood for RPT				
T	NT	-82113.4	-25732.3	-24495.5	-31872.8	25.4	20	37.6	1
	NE	-36015.9	-11358.2	-9812.3	-14833.1	24.6	20	37.6	1
	B1	-7127.3	-3055.8	-1868.1	-2200.2	6.5	20	37.6	1
	B2	-9016.2	-3400.4	-2605.0	-2997.2	27.3	20	37.6	1
	RA	-6016.4	-2019.0	-1987.0	-2003.6	13.6	20	37.6	1
	JN	-17307.6	-5834.6	-6141.2	-5323.7	16.1	20	37.6	1
	GR	-2517.7	-755.6	-959.3	-800.5	4.4	20	37.6	1
D	NT	-58100.9	-18279.2	-15589.9	-24224.2	15.2	20	37.6	1
	NE	-25637.9	-8186.2	-6420.2	-11017.8	27.6	20	37.6	1
	B1	-5111.3	-2491.1	-1073.5	-1538.9	15.5	20	37.6	1
	B2	-6367.0	-2608.3	-1563.6	-2187.6	14.9	20	37.6	1
	RA	-3600.8	-1285.1	-1164.1	-1137.3	28.4	20	37.6	1
	JN	-12773.0	-3374.7	-3790.5	-5597.6	20.5	20	37.6	1
	GR	-1681.3	-583.4	-556.8	-537.7	6.8	20	37.6	1
W	NT	-43386.7	-13615.4	-14588.8	-15166.4	32.2	20	37.6	1
	NE	-18120.7	-5009.0	-5323.3	-7784.5	7.8	20	37.6	1
	B1	-3510.8	-1194.7	-1140.0	-1171.9	8.5	20	37.6	1
	B2	-4572.9	-1506.9	-1324.2	-1727.6	28.3	20	37.6	1
	RA	-2000.7	-661.7	-723.8	-600.2	30.0	20	37.6	1
	JN	-9660.8	-2537.0	-3383.1	-3727.0	27.5	20	37.6	1
	GR	-1457.0	-511.4	-525.5	-411.8	16.7	20	37.6	1
SL	NT	-70801.7	-21073.6	-24134.0	-25583.4	21.5	20	37.6	1
	NE	-31122.3	-9548.6	-8581.5	-12981.7	21.0	20	37.6	1
	B1	-6227.7	-2686.6	-1603.4	-1923.7	28.2	20	37.6	1
	B2	-7954.7	-2857.4	-2310.5	-2785.7	2.2	20	37.6	1
	RA	-4900.9	-1575.3	-1565.5	-1754.8	10.4	20	37.6	1
	JN	-15855.3	-5308.9	-5321.3	-5223.7	2.8	20	37.6	1
	GR	-2204.4	-788.5	-802.4	-605.6	15.8	20	37.6	1
SF	NT	-27541.4	-8627.6	-7808.5	-11101.0	8.6	20	37.6	1
	NE	-10707.5	-3268.4	-2699.6	-4727.9	23.1	20	37.6	1
	B1	-2077.3	-929.5	-420.2	-717.5	20.2	20	37.6	1
	B2	-2590.2	-1064.7	-695.5	-823.7	12.5	20	37.6	1
	RA	-2410.6	-845.3	-858.3	-701.6	10.8	20	37.6	1
	JN	-6808.9	-2099.8	-2004.5	-2695.7	17.9	20	37.6	1
	GR	-700.5	-210.6	-278.2	-200.5	22.5	20	37.6	1

4.6 Summary

The main aim of this chapter was to develop and select the most appropriate models to represent the total, dry, wet, slight and serious and fatal accident frequencies and rates for NT, NE, B1, B2, RA, JN and GR site categories at 3C, Norfolk, Oxfordshire and Nottinghamshire A road networks, by using different statistical tools.

First, the extent of correlation was identified between all independent variables (traffic, geometrics and pavement characteristics) was used to build the models. The collinearity test reveals that all VIF values between the independent variables (traffic, geometrics and pavement characteristics) for all site categories were all less than 5. Therefore, no evidence was established for the existence of a collinearity problem.

Second, both AIC and BIC are powerful tools for comparing the models, with respect to the parameters selected, based on the log-likelihood value of the model, the number of estimated coefficient parameters and the number of observations. All AIC and BIC values were compared for all fixed parameters Negative Binomial model's accident frequencies. Model 11 (Constant, Ln AADF, heavy vehicles percentage (%HV), speed limit(SPL), radius of curvature (RC), gradient (%G), number of lanes (NL), number of minor access (NMA), skid resistance (SR), rut depth(RD), texture depth (TX)) in all FPNB models for total, dry, wet, slight and serious and fatal accident frequencies and rates in all site categories for 3C, Norfolk, Oxfordshire and Nottinghamshire had the lowest AIC and BIC, thus it was considered the best fit model.

Third, with respect to the results from the log likelihood ratio test, it was concluded that RPNB models were statistically better in predicting total, dry, wet, slight and serious and fatal accident frequencies, in all site categories at 3C, Norfolk, Oxfordshire and Nottinghamshire A road networks, than FPNB models, at a level of confidence interval of 99%. Similarly, RPT models were statistically better in predicting total, dry, wet, slight and serious and fatal accident rates in all site categories at 3C, Norfolk, Oxfordshire and Nottinghamshire A road networks, than FPT models, at a level of confidence interval of 99%.

Finally, the log likelihood ratio test for parameter transferability was performed to check the suitability of separate models for Norfolk, Oxfordshire and Nottinghamshire, over one aggregate model (3C) in all RPNB models for total, dry, wet, slight and serious and fatal accident frequencies, and in all RPT models for total, dry, wet, slight and serious and fatal accident rates, in all site categories for 3C, Norfolk, Oxfordshire and Nottinghamshire. Regarding the log likelihood ratio test for parameter transferability, for all RPNB and FPT models, the null hypothesis, which assumed no significant difference in parameter values for the independent variables between the full data model (3C) and separate models (Norfolk, Oxfordshire and Nottinghamshire) was accepted, with over a 99.99% level of confidence, suggesting the estimation of separate models was statistically unnecessary.

It is concluded that for accident frequency models the RPNB model with 11 independent variables (Constant, Ln AADF, heavy vehicles percentage (%HV), speed limit(SPL), radius of curvature (RC), gradient (%G), number of lanes (NL), number of minor access (NMA), skid resistance (SR), rut depth(RD), texture depth (TX)) for total, dry, wet, slight and serious and fatal accident frequencies for all site categories in 3C networks, were considered the best models (Chapter 5). Regarding the accident rate models, the RPNB model with 11 independent variables (Constant, Ln AADF, heavy vehicles percentage (%HV), speed limit(SPL), radius of curvature (RC), gradient (%G), number of lanes (NL), number of minor access (NMA), skid resistance (SR), rut depth(RD), texture depth (TX)) for total, dry, wet, slight and serious and fatal accident rates, for all site categories in 3C networks, were considered the best models (Chapter 6).

CHAPTER FIVE

FREQUENCY MODELS RESULTS

CHAPTER FIVE: FREQUENCY MODELS RESULTS

5.1 Overview

Employing the methods and the datasets discussed in Chapters 3 and 4, a series of models were developed for accident frequency using RPNB models. Through these models, it was possible to quantify the relationships between different types of accidents and traffic characteristics (Ln AADF, heavy vehicles percentage, and speed limit), geometric characteristics (radius of curvature, gradient, number of lanes and number of minor access), and pavement characteristics (skid resistance, rut depth and texture depth). This chapter presents and discusses the results of these models. The following sections represent the model estimation results of different types of accidents that occurred at NT level and at different site categories (see section 3.5):

- NE
- B1
- B2
- RA
- JN
- GR

The types of accidents included in these sections are:

- All accidents (total accidents)
- Accidents by road condition situation (dry and wet accidents).
- Accidents by severity level (slight and serious and fatal accidents).

5.2 Random parameters Negative Binomial (RPNB) models results

The RPNB model estimation results for total, dry, wet, slight and serious and fatal accidents, at different site categories, for Norfolk, Oxfordshire and Nottinghamshire are provided in Appendix A. The next sections present the RPNB model results for total, dry, wet, slight and serious and fatal accident frequencies at different site categories for 3C.

5.2.1 Total (T) accident frequency models

Table 5-1 presents the FPNB, while Table 5-2 presents the RPNB models estimation results for total accidents at different site categories for 3C network.

5.2.1.1 Traffic characteristics

- Ln AADF

The results revealed that Ln AADF was found to be a significant fixed parameter at 99 % level of confidence, for total accidents in all site categories for the 3C models. The results (Table 5-2), indicated a positive correlation between Ln AADF and the frequency of total accidents. This meant that all roadway segments of site categories experienced an increase in total accident frequencies, as Ln AADF increased. The average elasticity effects of Ln AADF on the frequency of total accidents for the 3C models in all site categories, are shown in Figure 5-1.

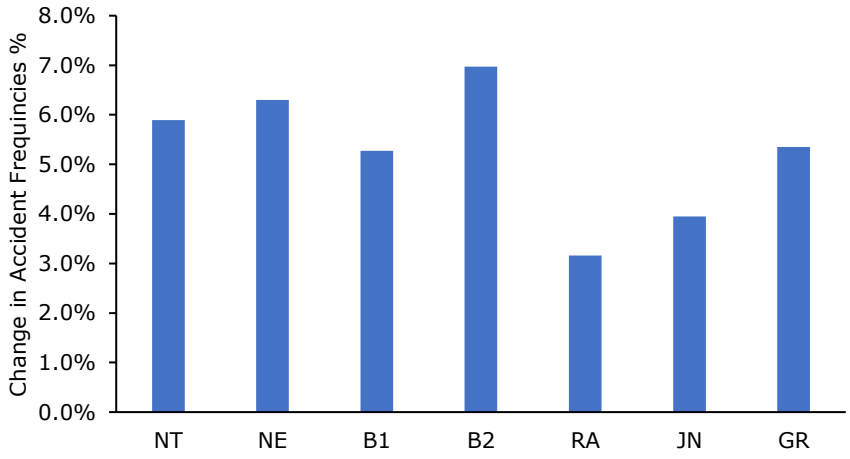


Figure 5-1: Estimated elasticity effects of a 1% increase in Ln AADF on total accident frequencies across NT level and all site categories in 3C network

Table 5-1: FPNB models estimation results for total accident frequencies for 3C site categories

Variables	NT		NE		B1		B2		RA		JN		GR	
	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t
Constant	-5.694	-30.21	-5.668	-19.68	-5.557	-8.97	-5.451	-7.81	-2.085	-3.30	-4.324	-10.58	-5.186	-3.04
Ln AADF	0.640	37.63	0.715	25.83	0.509	9.17	0.678	11.03	0.380	7.53	0.476	13.09	0.447	3.18
%HV	0.072	26.68	0.052	15.12	0.050	2.75	0.035	2.60	0.044	4.03	0.049	5.75	0.127	3.56
SPL	-0.009	-17.19	-0.011	-13.19	-0.010	-4.98	-0.007	-4.24	-0.002	-1.48	-0.005	-4.22	-0.005	-1.05
RC	$-0.276*10^{-4}$	-2.66	$-0.841*10^{-4}$	-4.92	-0.002	-3.41	-0.001	-1.94	$-0.892*10^{-4}$	-2.70	$-0.651*10^{-4}$	-0.28	$-0.900*10^{-4}$	-0.13
%G	0.040	5.58	0.036	2.02	0.020	1.03	0.006	0.27	0.017	0.84	0.034	2.27	0.047	0.83
NL	-0.291	-20.45	-0.118	-5.20	-0.123	-2.38	-0.029	-0.60	-0.117	-2.39	-0.239	-8.62	-0.563	-8.09
NMA	0.389	19.22	0.348	11.45	0.120	1.58	0.337	5.06	0.307	6.60	0.213	6.24	0.275	1.67
SR	-1.406	-5.96	-3.042	-8.75	-1.712	-1.92	-1.413	-2.02	-0.944	-1.57	-0.002	0.00	-2.493	-1.62
RD	0.012	2.49	0.007	0.93	0.019	1.04	0.012	0.74	0.028	1.95	0.017	1.40	0.002	0.06
TX	-0.139	-2.34	-0.005	-0.06	-0.598	-2.57	-0.066	-0.37	-0.411	-2.32	-0.236	-1.64	-0.728	-1.59

Table 5-2: RPNB models estimation results for total accident frequencies for 3C site categories

Variables	NT		NE		B1		B2		RA		JN		GR	
	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t
Constant	-5.301	-29.23	-4.781	-17.20	-4.832	-9.92	-5.829	-9.43	-1.638	-4.21	-4.233	-10.72	-5.602	-4.67
Ln AADF	0.732	38.90	0.686	25.98	0.608	13.28	0.824	13.90	0.351	10.51	0.457	12.05	0.622	5.57
Std.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
%HV	0.086	25.24	0.022	13.72	0.054	4.68	0.066	1.74	0.051	6.74	0.052	6.78	0.143	5.00
Std.	0.127	26.96	0.051	9.23	0.997	9.03	-	-	0.733	9.19	0.641	9.07	-	-
SPL	-0.016	-28.67	-0.015	-18.33	-0.021	-12.59	-0.022	-11.59	-0.002	-2.02	-0.005	-4.01	-0.003	-0.9
Std.	0.009	66.31	0.007	36.36	0.012	27.23	0.013	27.34	0.003	12.98	-	-	0.010	12.35
RC	$-0.662*10^{-4}$	-5.55	$-0.982*10^{-4}$	-4.06	-0.002	-3.74	$-0.611*10^{-3}$	-1.75	$-0.592*10^{-4}$	-4.52	$-0.585*10^{-4}$	-2.33	$-0.291*10^{-4}$	-2.20
Std.	$0.628*10^{-4}$	21.15	$0.151*10^{-3}$	7.54	0.001	7.62	-	-	$1.457*10^{-4}$	10.39	$0.151*10^{-3}$	7.71	-	-
%G	0.018	5.59	0.029	1.80	0.042	2.05	0.035	2.44	0.009	1.71	0.008	3.19	0.056	2.23
Std.	0.359	5.17	0.038	4.74	0.078	7.52	-	-	0.076	10.72	-	-	-	-
NL	-0.164	-15.25	-0.233	-1.68	-0.241	-2.63	-0.036	-1.89	-0.065	-5.53	-0.215	-8.35	-0.242	-3.23
Std.	0.094	33.6	0.138	23.61	-	-	0.146	6.54	0.088	-	0.113	13.43	0.282	10.86
NMA	0.352	22.7	0.376	12.71	0.196	4.14	0.331	5.92	0.226	10.51	0.351	7.39	0.352	3.65
Std.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SR	-3.059	-14.06	-2.174	-18.19	-5.979	-3.45	-2.339	-3.52	-2.213	-6.28	-1.558	-2.23	-2.783	-2.15
Std.	2.095	74.21	2.755	65.15	2.699	34.41	2.328	13.57	1.132	45.78	1.637	27.63	-	-
RD	0.008	2.05	0.013	2.19	0.018	2.81	0.028	1.83	0.028	3.16	0.019	3.86	0.002	3.06
Std.	0.015	3.41	0.034	8.46	0.079	1.90	-	-	-	-	0.024	3.86	-	-
TX	-0.251	-1.89	-0.109	-2.28	-0.427	-2.49	-0.216	-2.62	-0.432	-3.95	-0.304	-2.45	-0.069	-2.23
Std.	0.222	3.51	1.388	10.19	-	-	0.607	21.37	-	-	0.162	3.95	0.061	3.11

- Heavy vehicles percentage

The heavy vehicles percentage result was a random parameter for all site categories, except for the B2 and GR site categories, where it was a fixed parameter. For example, the model parameter of heavy vehicles percentage for total accident model in the NT roadway segments, was found to vary across roadway segments, with a mean of 0.086, and standard deviation of 0.127 (Table 5-2). The distribution of this parameter, (Figure 5-2), showed that 25% (positive effect) of the distribution was less than 0 and 75% (negative effect) is greater than 0. This implied that for 25% of roadway segments, they resulted in increased total accident frequencies, as heavy vehicles percentage increased. On the other hand, for 75% of NT roadway segments, they resulted in decreased in total accident frequencies, as heavy vehicles percentage increased.

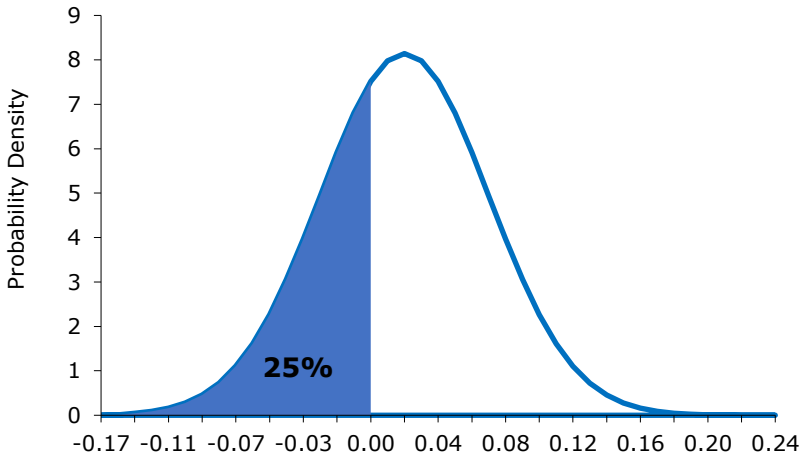


Figure 5-2: Distribution of parameter estimation for heavy vehicles percentage of NT roadway segments in 3C for total accident frequency model

The elasticity effects of heavy vehicles percentage on total accident frequencies, for all site categories is presented in Figure 5-3.

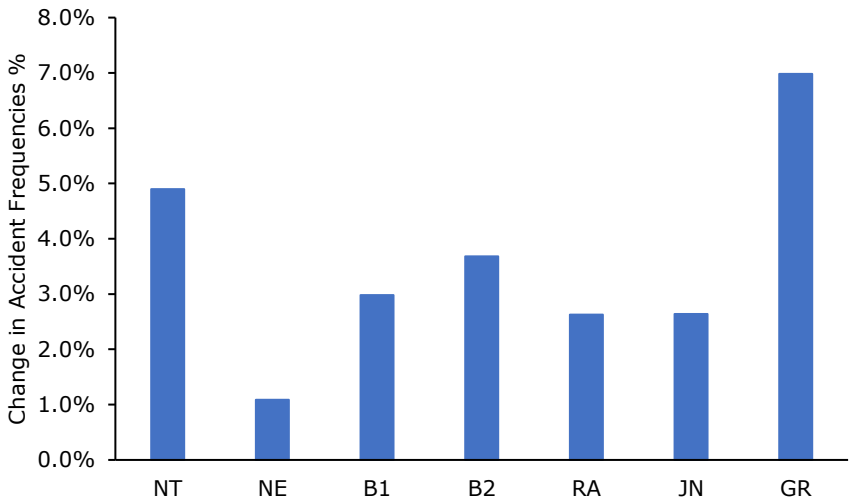


Figure 5-3: Estimated elasticity effects of a 10% increase in heavy vehicles percentage on total accident frequencies across NT level and all site categories in 3C network

- Speed limit

Roadway segments with lower speed limit were associated with higher total accident frequencies, in all site category models. As shown in Table 5-1, the speed limit was determined as a negative random parameter for the NT roadway segments model, with a mean of -0.016, and a standard deviation of 0.009. According to the normal distribution assumption, this shows that 96% of the distribution was less than 0, and 4% was greater than 0 (Figure 5-4). This implied that the majority of NT roadway segments, with lower speed limit, was associated with high total accident frequencies.

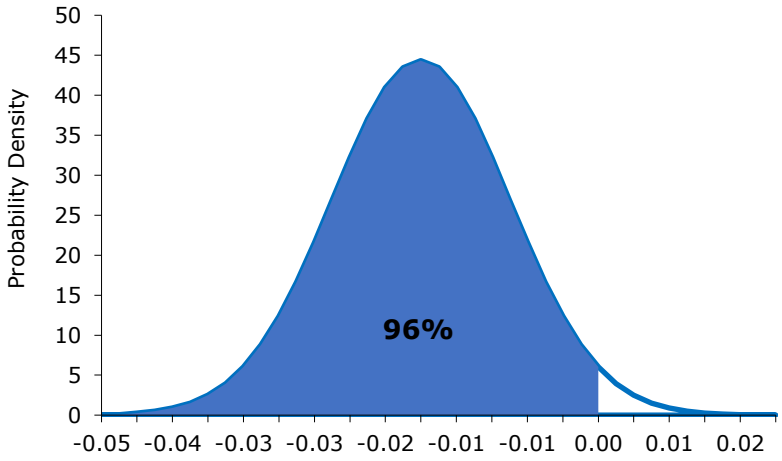


Figure 5-4: Distribution of parameter estimation for speed limit of NT roadway segments in 3C for total accident frequency model

Figure 5-5 shows the average elasticity effects of speed limit on total accident frequencies, in all site categories. A 10% increase in speed limit led to a decrease in total accident frequency of 17.11%, for NT roadway segments.

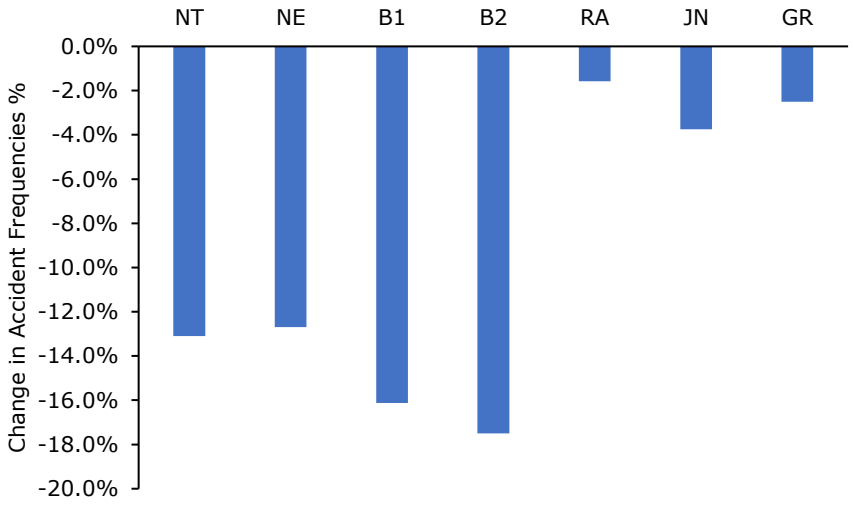


Figure 5-5: Estimated elasticity effects of a 10% increase in speed limit on total accident frequencies across NT level and all site categories in 3C network

5.2.1.2 Geometric characteristics

- Radius of curvature

Negative coefficients for all T accident models, corresponding to radius of curvature for roadway segments, indicated that roadway segments with higher radius of curvature were associated with lower total accident frequencies, for all site categories. Regarding the model for the NT roadway segments, the estimated random coefficient of radius of curvature followed a normal distribution, with a mean of -0.662×10^{-4} and a standard deviation of 0.628×10^{-4}. The distribution of this parameter, described in Figure 5-6, showed that 86% of the distribution was less than 0, and 14% was greater than 0. This meant that for 86% of roadway segments, an increase in radius of curvature was associated with a decrease in total accidents, and for 16% of roadway segments, an expected increase in total accident frequencies were due to increases in radius of curvature.

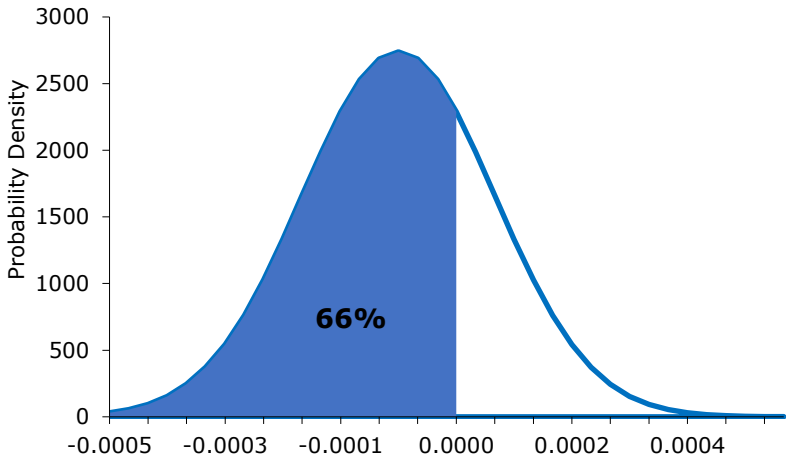


Figure 5-6: Distribution of parameter estimation for radius of curvature of NT roadway segments in 3C for total accident frequency model

The elasticity effects of radius of curvature on the frequency of total accidents, for all site categories are presented in Figure 5-7.

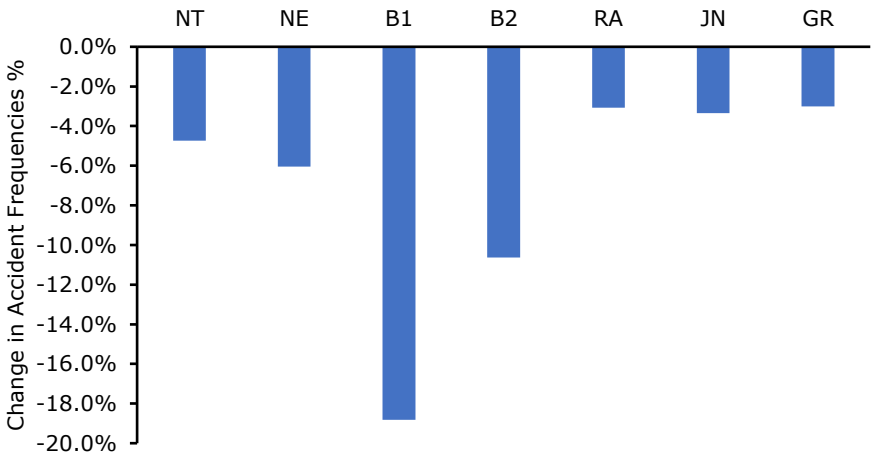


Figure 5-7: Estimated elasticity effects of a 10% increase in radius of curvature on total accident frequencies across NT level and all site categories in 3C network

- Gradient

As shown in Table 5-2, the gradient was positively related to total accident frequencies in all models, indicating a roadway segment with higher gradient was associated with higher total accident frequencies. For the NT roadway segments, the gradient parameter was determined to be random, with a mean of 0.018 and standard deviation of 0.359. The parameter distribution indicated that for 48% of

roadway segments, the increasing gradient led to increases in total accidents. However, for 52% of roadway segments, increasing the gradient had a negative effect on total accident frequencies (Figure 5-8).

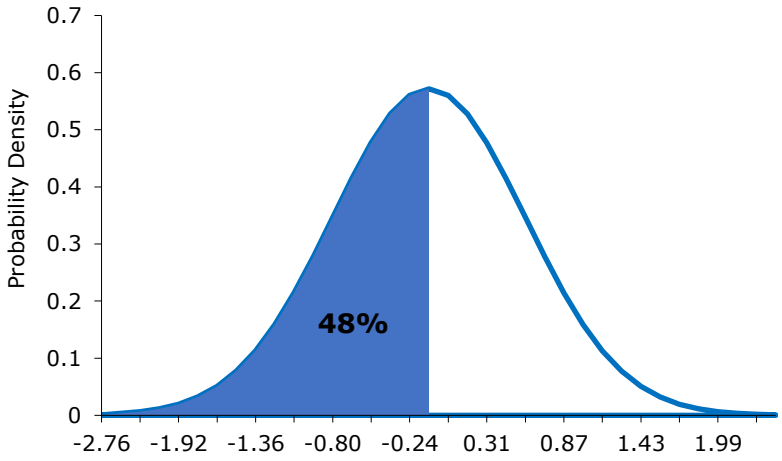


Figure 5-8: Distribution of parameter estimation for gradient of NT roadway segments in 3C for total accident frequency model

Figure 5-9 represents the elasticity effects of gradient on total accident frequencies, for all site categories. A 10% increase in gradient is expected to increase the frequency of total accidents by a 0.7 % for NT roadway segments.

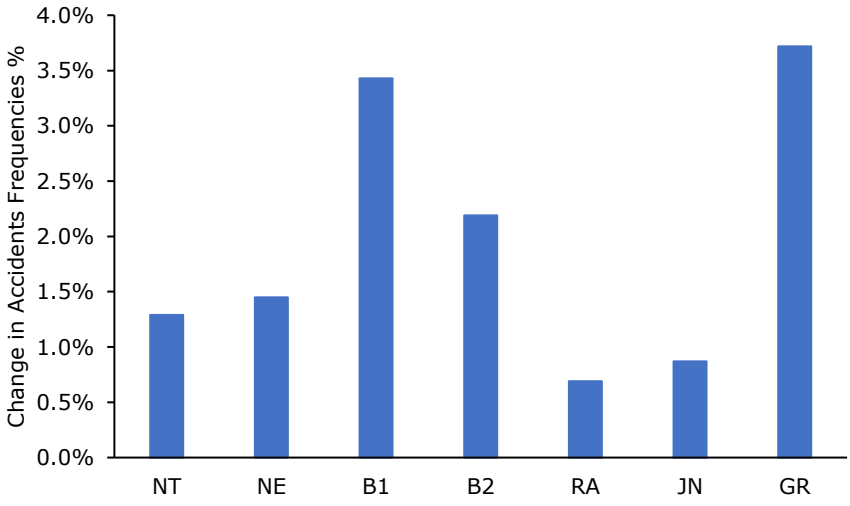


Figure 5-9: Estimated elasticity effects of a 10% increase in gradient on total accident frequencies across NT level and all site categories in 3C network

- Number of lanes

Regarding NL, as can be seen from Table 5-2, for the RPNB models, a negative correlation was found between total accidents and NL. The negative coefficient for number of lanes indicated that roadway segments more lanes were associated with lower total accident frequencies. Relating to the NT roadway segments model, number of lanes was determined a random parameter, normally distributed, with a mean of -0.164 and standard deviation of 0.094 (Figure 5-10). These parameters given that for 96% of roadway segments, increased number of lanes was associated with a decrease in total accident frequencies. On the other hand, increasing number of lanes for 4% of roadway segments was positively associated with total accident frequencies.

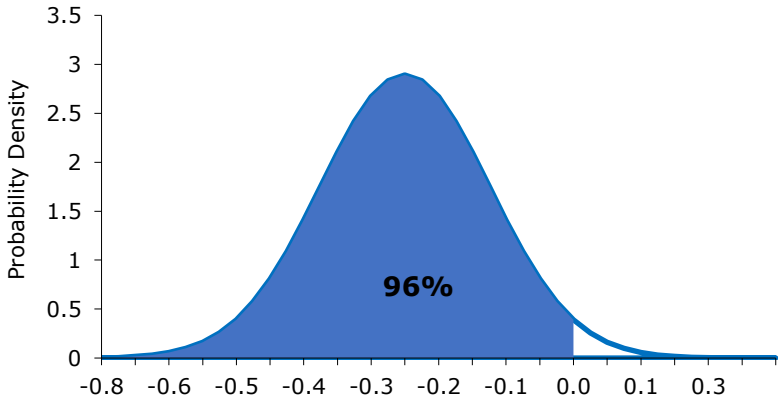


Figure 5-10: Distribution of parameter estimation for number of lanes of NT roadway segments in 3C for total accident frequency model

Figure 5-11 presents the elasticity effects of number of lanes on total accident frequencies, in all site categories. The numbers represented the percentage change in total accident frequencies due to a 100% increase in number of lanes.

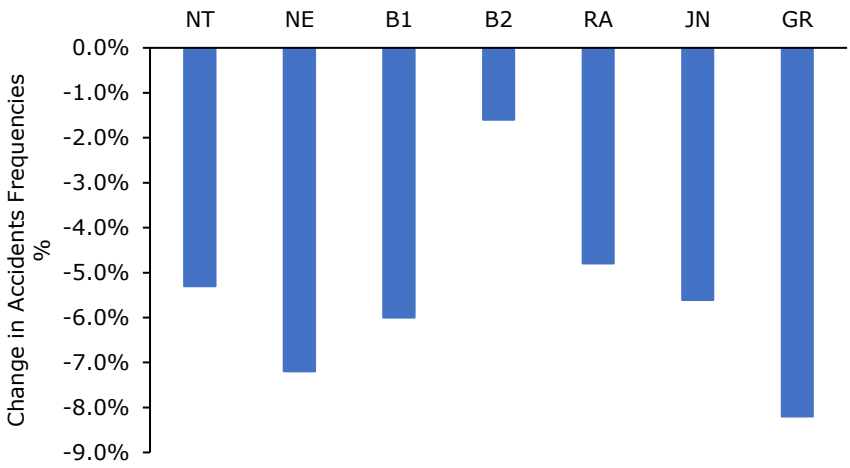


Figure 5-11: Estimated elasticity effects of a 100% increase in number of lanes on total accident frequencies across NT level and all site categories in 3C network

- Number of minor access

Based on the results from RPNB models (Table 5-2), number of minor access in each roadway segment, were found to be highly statistically significant (t-value was significant at 99% confidence level) and positively correlated with all total accident models. The effect of number of minor access was found to be a fixed parameter for all RPNB models. Figure 5-12 provides an overview of the elasticity effects of number of minor access on total accident frequencies. In respect of the NT roadway segments, a 100% increase in number of minor access was found to increase the total accident frequency by 29%.



Figure 5-12: Estimated elasticity effects of a 100% increase in number of minor access on total accident frequencies across NT level and all site categories in 3C network

5.2.1.3 Pavement characteristics

- Skid resistance

Regarding the effects of skid resistance on total accident frequencies, roadway segments with high skid resistance were found to have significantly less total accident frequencies, in all site categories. As can be seen from Table 5-2, skid resistance was determined as a random parameter for all models, except the GR site category, where this variable was fixed. With reference to the NT roadway segments, the skid resistance parameter was random, with a mean of -3.059 and standard deviation of 2.095. The parameter distribution indicated that increasing the skid resistance led to decreased total accidents at 93% of roadway segments. On the other hand, for only 7% of roadway segments, an expected increase in total accident frequencies were detected, due to increasing skid resistance.

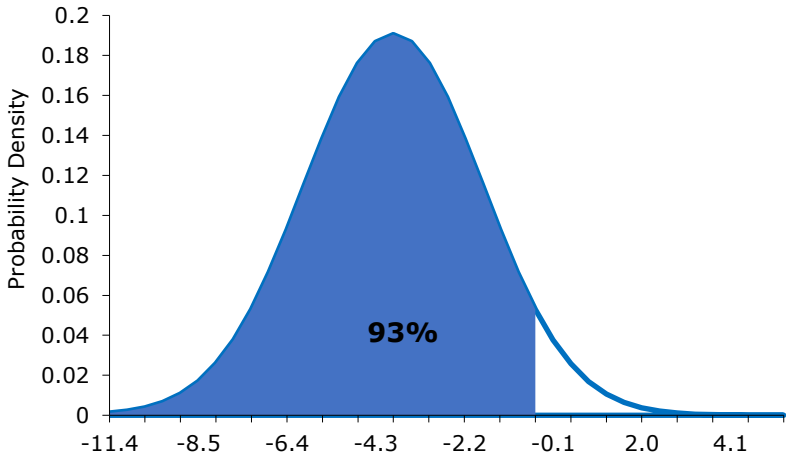


Figure 5-13: Distribution of parameter estimation for skid resistance of NT roadway segments in 3C for total accident frequency model

Figure 5-14 compares the elasticity effects of skid resistance on total accident frequencies, for all site categories.

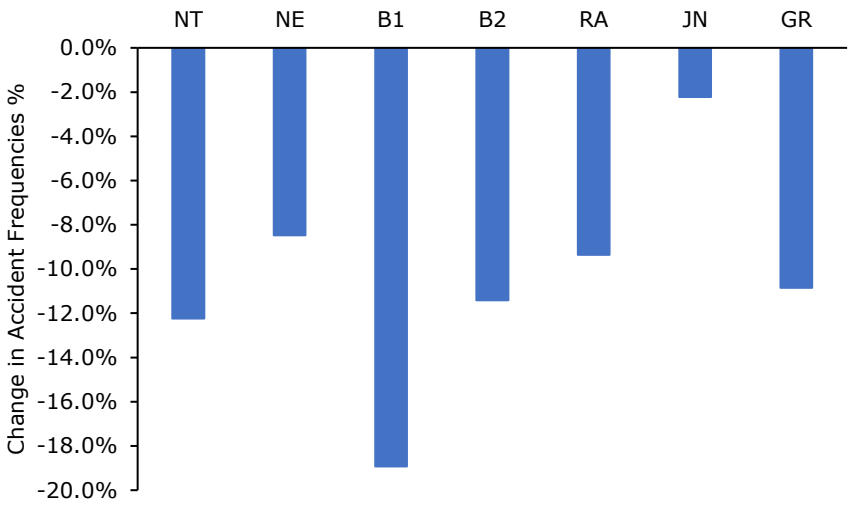


Figure 5-14: Estimated elasticity effects of a 10% increase in skid resistance on total accident frequencies across NT level and all site categories in 3C network

- Rut depth

The RPNB model result revealed that rut depth was positively correlated with total accident models, for all site categories. This indicated that roadway segments with higher rut depth were associated with higher total accident frequencies. Table 5-1 shows that rut depth was determined as a random parameter, for all site categories, except for the B2, RA and GR site category models, where it was a fixed parameter. The effect of rut depth on total accident frequencies was found to vary across roadway segments for the NT roadway segments, it had a normal distribution, with a mean of 0.008 and a standard deviation of 0.015. Given these distributional parameters, in about 30% of roadway segments, the increased rut depth had a positive effect on total accident frequencies, while in 70% of roadway segments, a negative effect for rut depth on total accident frequencies were observed (Figure 5-15).

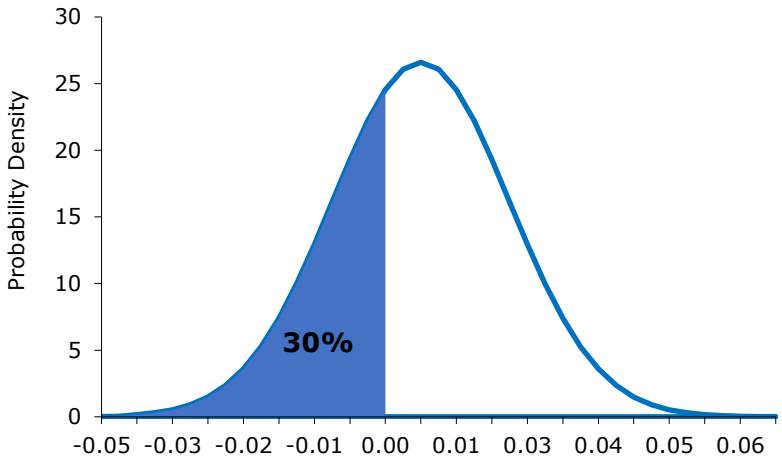


Figure 5-15: Distribution of parameter estimation for rut depth of NT roadway segments in 3C for total accident frequency model

Figure 5-16 represents the change in total accident frequencies, in all site categories due to a 10% increase in rut depth.

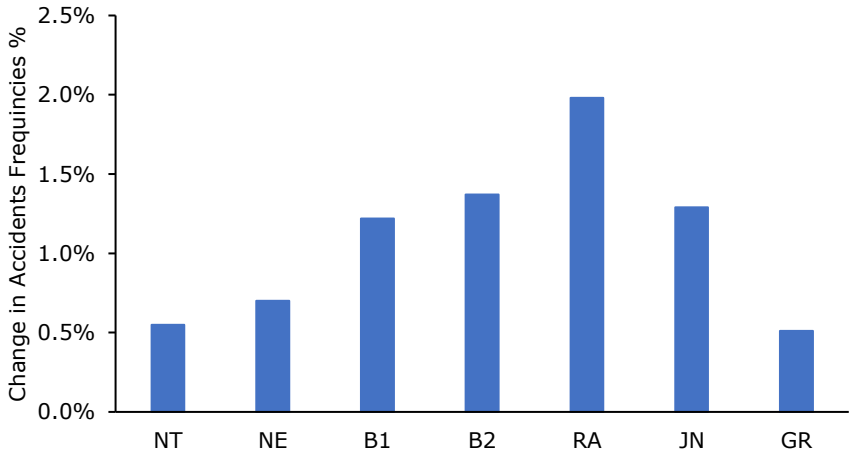


Figure 5-16: Estimated elasticity effects of a 10% increase in rut depth on total accident frequencies across NT level and all site categories in 3C network

- Texture depth

The results from RPNB models for total accident frequencies (Table 5-2) showed that texture depth had significant effects on decreasing total accident frequencies. This variable was a random parameter for all site category models, except the B1, B2 and RA site category models, where texture depth was a fixed parameter. The modelling result for total accident frequency in NT roadway segments, showed that texture

depth had a mean of -0.069 and a standard deviation of 0.061. As shown in Figure 5-17, increasing the texture depth in approximately 87% of roadway segments led to a decreased total accident frequency. On the other hand, on 13% of roadway segments, increasing texture depth was found to be positively correlated with total accident frequencies.

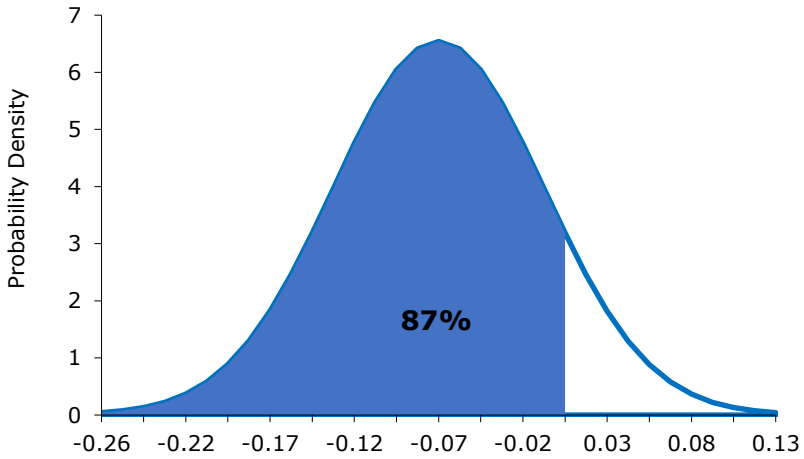


Figure 5-17: Distribution of parameter estimation for texture depth of NT roadway segments in 3C for total accident frequency model

Figure 5-18 shows the average elasticity effects of texture depth on total accident frequencies in all site categories. Regarding the NT roadway segments, a 10% increase in texture depth led to decreased total accident frequencies by 1.36%.

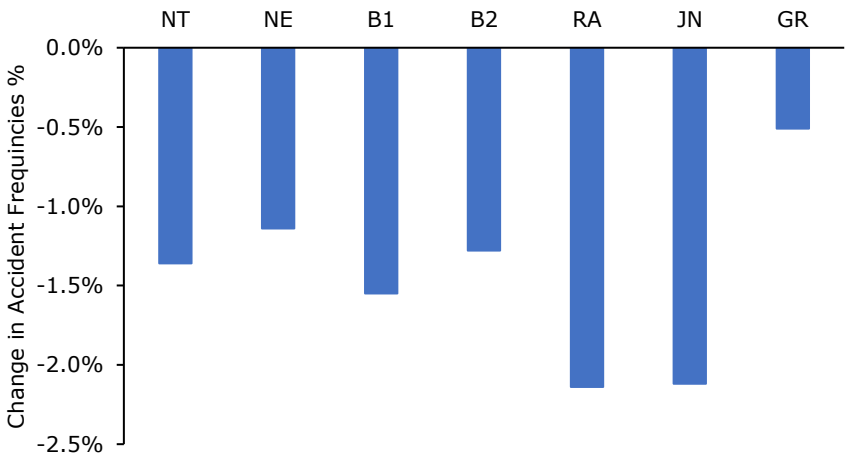


Figure 5-18: Estimated elasticity effects of a 10% increase in texture depth on total accident frequencies across NT level and all site categories in 3C network

5.2.2 Dry (D) and wet (w) accident models

Tables 5-3 and 5-4 present the FPNB and RPNB model estimation results for dry accidents, while Tables 5-5 and 5-6 present the FPNB and RPNB model estimation results for wet accidents at different site categories for 3C network.

5.2.2.1 Traffic characteristics

- Ln AADF

In terms of the effects of traffic variables on dry and wet accident frequencies, Ln AADF was the most significant and important variable in estimating D and W accident frequencies. Ln AADF had a fixed positive relationship with all dry and wet accidents, at all site categories in 3C models. Figure 5-19 shows the elasticity effects of this variable on dry and wet accidents in all site categories. A 1% increase in Ln AADF led to an increase in dry and wet accident frequencies of 7.15% and 4.57%, respectively, for the NT roadway segments.

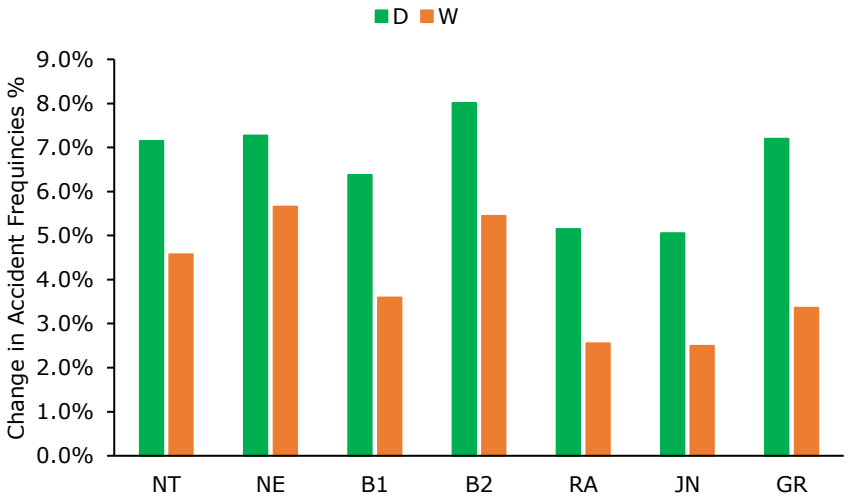


Figure 5-19: Estimated elasticity effects of a 1% increase in Ln AADF on dry and wet accident frequencies across NT level and all site categories in 3C network

Table 5-3: FPNB models estimation results for dry accident frequencies for 3C site categories

Variables	NT		NE		B1		B2		RA		JN		GR	
	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t
Constant	-6.897	-32.16	-6.587	-19.41	-6.542	-10.16	-6.545	-8.47	-0.604	-7.71	-5.173	-10.86	-6.777	-3.36
Ln AADF	0.820	38.07	0.766	23.23	0.788	11.24	0.911	11.65	0.037	2.55	0.595	13.48	0.937	4.94
%HV	0.070	22.65	0.008	1.83	0.047	2.19	0.027	1.69	0.005	2.47	0.092	8.28	0.097	2.55
SPL	-0.012	-18.99	-0.010	-10.49	-0.015	-6.66	-0.011	-5.42	-0.004	-1.24	-0.006	-3.93	-0.007	-1.32
RC	$-0.181*10^{-4}$	-1.46	$-0.445*10^{-4}$	-8.82	-0.002	-3.24	-0.001	-1.56	-0.015	-0.52	$-0.276*10^{-4}$	-0.10	$-0.427*10^{-4}$	-0.05
%G	0.030	3.59	0.047	2.32	0.006	0.28	0.023	0.78	0.190	2.86	0.034	1.82	0.002	0.03
NL	-0.225	-13.32	-0.212	-8.10	-0.184	-3.49	-0.131	-2.28	-0.421	-5.99	-0.239	-6.98	-0.414	-4.93
NMA	0.468	20.42	0.496	14.63	0.199	2.60	0.403	5.49	2.028	2.38	0.307	7.39	0.450	2.55
SR	-2.314	-7.98	-2.472	-5.96	-0.122	-0.12	-2.869	-3.26	-0.024	-1.21	-0.922	-1.44	-6.481	-3.49
RD	0.001	0.21	0.126	13.61	0.011	0.86	0.024	1.27	0.243	0.93	0.001	0.08	0.064	1.52
TX	-0.016	-0.22	-0.315	-2.99	-0.358	-1.46	-0.150	-0.66	-2.792	-2.90	-0.171	-0.99	-0.033	-0.06

Table 5-4: RPNB models estimation results for dry accident frequencies for 3C site categories

Variables	NT		NE		B1		B2		RA		JN		GR	
	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t
Constant	-6.372	-28.44	-6.093	-17.74	-5.329	-8.87	-6.676	-8.62	-2.864	-3.64	-5.031	-10.40	-6.329	-3.88
Ln AADF	0.832	37.02	0.844	23.77	0.759	12.15	0.947	12.30	0.571	8.71	0.585	12.51	0.837	5.09
Std.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
%HV	0.116	22.64	0.029	12.42	0.061	3.35	0.068	1.77	0.063	4.36	0.098	9.43	0.164	4.20
Std.	0.359	28.48	0.931	16.24	0.342	4.19	0.245	4.02	0.262	8.49	0.193	9.64	-	-
SPL	-0.017	-25.36	-0.018	-18.00	-0.025	-11.53	-0.018	-8.39	-0.007	-3.58	-0.006	-4.05	-0.003	-2.61
Std.	0.008	45.49	0.009	34.97	0.011	19.63	0.009	15.97	0.005	9.04	0.002	5.62	0.003	2.67
RC	$-0.749 *10^{-4}$	-25.36	$-0.726*10^{-4}$	-3.51	-0.002	-2.99	-0.001	-2.01	$-0.713 *10^{-4}$	-1.74	$-0.691*10^{-4}$	-2.53	$-0.716 *10^{-4}$	-2.47
Std.	$0.749 *10^{-4}$	19.00	$0.399*10^{-4}$	3.79	-	-	-	-	$0.200 *10^{-3}$	2.96	$0.166*10^{-3}$	10.46	-	-
%G	0.019	3.78	0.018	1.06	0.036	0.85	0.021	0.77	0.013	2.47	0.015	2.27	0.083	4.03
Std.	0.024	1.77	0.051	6.94	0.204	3.98	0.071	1.73	-	-	-	-	-	-
NL	-0.072	-0.448	-0.098	-5.67	-0.198	-6.03	-0.144	-2.59	-0.219	-4.41	-0.244	-4.11	-0.172	-1.83
Std.	0.166	21.73	0.216	40.82	0.135	12.83	0.076	4.48	-	-	-	-	0.269	7.88
NMA	0.429	21.23	0.453	3.69	0.225	3.95	0.373	5.48	0.359	11.48	0.405	6.74	0.317	7.83
Std.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SR	-2.545	-2.51	-4.607	-11.54	-2.552	-3.24	-2.445	-2.92	-2.922	-3.79	-2.052	-1.79	-3.572	-4.01
Std.	3.566	26.36	1.915	38.10	-	-	0.657	6.36	2.836	28.05	1.109	15.29	-	-
RD	0.017	2.51	0.014	1.95	0.015	2.68	0.033	1.89	0.001	0.07	0.032	1.75	0.042	4.59
Std.	0.032	2.77	0.013	2.04	0.027	14.57	-	-	0.065	11.49	0.024	4.21	0.068	25.4
TX	-0.027	-0.38	-0.229	-2.28	-0.357	-1.62	-0.211	-0.96	-0.029	-0.13	-0.237	-1.99	-0.268	-2.53
Std.	0.072	29.67	0.357	10.26	0.204	2.83	0.255	3.28	0.652	8.44	-	-	-	-

Table 5-5: FPNB models estimation results for wet accident frequencies for 3C site categories

Variables	NT		NE		B1		B2		RA		JN		GR	
	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t
Constant	-5.586	-18.87	-5.686	-13.46	-4.487	-3.68	-5.332	-5.22	-0.205	-2.90	-4.193	-6.89	-6.424	-2.62
Ln AADF	0.415	16.16	0.443	11.41	0.266	2.45	0.408	4.80	0.045	2.46	0.284	5.23	0.235	1.23
%HV	0.089	16.74	0.021	2.82	0.043	1.53	0.006	0.29	0.008	0.06	0.077	4.92	0.128	2.52
SPL	-0.006	-7.57	-0.004	-2.96	-0.019	-6.01	-0.004	-1.64	$-0.995*10^{-4}$	-0.84	-0.004	-2.27	-0.010	-1.37
RC	$-0.131*10^{-4}$	-0.85	$-0.305*10^{-4}$	-9.11	-0.003	-3.45	$-0.668*10^{-4}$	-0.24	-0.017	-0.56	$-0.428*10^{-4}$	-0.17	$-0.118*10^{-4}$	-0.12
%G	0.053	5.40	0.059	2.36	0.039	1.36	0.098	3.16	0.079	1.09	0.049	2.69	0.042	0.53
NL	-0.363	-16.91	-0.098	-2.91	-0.452	-4.52	-0.281	-4.07	-0.231	-3.29	-0.250	-6.43	-0.610	-5.59
NMA	0.274	8.85	0.267	6.43	0.066	0.52	0.227	2.45	0.221	0.26	0.061	1.23	0.056	0.20
SR	-0.653	-1.94	-3.033	-6.38	-3.850	-2.42	-0.637	-0.60	-0.053	-2.36	-0.506	-0.76	-0.756	-0.33
RD	0.041	5.60	0.028	2.44	0.068	4.05	0.083	3.51	0.543	2.26	0.066	4.22	0.030	0.67
TX	-0.219	-2.59	-0.111	-0.88	-0.850	-2.19	-0.172	-0.73	-2.530	-3.30	-0.158	-0.87	-1.054	-1.53

Table 5-6: RPNB models estimation results for wet accident frequencies for 3C site categories

Variables	NT		NE		B1		B2		RA		JN		GR	
	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t
Constant	-5.599	-20.35	-5.294	-12.61	-5.317	-6.85	-5.602	-6.76	-3.471	-4.95	-4.222	-7.05	-6.424	-2.62
Ln AADF	0.532	20.64	0.657	15.77	0.428	6.57	0.644	8.55	0.283	4.94	0.289	5.35	0.391	2.71
Std.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
%HV	0.089	16.76	0.031	1.68	0.116	5.11	0.076	4.45	0.044	3.22	0.065	9.59	0.119	3.26
Std.	0.174	3.58	0.429	3.48	0.117	11.33	-	-	0.341	2.99	1.068	3.55	-	-
SPL	-0.016	-20.07	-0.023	-17.24	-0.012	-4.33	-0.027	-10.31	$-0.600*10^{-3}$	-0.32	-0.005	-2.95	-0.014	-2.86
Std.	0.012	54.46	0.014	45.22	-	-	0.018	28.49	0.001	3.14	0.004	9.02	0.020	14.72
RC	$-0.522*10^{-4}$	-0.35	$-0.648*10^{-4}$	-2.71	-0.017	-2.31	-0.004	-0.75	$-0.737*10^{-4}$	-2.21	$-0.407*10^{-4}$	-2.12	$-0.665*10^{-4}$	-1.10
Std.	$0.221*10^{-4}$	2.26	$0.846*10^{-4}$	6.82	-	-	0.011	9.89	-	-	-	-	-	-
%G	0.029	1.02	0.006	0.29	0.051	2.75	0.042	4.52	0.027	1.10	0.049	1.95	0.057	1.86
Std.	0.126	7.83	0.024	1.92	-	-	0.039	6.97	0.065	5.35	-	-	-	-
NL	-0.148	-2.75	-0.299	-15.53	-0.081	1.67	-0.054	-1.68	-0.033	-0.63	-0.251	-6.61	-0.461	-5.79
Std.	-	-	-	-	-	-	0.114	12.48	0.105	8.86	-	-	-	-
NMA	0.269	6.59	0.286	11.15	0.122	3.65	0.187	2.48	0.265	5.58	0.119	1.71	0.063	2.29
Std.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SR	-3.053	-11.25	-2.051	-2.28	-4.282	-8.85	-2.265	-7.02	-1.929	-2.94	-0.553	-0.84	-1.308	-3.77
Std.	1.526	44.37	0.786	7.59	1.195	20.17	1.785	43.53	2.428	26.68	0.333	0.414	-	-
RD	0.032	5.09	0.062	4.42	0.067	4.18	0.047	2.54	0.018	1.71	0.015	1.71	0.037	3.12
Std.	0.318	9.39	-	-	-	-	0.077	12.53	0.024	7.72	-	-	-	-
TX	-0.071	-0.85	-0.408	-3.14	-0.178	-0.64	-0.338	-1.43	-0.674	-3.68	-0.061	-0.33	-0.318	-0.62
Std.	0.113	4.02	0.998	23.16	1.116	12.84	0.397	4.97	-	-	0.423	6.99	0.343	2.17

- Heavy vehicles percentage

The heavy vehicles parentage was a significant parameter with a positive sign in all dry and wet accident models. This indicated that both dry and wet accidents increased with increasing % HV in all site categories (Tables 5-4 and 5-6). With respect to the NT roadway segments, heavy vehicles percentage was a random parameter, with a mean of 0.116 and a standard deviation of 0.359 for dry accident models and for wet accident models, the mean was 0.089 and standard deviation was 0.174. Given these estimated distributional parameters, for 37% and 30% of NT roadway segments, increasing heavy vehicles percentage led to increased dry and wet accidents, respectively. On the other hand, for 63% and 70% of NT roadway segments, an expected decrease in dry and wet accident frequency due to increasing heavy vehicles percentage in traffic stream. The results from the elasticity effects of heavy vehicles percentage on both dry and wet W accident frequencies in all site categories, are presented in Figure 5-20. These numbers represent the percentage change in both dry and wet accident frequencies, in response to a 10% increase in heavy vehicles percentage. For example, a 5.59 and 5.07% increase in dry and wet accident frequencies for NT roadway segments, respectively, were due to a 10% increase in heavy vehicles percentage.

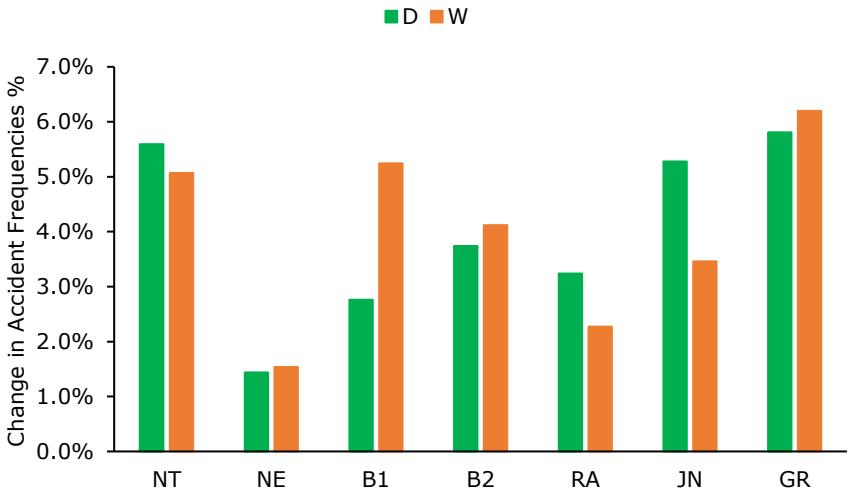


Figure 5-20: Estimated elasticity effects of a 10% increase in heavy vehicles percentage on dry and wet accident frequencies across NT level and all site categories in 3C network

- Speed limit

In terms of traffic characteristics, the RPNB models showed that roadway segments with higher SPL, were expected to have lower D and W accident frequencies in all site categories. The speed limit was found to be a significant random parameter, with a negative sign in all dry and wet accidents models. For the NT roadway segments, speed limit was normally distributed, with a mean of -0.017 and -0.016 and a standard deviation of 0.008 and 0.012 for dry and wet accidents, respectively (Tables 5-4 and 5-6). These parameter values indicated that increasing speed limit, decreased the D and W accident frequencies in 98% and 91% of roadway segments, and increased the dry and wet accident frequencies in 2% and 9% of roadway segments, respectively. Thus, for the majority of NT roadway segments, both dry and wet accidents were expected to decrease with increasing speed limit. Figure 5-21 shows the elasticity effects of speed limit on dry and wet accident frequencies, across all site category. For the NT roadway segments, a 10% increase in speed limit decreased the dry and wet accident frequencies by 13.92 and 13.10%, respectively.

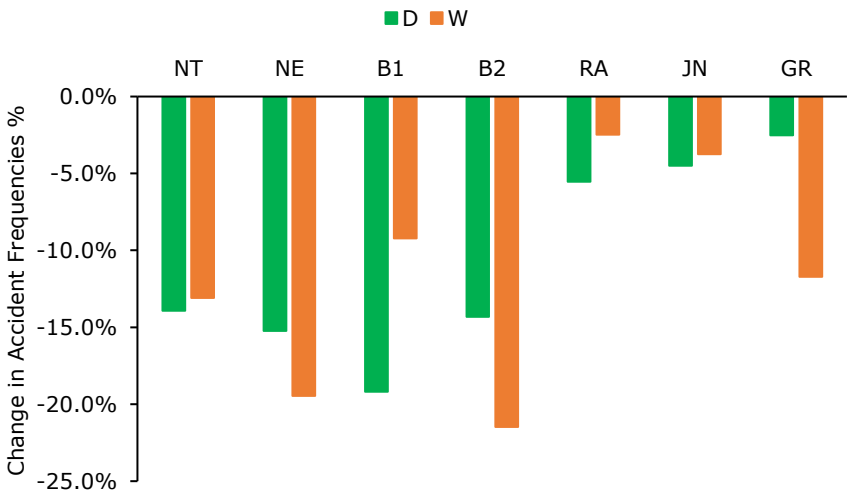


Figure 5-21: Estimated elasticity effects of a 10% increase in speed limit on dry and wet accident frequencies across NT level and all site categories in 3C network

5.5.2.2 Geometric characteristics

- Radius of curvature

It can be seen from the RPNB model outcomes in Tables 5-2 and 5-3 that roadway segments with small radius of curvature, increased the frequency of both dry and wet accidents, in all site categories. The NT roadway segments models for both dry and wet accidents revealed that RC was determined as a random parameter, normally distributed, with a mean of -0.749 x 10^{-4} and -0.522 x 10^{-4} and a standard deviation of 0.749 x 10^{-4} and 0.221 x 10^{-4} for dry and wet accidents, respectively. These parameter values indicated that increasing the radius of curvature, decreased the dry and wet accident frequencies in 86% and 99% of roadway segments, respectively. Therefore, for the majority of roadway segments, both dry and wet accident frequencies were expected to decrease, with increasing radius of curvature. The average elasticity effects (Figure 5-22) indicated that increasing radius of curvature for roadway segment by 10 %, for NT site categories, decreased the frequency of both dry and wet accidents by an average of 3.86 and 3.64%, respectively.

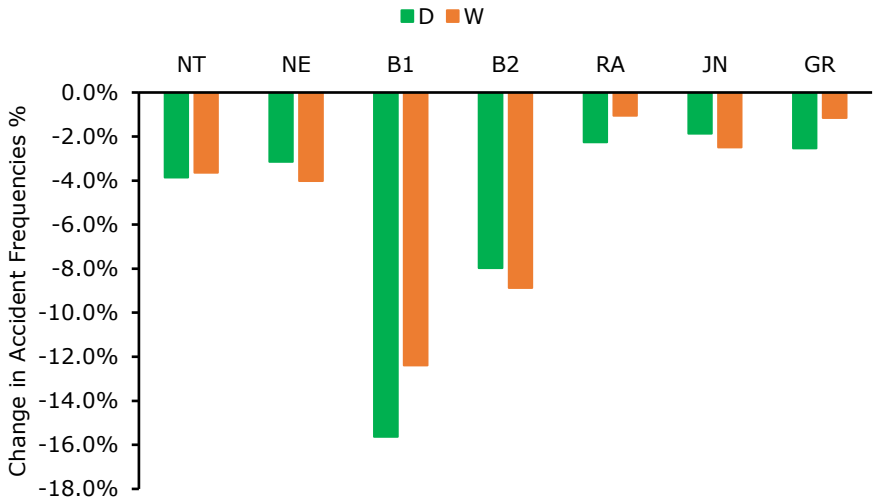


Figure 5-22: Estimated elasticity effects of a 10% increase in radius of curvature on dry and wet accident frequencies across NT level and all site categories in 3C network

- Gradient

As shown in Tables 5-4 and 5-6, the gradient was significant and positively correlated with both D and W accident frequencies. For the NT roadway segments, the gradient was random, with a mean of 0.019 and 0.029 and with a standard deviation of 0.024 and 0.126 for dry and wet accidents, respectively. The parameter distribution indicated that increasing gradient for 21% and 41% of roadway segments, led to increases in both dry and wet accident frequencies. However, no increases in both dry and wet accident frequencies for 79% and 59% of NT roadway segments due to increasing the gradient. Figure 5-23 represents the elasticity effects of gradient on dry and wet accident frequencies, for all site categories. Regarding the NT roadway segments, a 10% increase in gradient led to increases in the frequency of dry and wet accidents, by 1.11 and 0.83%, respectively.

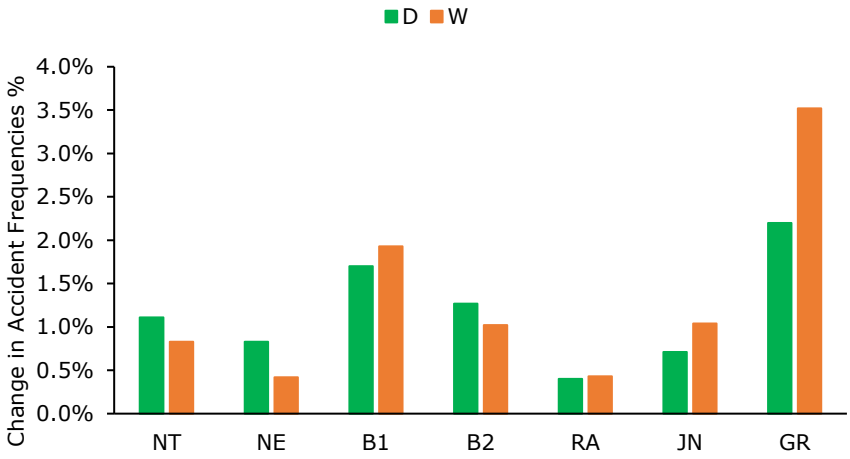


Figure 5-23: Estimated elasticity effects of a 10% increase in gradient on dry and wet accident frequencies across NT level and all site categories in 3C network

- Number of lanes

Regarding the number of lanes, as can be seen in Tables 5-4 and 5-6 for the RPNB models, a negative correlation was found between dry and wet accidents; and number of lanes. The negative coefficient for number of lanes indicated that roadway segments with more lanes, were generally associated with lower dry and wet accident frequencies. Figure 5-24 represents the elasticity effects of number of lanes on the dry and wet accident frequencies, in all site categories. The data represent the

percentage changes in dry and wet accident frequencies, due to a 100% increase in number of lanes.

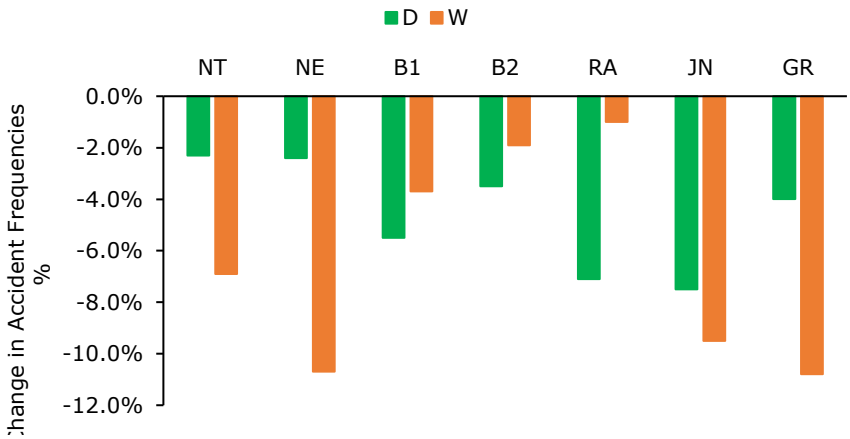


Figure 5-24: Estimated elasticity effects of a 100% increase in number of lanes on dry and wet accident frequencies across NT level and all site categories in 3C network

- Number of minor access

Number of minor access had significant positive effects on both dry and wet accident frequencies, for all site categories. According to the estimation results of the RPNB model for all site categories (Tables 5-4 and 5-6), this variable was a fixed parameter for all dry and wet accident models. Figure 5-25 provides an overview of the number of minor access elasticity effects on both dry and wet accident frequencies. Regarding the NT roadway segments, a 100% increase in number of minor access was found to increase dry and wet accident frequencies by 27.60 and 20.40%, respectively.

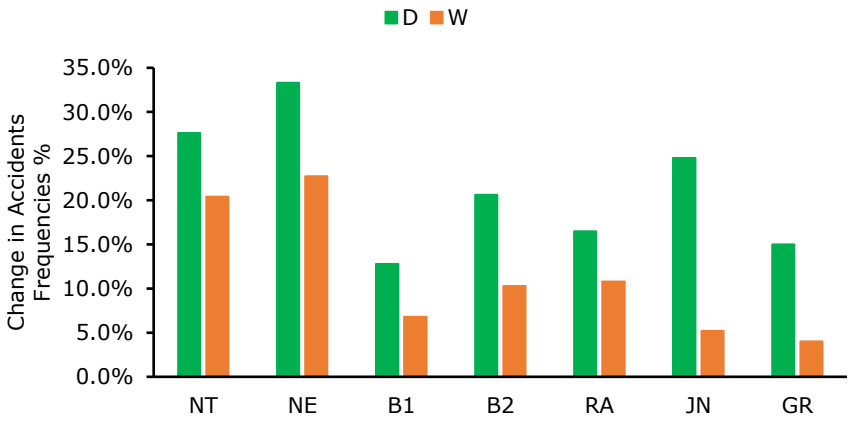


Figure 5-25: Estimated elasticity effects of a 100% increase in number of minor access on dry and wet accident frequencies across NT level and all site categories in 3C network

5.2.2.3 Pavement characteristics

- Skid resistance

Regarding the effects of skid resistance on both dry and wet accident frequencies, roadway segments with high skid resistance had significantly lower dry and wet accident frequencies, in all site categories. From Tables 5-4 and 5-6, the effects of skid resistance on dry and wet accident frequencies followed two independent normal distributions, with means of -2.545 and -3.053 and standard deviations of 3.566 and 1.526, respectively. These parameters show that 76% and 99% of the distribution was less than 0, and 24% and 1% was less than 0. This implied that increasing skid resistance for the majority of NT roadway segments, led to decreases in both dry and wet accident frequencies. Figure 5-26 compares change in the expected dry and wet accident frequencies for all site categories, due to a 10% increase in skid resistance.

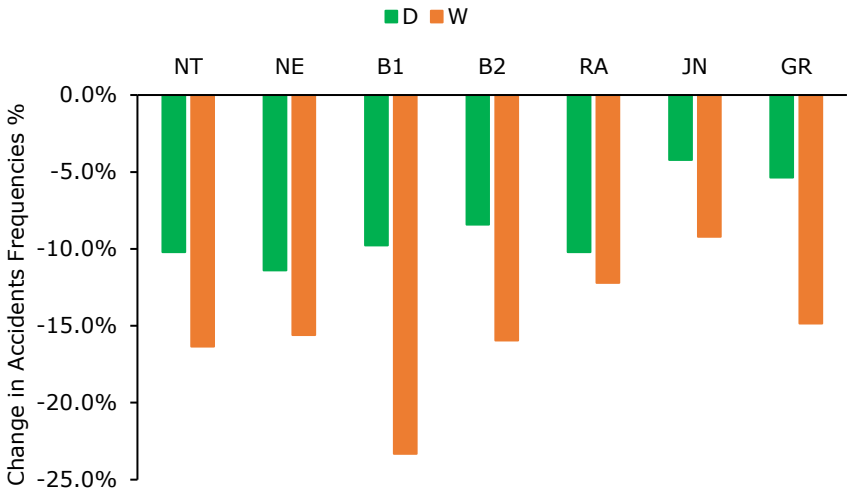


Figure 5-26: Estimated elasticity effects of a 10% increase in skid resistance on dry and wet accident frequencies across NT level and all site categories in 3C network

- Rut depth

The results of RPNB models for dry and wet accident frequencies, revealed that rut depth was positively correlated with both dry and wet accidents for all site categories. The NT roadway segments illustrated rut depth as a random parameter; the mean and standard deviation for dry accidents were, 0.017 and 0.032, respectively, whereas those for wet accident were 0.032 and 0.318, respectively. Given these

distributional parameter increases, the rut depth in 30% and 46% of roadway segments would increase the dry and wet accident frequencies, respectively. On the other hand, for 70% and 54%, an expected decrease in both dry and wet accident frequencies were observed due to increases in rut depth. Figure 5-27 represents an overview of the elasticity effects of rut depth on both dry and wet accident frequencies, in all site categories.

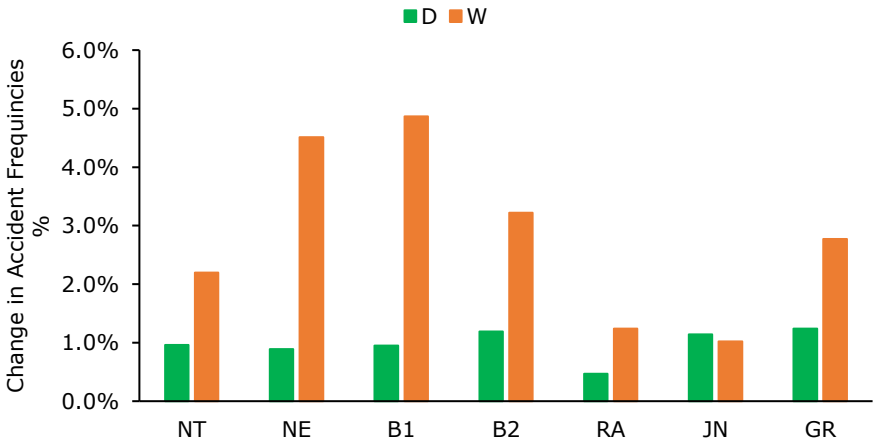


Figure 5-27: Estimated elasticity effects of a 10% increase in rut depth on dry and wet accident frequencies across NT level and all site categories in 3C network

- Texture depth

Tables 5-4 and 5-6 represent the estimation coefficients of texture depth in the RPNB models for dry and wet accident frequencies. The texture depth was significantly negative, indicating that both dry and wet accident frequencies decreased with texture depth. The modelling results for dry and wet accidents in the NT roadway segments indicated that texture depth had a mean of -0.027 and -0.071 and a standard deviation of 0.072 and 0.113, for dry and wet accidents, respectively. According to the normal distribution assumption, increasing texture depth in about 65% and 74% of roadway segments leads to decreases in dry and wet accidents, respectively. On the other hand, for 35% and 26% of roadway segments, no significant reductions in dry and wet accident frequencies were observed. Figure 5-28 shows the average elasticity effects of texture depth on dry and wet accidents in all site categories.

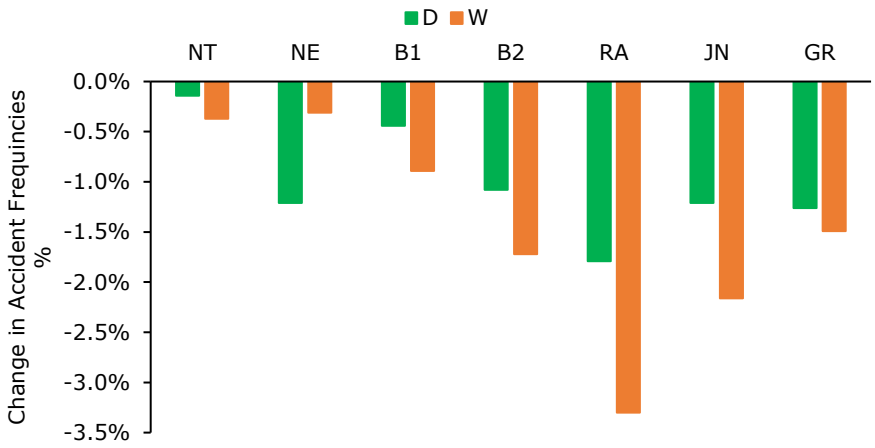


Figure 5-28: Estimated elasticity effects of 10% increasing in texture depth on dry and wet accidents frequency across NT level and all site categories in 3C network

5.2.3 Slight (SL) and serious and fatal (SF) accident models

Tables 5-7 and 5-8 present the FPNB and RPNB model estimation results for slight accidents, while Tables 5-9 and 5-10 present the FPNB and RPNB model estimation results for serious and fatal accidents at different site categories for 3C network.

5.2.3.1 Traffic characteristics

- Ln AADF

Looking at the effects of traffic characteristics, similar to dry and wet accident models, Ln AADF was highly significant and was positively associated with a high frequency for all accident severity levels. The elasticity effects of Ln AADF on slight and serious and fatal accident frequencies are shown in Figure 5-29. A 1% increase in Ln AADF led to increases in slight and serious and fatal accident frequencies in NT site categories by 6.38 and 4.36%, respectively.

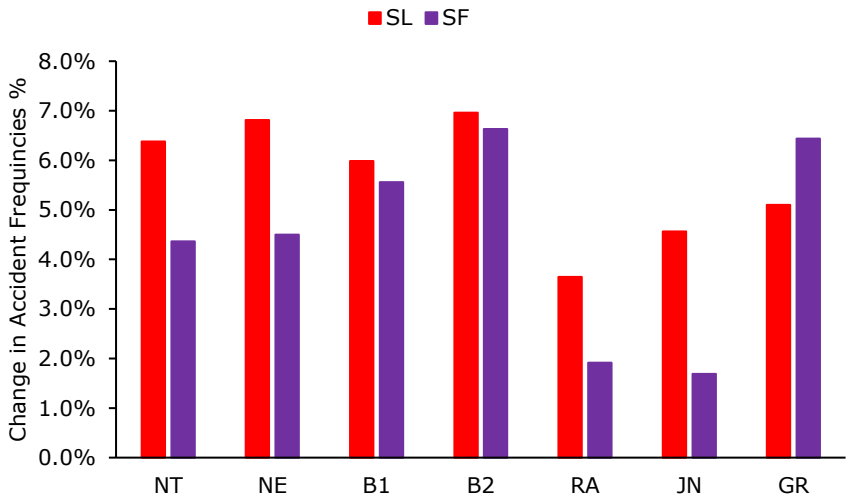


Figure 5-29: Estimated elasticity effects of a 1% increase in Ln AADF on slight and serious and fatal accident frequencies across NT level and all site categories in 3C network

- Heavy vehicles percentage

The heavy vehicles percentage was positively related to both slight and serious and fatal accident frequency models for all site categories (Tables 5-8 and 5-10). For the NT roadway segments, heavy vehicles percentage was a random parameter, the mean and standard deviation of slight accidents were 0.086 and 0.059, respectively, whereas those for serious and fatal accidents were 0.378 and 0.469, respectively. These distributional parameters indicated that increasing the heavy vehicles percentage in 41 and 45% of NT roadway segments, increased slight and serious and fatal accident frequencies, respectively. Nevertheless, for 59% and 55% of roadway segments increases, the heavy vehicles percentage have a negative effect on both slight and serious and fatal accident frequencies. Figure 5-30 compares the average elasticity effects of heavy vehicles percentage on slight and serious and fatal, at all site categories, for 3C network.

Table 5-7: FPNB models estimation results for SL accidents frequencies for 3C site categories

Variables	NT		NE		B1		B2		RA		JN		GR	
	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t
Constant	-6.258	-30.32	-6.315	-22.55	-5.842	-8.62	-5.570	-7.40	-4.411	-6.85	-4.979	-11.35	-4.816	-2.45
Ln AADF	0.678	36.93	0.680	26.67	0.481	7.98	0.662	10.06	0.045	3.52	0.545	13.81	0.389	2.44
%HV	0.077	26.18	0.006	1.61	0.058	2.93	0.040	2.72	0.003	1.56	0.073	7.42	0.113	2.79
SPL	-0.010	-17.64	-0.005	-6.52	-0.011	-5.25	-0.009	-4.52	-0.003	-1.84	-0.006	-4.63	-0.003	-0.66
RC	$-0.268*10^{-4}$	-2.39	$-0.551*10^{-4}$	-12.72	-0.002	-3.00	-0.001	-1.52	-0.026	-0.99	$-0.208*10^{-4}$	-0.85	$-0.673*10^{-4}$	-0.08
%G	0.045	5.93	0.068	4.16	0.021	1.00	0.019	0.80	0.120	2.03	0.040	2.46	0.052	0.81
NL	-0.316	-20.38	-0.232	-10.94	-0.155	-2.62	-0.072	-1.41	-0.338	-5.50	-0.252	-8.43	-0.562	-7.19
NMA	0.395	17.92	0.415	15.75	0.102	1.25	0.308	4.31	1.104	1.52	0.223	5.96	0.273	1.50
SR	-1.371	-5.36	-3.048	-9.29	-2.557	-2.63	-1.417	-1.87	-0.037	-2.12	-0.144	-0.26	-2.510	-1.42
RD	0.017	3.08	0.080	10.56	0.016	0.94	0.014	0.85	0.337	1.56	0.022	1.70	0.001	0.02
TX	-0.145	-2.25	-0.009	-0.11	-0.686	-2.79	-0.100	-0.53	-2.970	-3.19	-0.202	-1.33	-0.851	-1.66

Table 5-8: RPNB model estimation results for SL accident for 3C

Variables	NT		NE		B1		B2		RA		JN		GR	
	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t
Constant	-5.864	-29.57	-5.504	-17.90	-5.604	-10.09	-5.836	-9.11	-1.978	-4.10	-4.809	-11.16	-5.287	-3.71
Ln AADF	0.743	38.78	0.791	25.45	0.713	13.56	0.823	13.45	0.405	9.86	0.528	12.63	0.593	4.69
Std.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
%HV	0.086	23.66	0.059	12.64	0.137	7.93	0.087	2.04	0.075	7.66	0.081	8.12	0.147	3.93
Std.	0.378	17.03	2.042	8.842	0.331	17.55	-	-	0.576	16.78	0.841	8.15	-	-
SPL	-0.019	-31.06	-0.018	-19.45	-0.025	-13.61	-0.021	11.54	-0.004	-3.02	-0.006	-4.99	-0.005	-1.25
Std.	0.013	68.21	0.009	40.20	0.014	29.93	0.013	26.33	0.003	9.13	-	-	0.009	10.46
RC	$-0.632*10^{-4}$	-5.14	$-0.381*10^{-4}$	-2.20	-0.002	-3.24	$-0.572*10^{-3}$	-1.27	$-0.741*10^{-4}$	-2.92	$-0.760*10^{-4}$	-3.13	$-0.576*10^{-4}$	-3.00
Std.	$0.158*10^{-3}$	21.05	$0.155*10^{-3}$	16.84	-	-	$0.400*10^{-3}$	4.53	-	-	$0.172*10^{-3}$	10.91	$0.629*10^{-4}$	4.08
%G	0.036	5.18	0.026	1.423	0.028	1.45	0.017	3.81	0.033	2.01	0.046	3.28	0.066	1.29
Std.	0.041	9.416	0.017	1.982	0.088	7.58	-	-	0.029	3.35	-	-	-	-
NL	-0.185	-12.76	-0.075	-3.231	-0.246	-5.43	-0.042	0.97	-0.201	-2.92	-0.225	-8.11	-0.26	-3.18
Std.	0.191	42.58	0.104	15.44	0.281	19.51	0.09	6.61	-	-	0.123	13.92	0.255	8.95
NMA	0.384	21.65	0.344	12.17	0.167	3.13	0.286	5.03	0.347	10.91	0.231	7.03	0.345	3.23
Std.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SR	-2.669	-11.38	-5.504	-15.21	-0.606	-0.87	-2.42	-3.56	-3.049	-6.61	-0.771	-1.55	-2.974	-2.09
Std.	1.672	56.24	2.405	52.80	0.75	8.66	1.31	15.15	2.702	39.47	1.678	26.02	-	-
RD	0.007	1.46	0.005	0.65	0.001	0.15	0.028	1.91	0.043	3.87	0.021	1.88	0.002	0.07
Std.	0.009	5.69	0.039	16.84	0.033	7.24	0.018	3.83	-	-	0.009	2.71	0.036	3.89
TX	-0.125	-2.01	-0.159	-1.75	-0.398	-2.05	-0.283	-2.77	-0.292	-2.13	-0.253	-1.88	-0.248	-2.29
Std.	0.695	32.56	0.552	17.78	0.446	7.25	-	-	-	-	-	-	-	-

Table 5-9: FPNB models estimation results for SF accidents frequencies for 3C site categories.

Variables	NT		NE		B1		B2		RA		JN		GR	
	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t
Constant	-5.966	-17.18	-5.353	-9.22	-6.839	-5.98	-7.255	-5.54	-5.233	-2.73	-3.947	-5.49	-8.766	-3.21
Ln AADF	0.489	14.36	0.514	9.01	0.674	4.97	0.779	5.84	0.041	1.96	0.196	3.02	0.708	2.49
%HV	0.063	10.26	0.059	6.47	0.022	0.67	0.021	0.76	0.001	0.40	0.010	0.79	0.179	2.92
SPL	-0.005	-5.09	-0.007	-4.33	-0.004	-1.06	-0.003	-1.03	-0.004	-2.96	-0.007	-0.10	-0.011	-1.41
RC	$-0.325*10^{-4}$	-1.72	$-0.593*10^{-4}$	-1.76	-0.002	-1.93	-0.002	-1.76	-0.017	-0.57	$-0.407*10^{-4}$	-1.05	$-0.692*10^{-4}$	-0.76
%G	0.017	1.38	0.042	1.21	0.011	0.31	0.048	1.02	0.055	0.73	0.010	0.44	0.012	0.12
NL	-0.180	-7.01	-0.022	-0.52	-0.073	-0.73	-0.257	-2.51	-0.184	-2.58	-0.188	-4.14	-0.496	-3.69
NMA	0.335	9.89	0.290	4.93	0.172	1.21	0.419	3.84	0.037	0.04	0.188	3.40	0.139	0.52
SR	-1.420	-3.51	-2.915	-4.42	-2.490	-1.58	-1.643	-1.16	-0.009	-0.39	-0.157	-0.20	-3.068	-1.35
RD	0.002	0.27	0.018	1.22	0.026	1.41	0.008	0.24	0.718	2.29	0.010	0.54	0.030	0.52
TX	-0.117	-1.04	-0.266	-1.53	-0.047	-0.10	-0.101	-0.26	-0.099	-2.11	-0.407	-1.81	-0.446	-0.48

Table 5-10: RPNB model estimation results for SF accident for 3C.

Variables	NT		NE		B1		B2		RA		JN		GR	
	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t
Constant	-5.928	-17.22	-4.545	-8.50	-6.396	-5.69	-7.255	-5.54	-2.526	-2.97	-3.947	-5.49	-8.917	-3.53
Ln AADF	0.508	14.96	0.523	9.68	0.662	5.05	0.784	6.38	0.213	2.71	0.196	3.02	0.749	2.84
Std.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
%HV	0.059	12.11	0.009	2.37	0.086	8.69	0.042	2.27	0.035	1.06	0.011	1.79	0.245	4.13
Std.	0.469	15.55	-	-	0.091	12.51	-	-	0.052	3.56	-	-	-	-
SPL	-0.009	-9.15	-0.011	-7.19	-0.005	-1.79	-0.018	-5.51	-0.001	-2.35	$-0.200*10^{-3}$	-2.15	-0.011	-1.77
Std.	0.007	23.39	0.008	22.99	-	-	0.013	15.15	-	-	-	-	-	-
RC	$-0.911*10^{-4}$	-4.44	$-0.328*10^{-4}$	-0.94	-0.003	-2.18	-0.002	-2.20	$-0.191*10^{-3}$	-3.20	$-0.406*10^{-4}$	-1.75	$-0.608*10^{-4}$	-4.60
Std.	$0.174*10^{-3}$	12.91	$0.185*10^{-3}$	11.28	-	-	-	-	$0.134*10^{-3}$	3.64	-	-	-	-
%G	0.015	1.27	0.031	0.97	0.131	2.77	0.041	3.95	0.042	1.42	0.015	2.44	0.003	2.04
Std.	0.027	3.59	0.062	4.11	0.194	6.76	-	-	0.081	4.74	-	-	-	-
NL	-0.164	-6.52	-0.005	-0.11	-0.081	-1.81	-0.237	-2.46	-0.135	-1.96	-0.188	-4.14	-0.427	-3.36
Std.	0.057	7.51	0.098	8.36	-	-	-	-	0.16	10.28	-	-	-	-
NMA	0.319	9.95	0.252	4.99	0.146	1.68	0.399	4.29	0.166	2.61	0.188	3.46	0.137	2.55
Std.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SR	-1.218	-3.07	-5.929	-9.79	-2.699	-1.78	-0.981	-0.75	-0.852	-2.09	-0.957	-2.27	-2.891	-1.31
Std.	-	-	2.767	35.18	-	-	1.112	7.02	-	-	0.781	3.77	-	-
RD	0.006	0.84	0.023	1.67	0.025	1.67	0.007	0.25	0.029	1.37	0.009	1.74	0.033	2.63
Std.	0.021	7.73	0.022	5.28	-	-	0.011	1.72	0.055	9.22	-	-	-	-
TX	-0.146	-1.33	-0.183	-1.87	-0.051	-0.11	-0.113	-2.32	-0.674	-2.48	-0.407	-1.81	-0.248	-1.79
Std.	0.064	1.74	-	-	0.227	1.66	-	-	-	-	-	-	0.448	3.09

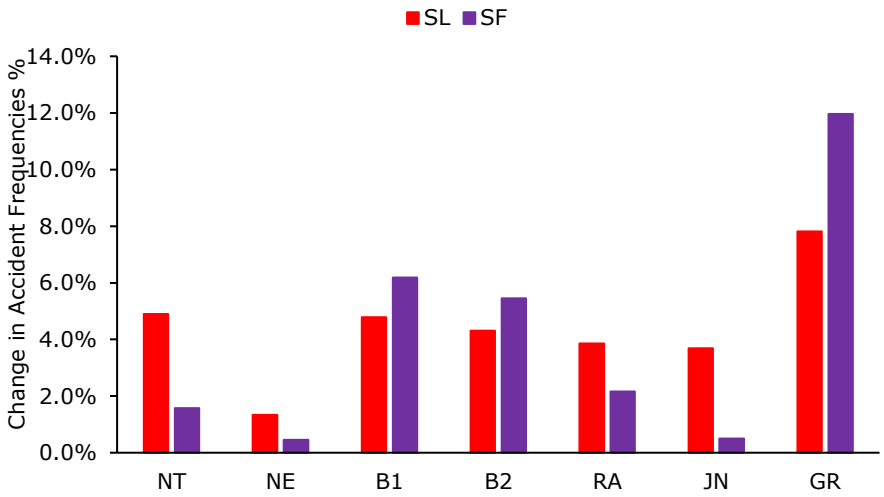


Figure 5-30: Estimated elasticity effects of a 10% increase in heavy vehicles percentage on slight and serious and fatal accident frequencies across NT level and all site categories in 3C network

- Speed limit

The RPNB outcomes showed that both slight and serious and fatal accident frequencies were negatively influenced by increasing the speed limit for roadway segments. This indicated that roadway segments with high speed limit decreased the frequency of slight and serious and fatal accidents. The effect of speed limit varied across NT roadway segments; this variable had a normal distribution with a mean of -0.019 and -0.009 and standard deviation of 0.013 and 0.007 for slight and serious and fatal accidents, respectively. These parameters revealed that 93% and 90% of slight and serious and fatal accident observations occurred at roadway segments with lower speed limit. On the other hand, 7 and 10% of slight and serious and fatal accident observations occurred at roadway segments with higher speed limit. Figure 5-31 represents the elasticity effects of speed limit on both slight and serious and fatal accident frequencies, at all site categories. In the NT roadway segments, a 10% increase in speed limit led to increases in both slight and serious and fatal accidents, by 15.56 and 7.37% respectively.

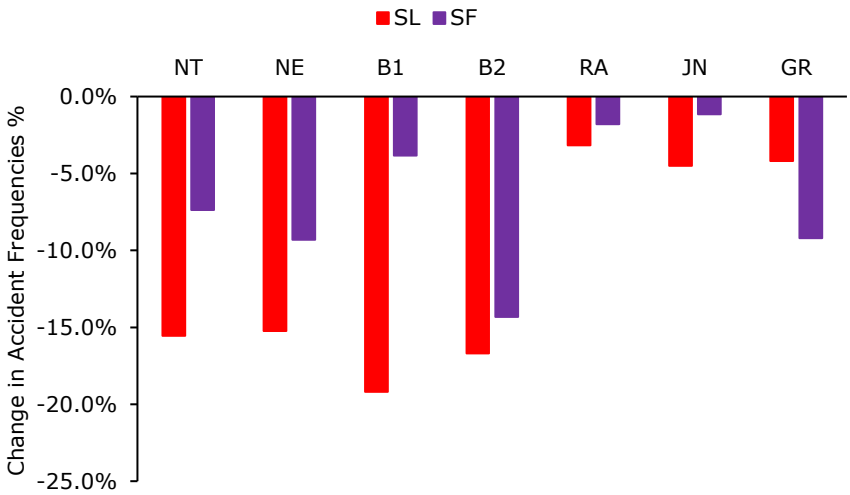


Figure 5-31: Estimated elasticity effects of a 10% increase in speed limit on slight and serious and fatal accident frequencies across NT level and all site categories in 3C network

5.2.3.2 Geometric characteristics

- Radius of curvature

According to the RPNB models for slight and serious and fatal accident frequencies, as expected, roadway segments with small radius of curvature, increased the frequency of both slight and serious and fatal accidents in the majority of roadway segments, for different site categories. Regarding the NT roadway segments, the radius of curvature for road segments was a random parameter, normally distributed with a mean of -0.632×10^{-4} and -0.911×10^{-4} and a standard deviation of 0.158×10^{-3} and 0.174×10^{-3} for SL and SF accidents, respectively. These parameters suggested that for 65% and 70% of roadway segments, both slight and serious and fatal accident frequencies were expected to decrease with increasing radius of curvature. The average elasticity effects of radius of curvature on slight and serious and fatal accidents is shown (Figure 5-32).

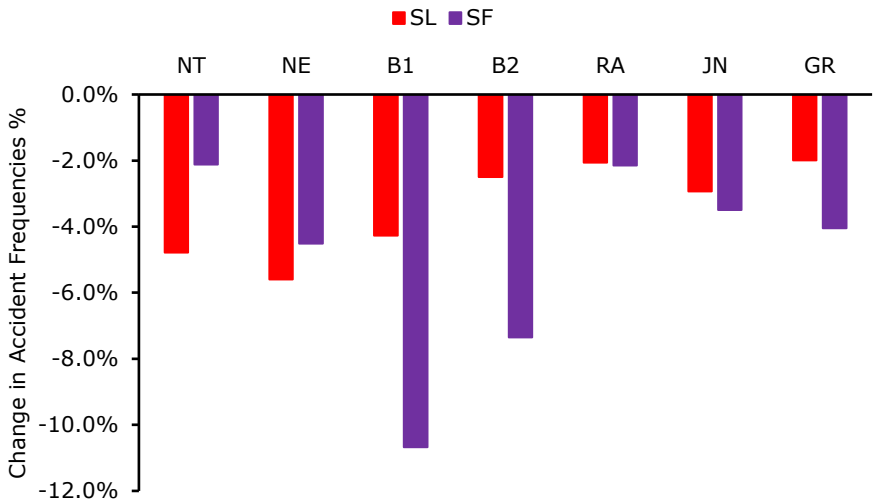


Figure 5-32: Estimated elasticity effects of a 10% increase in radius of curvature on slight and serious and fatal accident frequencies across NT level and all site categories in 3C network

- Gradient

The modelling results of the RPNB models that are presented in Tables 5-4 and 5-5 revealed that gradient was statistically significant and positively correlated with the frequency of slight and serious and fatal accidents for all site categories. For the NT roadway segments, gradient parameter resulted to be random with a mean 0.036 and 0.015 and with a standard deviation of 0.041 and 0.027 for slight and serious and fatal accident, respectively. The distribution parameter suggested that increasing gradient for 19% and 28% roadway segments have a positive effect on of slight and serious and fatal accident frequencies, respectively. Figure 5-33 presents the elasticity effects of gradient on slight and serious and fatal accidents frequency for all site categories.

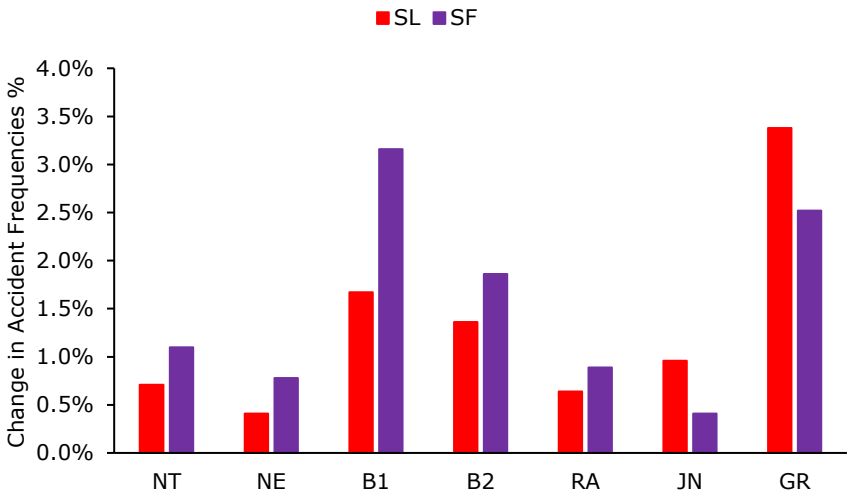


Figure 5-33: Estimated elasticity effects of a 10% increase in %G on SL and SF accident frequencies across NT level and all site categories in 3C network

- Number of lanes

A negative correlation was found between number of lanes and both slight and serious and fatal accidents, Tables 5-4 and 5-6 illustrated that there was a trend of decreasing in the frequency of slight and serious and fatal accidents in all site categories due to increasing number of lanes in roadway segments. For the NT roadway segments, number of lanes parameter resulted to be random with a mean -0.185 and 0.191 and with a standard deviation of -0.164 and 0.057 for slight and serious and fatal accident, respectively. The distribution parameter suggested that increasing number of lanes for 83% and 99% roadway segments have a negative correlation with both slight and serious and fatal accident frequencies, respectively. The results of the elasticity effects of number of lanes on slight and serious and fatal accident frequencies are presented in Figure 5-34. Respecting to NT roadway segments, a 100% increase in the number of lanes contributed to a 4.30% and 3.80% decrease in slight and serious and fatal accidents, respectively.

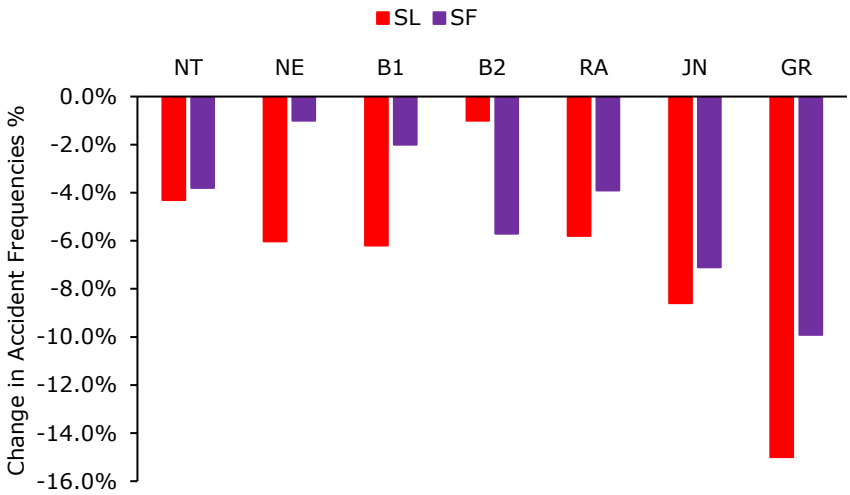


Figure 5-34: Estimated elasticity effects of a 100% increase in number of lanes on slight and serious and fatal accidents frequencies across NT level and all site categories in 3C network

- Number of minor access

From the Tables 5-4 and 5-5, it can see that number of minor access were significant for both slight and serious and fatal accidents, this variable resulted as a fixed parameter for all slight and serious and fatal models. The positive correlation with slight and serious and fatal accidents indicated that an increase in number of minor access in all roadway segment for different site categories leads to increase both slight and serious and fatal accident frequency. The results of the elasticity effects of number of minor access on accident frequency for both slight and serious and fatal are shown in Figure 5-35. Regarding to NT roadway segments, a 100% increase in number of minor access results in a 26.50 and 19.40% increase in the predicted accident frequency for slight and serious and fatal, respectively.

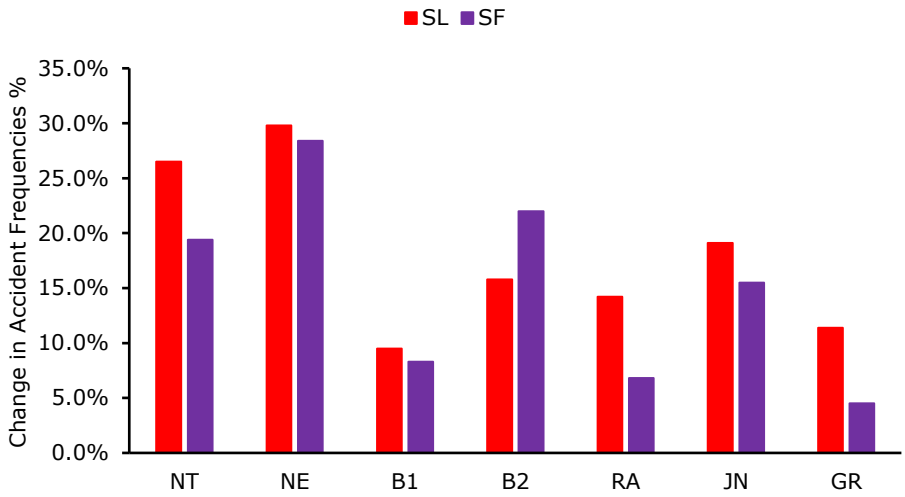


Figure 5-35: Estimated elasticity effects of a 100% increase in number of minor access on slight and serious and fatal accident frequencies across NT level and all site categories in 3C network

5.5.3.3 Pavement characteristics

- Skid resistance

It can be seen from the RPNB outcome in Tables 5-4 and 5-5 that the coefficient of skid resistance is significantly negative in all slight and serious and fatal models, this indicates that both slight and serious and fatal accidents significantly decrease with increasing of skid resistance at the majority roadway segments for all site categories. For slight model, this variable resulted as a random parameter for NT roadway segments, it resulted with means of -2.669 and standard deviations of 1.672. These parameters given that 99% less than 0, while 1% are greater than 0. This imply, that slight frequency is expected to decrease for the vast majority of roadway segments. For serious and fatal models, this variable resulted as a fixed parameter for NT roadway segments. Figure 5-36 shows the elasticity effects of skid resistance on both slight and serious and fatal accident frequency. For example, a 10% increasing in the skid resistance can be decreased the frequency of slight and serious and fatal by 10.68 and 4.87%, respectively.

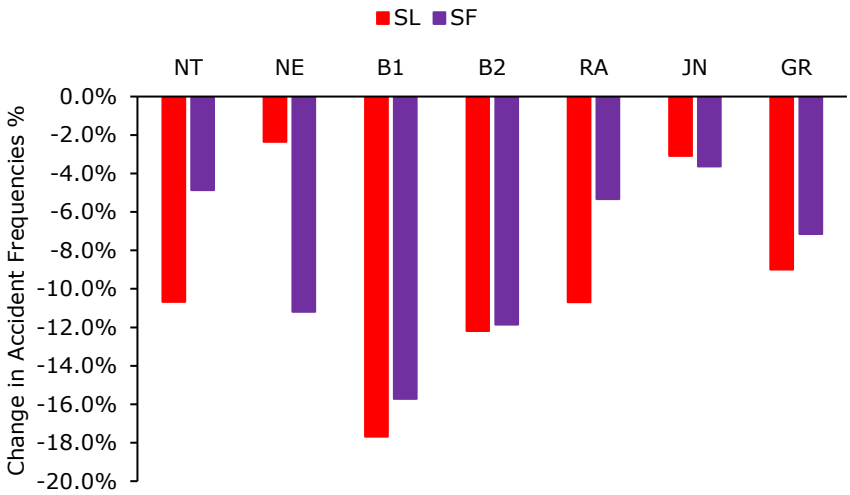


Figure 5-36: Estimated elasticity effects of a 10% increase in skid resistance on slight and serious and fatal accident frequencies across NT level and all site categories in 3C network

- Rut depth

It would be interesting to investigate the effect of rut depth on the frequency of the severity level of accidents that occurred at different site categories. Rut depth was found to be positively associated with both slight and serious and fatal outcomes, which means that roadway segments with high value of rut depth were more prone to higher number of slight and serious and fatal accidents. This result can also be derived from the elasticity effects of rut depth on the frequencies of slight and serious and fatal accidents (see Figure 5-37). Relating to the elasticity effects of rut depth on NT roadway segments, a 10% increase in rut depth leads to increase both slight and serious and fatal by 0.48, 0.41% respectively.

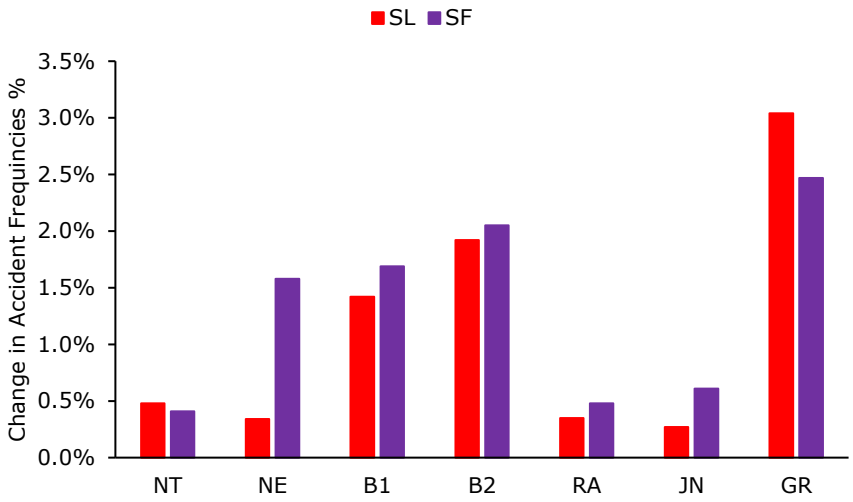


Figure 5-37: Estimated elasticity effects of a 10% increase in rut depth on slight and serious and fatal accidents frequencies across NT level and all site categories in 3C network

- Texture depth

The coefficient of texture depth is significantly negative in all severity accident models, which indicates that for both slight and serious and fatal significantly decrease with increase of texture depth in roadway segments. Regarding the NT roadway segments, the texture depth for road segments was a random parameter, normally distributed with a mean of -0.125 and -0.146 and a standard deviation of 0.695 and 0.064 for slight and serious and fatal accidents, respectively. These parameters suggested that for 57% and 99% of roadway segments, both slight and serious and fatal accident frequencies were expected to decrease with increasing texture depth. On the other hand, for 43% and 1% of roadway segments, both slight and serious and fatal accident frequencies were expected to increase with decreasing texture depth. The results obtained from the elasticity effects of texture depth on slight and serious and fatal accidents for all site categories are shown in Figure 5-38.

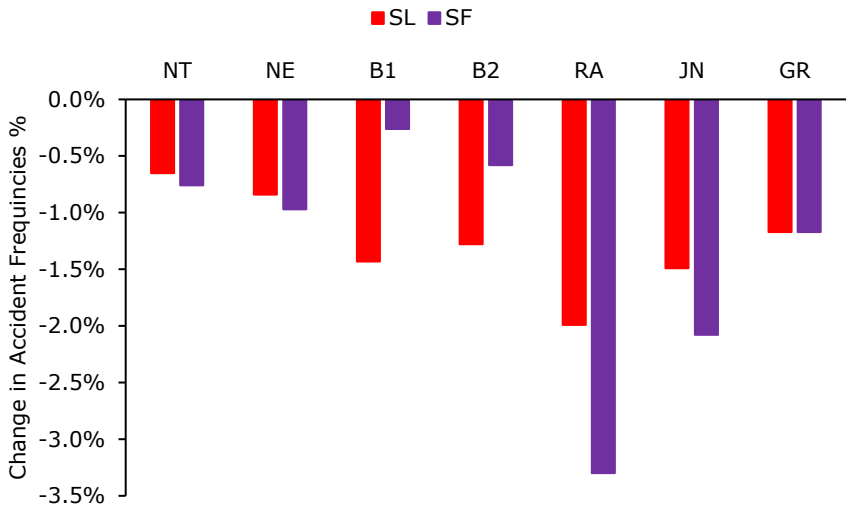


Figure 5-38: Estimated elasticity effects of a 10% increase in texture depth on slight and serious and fatal accident frequencies across NT level and all site categories in 3C network

5.3 Summary

This chapter examines the factors contributing to T, D, W, SL and SF accident frequencies that occurred in NT, NE, B1, B2, RA, JN and GR site categories in A – roads networks in 3C network from 2005-2010, using RPNB model which was considered as an appropriate approach because its ability to account the unobserved heterogeneity that can be raised from the independent variables. Three types of independent variables: traffic characteristics (Ln AADF, heavy vehicles percentage and speed limit), geometric characteristics (radius of curvature, gradient, number of lanes and number of minor access), and pavement characteristics (skid resistance, rut depth and texture depth) were considered. Regarding the parameter estimation results of the RPNB models, our findings suggest that:

5.3.1 Traffic characteristics

- Ln AADF

Table 5-11 provides an overview of Ln AADF effect on total, dry, wet, slight and serious and fatal accident frequencies at all site categories. Ln AADF had significant positive effects on total, dry, wet, slight and serious and fatal accidents frequencies

in all site categories, this indicated that increased Ln AADF in all roadway segments leads to higher total, dry, wet, slight and serious and fatal accident frequencies.

Table 5-11: The effect of Ln AADF on total, dry, wet, slight and serious and fatal accident frequencies using RPNB model for 3C site categories

Site category	T		D		W		SL		SF	
	Ln AADF effect	Positive effect (%)	Ln AADF effect	Positive effect (%)	Ln AADF effect	Positive effect (%)	Ln AADF effect	Positive effect (%)	Ln AADF effect	Positive effect (%)
NT	↑	100 (F)	↑	100 (F)	↑	100 (F)	↑	100 (F)	↑	100 (F)
NE	↑	100 (F)	↑	100 (F)	↑	100 (F)	↑	100 (F)	↑	100 (F)
B1	↑	100 (F)	↑	100 (F)	↑	100 (F)	↑	100 (F)	↑	100 (F)
B2	↑	100 (F)	↑	100 (F)	↑	100 (F)	↑	100 (F)	↑	100 (F)
RA	↑	100 (F)	↑	100 (F)	↑	100 (F)	↑	100 (F)	↑	100 (F)
JN	↑	100 (F)	↑	100 (F)	↑	100 (F)	↑	100 (F)	↑	100 (F)
GR	↑	100 (F)	↑	100 (F)	↑	100 (F)	↑	100 (F)	↑	100 (F)

- Heavy vehicles percentage

Table 5-12 provides an overview of heavy vehicles percentage effect on total, dry, wet, slight and serious and fatal accidents frequencies in all site categories. This table shows that heavy vehicles percentage resulted as random parameter in the majority of all site categories models, except for GR site category where heavy vehicles percentage resulted as a fixed parameter for all accidents frequencies models. In general, increasing heavy vehicles percentage was statistically related to increasing the total, dry, wet, slight and serious and fatal accident frequencies, in all site categories. This is practically true for total, dry, wet, slight and serious and fatal accidents frequencies in GR site category.

Table 5-12: The effect of heavy vehicles percentage on total, dry, wet, slight and serious and fatal accident frequencies using RPNB model for 3C site categories

Site category	T		D		W		SL		SF	
	%HV effect	Positive effect (%)	%HV effect	Positive effect (%)	%HV effect	Positive effect (%)	%HV effect	Positive effect (%)	%HV effect	Positive effect (%)
NT	↑	25 (R)	↑	37 (R)	↑	30 (R)	↑	41 (R)	↑	45 (R)
NE	↑	33 (R)	↑	49 (R)	↑	47 (R)	↑	49 (R)	↑	100 (F)
B1	↑	48 (R)	↑	43 (R)	↑	16 (R)	↑	34 (R)	↑	17 (R)
B2	↑	100 (F)	↑	39 (R)	↑	100 (F)	↑	100 (F)	↑	100 (F)
RA	↑	47 (R)	↑	41 (R)	↑	45 (R)	↑	45 (R)	↑	25 (R)
JN	↑	47 (R)	↑	31 (R)	↑	48 (R)	↑	46 (R)	↑	100 (F)
GR	↑	100 (F)	↑	100 (F)	↑	100 (F)	↑	100 (F)	↑	100 (F)

- Speed limit

One of the interesting findings in this chapter was that the majority of roadway segments, with higher speed limit, had lower accident frequencies in comparison to roadway segments with lower speed limit. This practically true for all accidents frequencies in all site categories (see Table 5-13). However, this finding must be taken with some caution, increasing SPL should not consider as a recommended policy to improve safety for A – roads network.

Table 5-13: The effect of speed limit on total, dry, wet, slight and serious and fatal accident frequencies using RPNB model for 3C site categories

Site category	T		D		W		SL		SF	
	SPL effect	Positive effect (%)	SPL effect	Positive effect (%)	SPL effect	Positive effect (%)	SPL effect	Positive effect (%)	SPL effect	Positive effect (%)
NT	↓	4 (R)	↓	2 (R)	↓	9 (R)	↓	7 (R)	↓	10 (R)
NE	↓	2 (R)	↓	2 (R)	↓	5 (R)	↓	2 (R)	↓	8 (R)
B1	↓	4 (R)	↓	1 (R)	↓	0 (F)	↓	R (R)	↓	0 (F)
B2	↓	4 (R)	↓	8 (R)	↓	7 (R)	↓	5 (R)	↓	8 (R)
RA	↓	15 (R)	↓	1 (R)	↓	27 (R)	↓	9 (R)	↓	0 (F)
JN	↓	0 (F)	↓	16 (R)	↓	11 (R)	↓	0 (F)	↓	0 (F)
GR	↓	0 (F)	↓	0 (F)	↓	24 (R)	↓	29 (R)	↓	0 (F)

5.4.2 Geometric characteristics

- Radius of curvature

Table 5-14 shows the effect of radius of curvature on total, dry, wet, slight and serious and fatal accident frequencies in all site categories. This table indicates that roadway segments with small RC are associated with higher total, dry, wet, slight and serious and fatal accident frequencies in the majority of roadway segments for all site categories.

Table 5-14: The effect of radius of curvature on total, dry, wet, slight and serious and fatal accident frequencies using RPNB model for 3C site categories

Site category	T		D		W		SL		SF	
	RC effect	Positive effect (%)	RC effect	Positive effect (%)	RC effect	Positive effect (%)	RC effect	Positive effect (%)	RC effect	Positive effect (%)
NT	↓	14 (R)	↓	16 (R)	↓	1 (R)	↓	35 (R)	↓	30 (R)
NE	↓	26 (R)	↓	3 (R)	↓	22 (R)	↓	40 (R)	↓	42 (R)
B1	↓	2 (R)	↓	0 (F)	↓	0 (F)	↓	0 (F)	↓	0 (F)
B2	↓	0 (F)	↓	0 (F)	↓	36 (R)	↓	8 (R)	↓	0 (F)
RA	↓	34 (R)	↓	36 (R)	↓	0 (F)	↓	0 (F)	↓	7 (R)
JN	↓	1 (R)	↓	34 (R)	↓	0 (F)	↓	33 (R)	↓	0 (F)
GR	↓	0 (F)	↓	0 (F)	↓	0 (F)	↓	0 (F)	↓	18 (R)

- Gradient

Table 5-15 shows an overview effect of gradient on accident frequency in all site categories. A significant positive correlation was found between total, dry, wet, slight and serious and fatal accident frequencies for all site categories and gradient for roadway segments. It appears from this table, that gradient have a greater impact on total, dry, wet, slight and serious and fatal accident frequencies in GR roadway segments rather than other roadway segments.

Table 5-15: The effect of gradient on total, dry, wet, slight and serious and fatal accident frequencies using RPNB model for 3C site categories

Site category	T		D		W		SL		S	
	%G effect	Positive effect (%)	%G effect	Positive effect (%)	%G effect	Positive effect (%)	%G effect	Positive effect (%)	%G effect	Positive effect (%)
NT	↑	20 (R)	↑	21 (R)	↑	41 (R)	↑	19 (R)	↑	28 (R)
NE	↑	22 (R)	↑	36 (R)	↑	40 (R)	↑	6 (R)	↑	31 (R)
B1	↑	30 (R)	↑	43 (R)	↑	100 (F)	↑	38 (R)	↑	25 (R)
B2	↑	100 (F)	↑	38 (R)	↑	14 (R)	↑	100 (F)	↑	100 (F)
A	↑	45 (R)	↑	100	↑	34 (R)	↑	15 (R)	↑	30 (R)
JN	↑	100 (F)	↑	100 (F)	↑	100 (F)	↑	100 (F)	↑	100 (F)
G	↑	100 (F)	↑	100 (F)	↑	100 (F)	↑	100 (F)	↑	100 (F)

- Number of lanes

Table 5-16 provides an overview of the effect of NL on accident frequency in all site categories. The result in this table revealed that the majority of roadway segments with fewer lanes expected more total, dry, wet, slight and serious and fatal accident frequencies in comparison with roadway segments with higher number of lanes.

Table 5-16: The effect of number of lanes on total, dry, wet, slight and serious and fatal accident frequencies using RPNB model for 3C site categories

Site category	T		D		W		SL		SF	
	NL effect	Positive effect (%)	NL effect	Positive effect (%)	NL effect	Positive effect (%)	NL effect	Positive effect (%)	NL effect	Positive effect (%)
NT	↓	4 (R)	↓	33 (R)	↓	0 (F)	↓	17 (R)	↓	1 (R)
NE	↓	5 (R)	↓	32 (R)	↓	0 (F)	↓	24 (R)	↓	48 (R)
B1	↓	0 (F)	↓	7 (R)	↓	0 (F)	↓	19 (R)	↓	0 (F)
B2	↓	40 (R)	↓	3 (R)	↓	32 (R)	↓	32 (R)	↓	0 (F)
RA	↓	33 (R)	↓	0 (F)	↓	2 (R)	↓	0 (F)	↓	20 (R)
JN	↓	3 (R)	↓	0 (F)	↓	0 (F)	↓	3 (R)	↓	0 (F)
GR	↓	19 (R)	↓	26 (R)	↓	0 (F)	↓	15 (R)	↓	0 (F)

- Number of minor access

As shown in Table 5-17, for all site categories, number of minor access has a fixed positive effect in all RPNB models on total, dry, wet, slight and serious and fatal

accidents frequencies. This meant that all roadway segments of site categories experienced an increase in total, dry, wet, slight and serious and fatal accidents frequencies, as number of minor access increased.

Table 5-17: The effect of number of minor access on total, dry, wet, slight and serious and fatal accidents frequency using RPNB model for 3C site categories

Site category	T		D		W		SL		SF	
	NMA effect	Positive effect (%)	NMA effect	Positive effect (%)	NMA effect	Positive effect (%)	NMA effect	Positive effect (%)	NMA effect	Positive effect (%)
NT	↑	100 (F)	↑	100 (F)	↑	100 (F)	↑	100 (F)	↑	100 (F)
NE	↑	100 (F)	↑	100 (F)	↑	100 (F)	↑	100 (F)	↑	100 (F)
B1	↑	100 (F)	↑	100 (F)	↑	100 (F)	↑	100 (F)	↑	100 (F)
B2	↑	100 (F)	↑	100 (F)	↑	100 (F)	↑	100 (F)	↑	100 (F)
RA	↑	100 (F)	↑	100 (F)	↑	100 (F)	↑	100 (F)	↑	100 (F)
JN	↑	100 (F)	↑	100 (F)	↑	100 (F)	↑	100 (F)	↑	100 (F)
GR	↑	100 (F)	↑	100 (F)	↑	100 (F)	↑	100 (F)	↑	100 (F)

5.4.3 Pavement characteristics

- Skid resistance

Table 5-18 provides an overview of the effect of skid resistance on total, dry, wet, slight and serious and fatal accident frequencies in all site categories. The analysis of skid resistance effect revealed that increasing skid resistance was associated with reduced total, dry, wet, slight and serious and fatal accident frequencies in the majority of roadway segments for all site categories.

Table 5-18: The effect of skid resistance on total, dry, wet, slight and serious and fatal accidents frequency using RPNB model for 3C site categories

Site category	T		D		W		SL		SF	
	SR effect	Positive effect (%)	SR effect	Positive effect (%)	SR effect	Positive effect (%)	SR effect	Positive effect (%)	SR effect	Positive effect (%)
NT	↓	7 (R)	↓	24 (R)	↓	1 (R)	↓	5 (R)	↓	0 (F)
NE	↓	21 (R)	↓	1 (R)	↓	1 (R)	↓	1 (R)	↓	2 (R)
B1	↓	1 (R)	↓	0 (F)	↓	1 (R)	↓	21 (R)	↓	0 (F)
B2	↓	16 (R)	↓	1 (R)	↓	10 (R)	↓	3 (R)	↓	19 (R)
RA	↓	2 (R)	↓	15 (R)	↓	21 (R)	↓	13 (R)	↓	0 (F)
JN	↓	17 (R)	↓	3 (R)	↓	5 (R)	↓	32 (R)	↓	11 (R)
GR	↓	0 (F)	↓	0 (F)	↓	0 (F)	↓	0 (F)	↓	29 (R)

- Rut depth

Table 5-19 provides an overview of the effect of rut depth on total, dry, wet, slight and serious and fatal accident frequencies in all site categories. There was a significant positive correlation between rut depth and total, dry, wet, slight and serious and fatal accidents frequencies at all site categories. Relatively, roadway segments with high rut depth were observed at higher accident frequencies.

Table 5-19: The effect of rut depth on total, dry, wet, slight and serious and fatal accidents frequency using RPNB model for 3C site categories

Site category	T		D		W		SL		SF	
	RD effect	Positive effect (%)	RD effect	Positive effect (%)	RD effect	Positive effect (%)	RD effect	Positive effect (%)	RD effect	Positive effect (%)
NT	↑	30 (R)	↑	30 (R)	↑	46 (R)	↑	22 (R)	↑	39 (R)
NE	↑	35 (R)	↑	14 (R)	↑	100 (F)	↑	45 (R)	↑	15 (R)
B1	↑	41 (R)	↑	29 (R)	↑	100 (F)	↑	49 (R)	↑	100 (F)
B2	↑	100 (F)	↑	100 (F)	↑	27 (R)	↑	6 (R)	↑	26 (R)
RA	↑	100 (F)	↑	50 (R)	↑	23 (R)	↑	100 (F)	↑	30 (R)
JN	↑	21 (R)	↑	10 (R)	↑	100 (F)	↑	31 (R)	↑	100 (F)
GR	↑	100 (F)	↑	27 (R)	↑	100 (F)	↑	48 (R)	↑	100 (F)

- Texture depth

Table 5-20 provides an overview of the effect of texture depth on total, dry, wet, slight and serious and fatal accident frequencies in all site categories. It can be seen

from the data in Table 5-20 that for the most roadway segments increasing texture depth leads to a significant reduction in total, dry, wet, slight and serious and fatal accident frequencies in all site categories.

Table 5-20: The effect of texture depth on total, dry, wet, slight and serious and fatal accidents frequency using RPNB model for 3C site categories

Site category	T		D		W		SL		SF	
	SR effect	Positive effect (%)	SR effect	Positive effect (%)	SR effect	Positive effect (%)	SR effect	Positive effect (%)	SR effect	Positive effect (%)
NT	↓	13 (R)	↓	35 (R)	↓	26 (R)	↓	43 (R)	↓	1 (R)
NE	↓	47 (R)	↓	26 (R)	↓	34 (R)	↓	39 (R)	↓	0 (F)
B1	↓	0 (F)	↓	4 (R)	↓	44 (R)	↓	19 (R)	↓	41 (R)
B2	↓	34 (R)	↓	20 (R)	↓	20 (R)	↓	0 (F)	↓	0 (F)
RA	↓	0 (F)	↓	48 (R)	↓	0 (F)	↓	0 (F)	↓	0 (F)
JN	↓	3 (R)	↓	0 (F)	↓	44 (R)	↓	0 (F)	↓	0 (F)
GR	↓	13 (R)	↓	0 (F)	↓	18 (R)	↓	0 (F)	↓	0 (F)

CHAPTER SIX

RATE MODELS RESULTS

CHAPTER SIX: RATE MODELS RESULTS

6.1 Overview

The aim of this chapter was to show the results of accident rate models while examining the factors affecting the rate of traffic accidents within NT level and different site categories as defined in section 3.5. This is in line with one of the objectives of this thesis: to develop appropriate statistical models to explore the relationship between total, dry, wet, slight and serious and fatal accidents rate and independent variables: traffic characterises (Ln AADF, heavy vehicles percentage and speed limit), Geometric characteristics (radius of curvature, gradient, number of lanes and number of minor access), and pavement characteristics (skid resistance, rut depth and texture depth). In terms of methodological approaches, as discussed in Chapter 3, total, dry, wet, slight and serious and fatal accident rates in each site category counted by using RPT model.

6.2 Random parameters Tobit (RPT) models results

The RPT model estimation results for total, dry, wet, slight and serious and fatal accident rates, at different site categories, for Norfolk, Oxfordshire and Nottinghamshire are provided in Appendix B. The next sections present RPT model results for total, dry, wet, slight and serious and fatal accident rates at different site categories for 3C.

6.2.1 Total (TAR) accident rate models

Table 6-1 presents the FPT, while Table 6-2 presents the RPT models estimation results for total accident rate at different site categories for 3C network.

6.2.1.1 Traffic characteristics

- Ln AADF

As shown in Table 6-2, the estimated coefficients of Ln AADF for total accident rate models was found to be positive and fixed parameter at 99 % level of confidence across roadway segments in all site categories.

Table 6-1: FPT models estimation results for TAR accident rates for 3C site categories

Variables	NT		NE		B1		B2		RA		JN		GR	
	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t
Constant	-864.233	-10.42	-788.992	-7.84	-1327.910	-4.09	-1012.470	-4.39	1775.000	6.06	1401.290	9.79	-1457.880	-2.41
Ln AADF	69.459	8.40	102.024	9.81	84.169	2.58	111.001	4.55	181.695	7.45	174.018	12.18	76.447	1.28
%HV	21.252	14.72	12.545	8.07	17.047	2.00	1.013	0.22	18.734	3.36	8.914	2.73	40.573	3.07
SPL	-3.632	-14.96	-3.469	-11.32	-5.178	-5.44	-2.768	-4.40	-0.004	-0.22	-1.074	-2.40	-1.715	-1.00
RC	-0.019	-4.28	-0.018	-3.00	-0.573	-1.88	-0.119	-0.73	-0.044	-2.77	-0.135	-18.82	-0.028	-1.20
%G	16.726	5.93	12.149	2.01	8.707	0.90	4.872	0.65	17.907	1.86	17.533	3.78	20.536	0.91
NL	-103.256	-16.28	-27.401	-3.00	-16.668	-0.58	-9.625	-0.50	-31.450	-1.40	-96.277	-8.58	-183.635	-4.96
NMA	145.816	20.93	99.808	9.57	70.686	2.08	104.743	4.71	158.531	8.85	73.518	7.85	182.756	4.87
SR	-636.585	-6.21	-1151.080	-9.25	340.454	0.82	-633.583	-2.41	-223.995	-0.69	183.015	0.96	-1220.590	-1.83
RD	6.277	3.21	0.689	0.25	12.114	2.09	1.760	0.33	11.222	1.62	8.081	2.08	13.388	1.05
TX	-34.398	-1.36	-36.548	-1.23	-248.097	-2.19	-20.454	-0.33	-253.538	-2.97	-61.903	-1.23	-174.422	-0.94

Table 6-2: RPT models estimation results for TAR accident rates for 3C site categories

Variables	NT		NE		B1		B2		RA		JN		GR	
	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t
Constant	-736.895	-8.86	-807.977	-7.98	-1149.390	-4.19	-886.922	-4.78	-1768.660	-6.91	-1401.320	-9.79	-1146.610	-2.70
Ln AADF	60.502	7.21	105.183	10.04	101.499	3.66	122.227	6.22	177.268	8.29	174.021	12.18	85.425	2.01
Std.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
%HV	-19.767	-13.27	-12.613	-8.07	31.331	4.08	3.099	0.81	18.766	3.89	8.914	2.73	47.144	4.87
Std.	64.707	6.42	20.502	12.01	46.338	14.16	9.558	5.34	-	-	-	-	-	-
SPL	-2.499	-10.16	-3.509	-11.38	-7.654	-9.02	-5.440	-10.06	-0.229	-0.33	-1.074	-2.40	-1.473	-1.22
Std.	1.693	6.22	-	-	5.331	24.27	4.561	32.80	1.359	9.63	-	-	0.972	3.66
RC	-0.111	-20.10	-0.018	-2.89	-0.602	-2.30	-0.172	-1.27	-0.045	-3.13	-0.135	-18.82	-0.028	-1.77
Std.	0.098	62.37	0.023	7.65	-	-	0.332	12.86	-	-	0.120	4.33	-	-
%G	16.226	5.79	12.279	2.02	5.501	0.60	5.470	0.89	16.994	1.93	17.533	3.78	19.507	3.25
Std.	64.051	3.88	-	-	51.060	9.01	14.196	4.52	50.357	12.40	-	-	-	-
NL	-107.199	-17.02	-27.257	-2.97	-68.222	-1.22	-4.479	-0.29	-28.425	-1.41	-96.279	-8.58	-86.782	-2.85
Std.	5.716	7.35	-	-	41.863	5.91	14.729	3.47	13.413	3.10	-	-	182.154	20.56
NMA	140.872	20.36	100.668	9.58	72.285	2.58	99.085	5.59	150.641	8.73	73.519	7.85	147.051	3.74
Std.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SR	-604.825	-5.75	-1177.590	-9.41	-294.229	-0.83	-499.733	-2.33	-231.678	-0.82	-183.018	-6.96	-1089.880	-2.32
Std.	451.108	3.21	-	-	239.244	5.67	-	-	170.021	5.44	208.473	7.41	383.118	6.86
RD	6.491	3.30	0.865	0.32	12.501	2.94	5.148	1.20	9.640	1.54	8.081	2.08	9.335	1.05
Std.	-	-	1.205	4.55	-	-	16.767	12.22	21.119	13.97	-	-	2.563	3.92
TX	-51.139	-2.00	-37.040	-2.24	-228.450	-2.37	-55.220	-1.03	-249.549	-3.27	-61.904	-1.93	-10.103	-1.07
Std.	15.784	1.82	-	-	188.594	6.08	184.553	10.91	-	-	-	-	548.407	11.70

The average elasticity effects of Ln AADF, which were illustrated in Figure 6-1, provide additional insights to the magnitude of change in total accidents rate for all site categories due to 1% increase in Ln AADF. With regard to NT roadway segments, the total accidents rate on average was increased by 4.35% due to 1% increasing in Ln AADF.

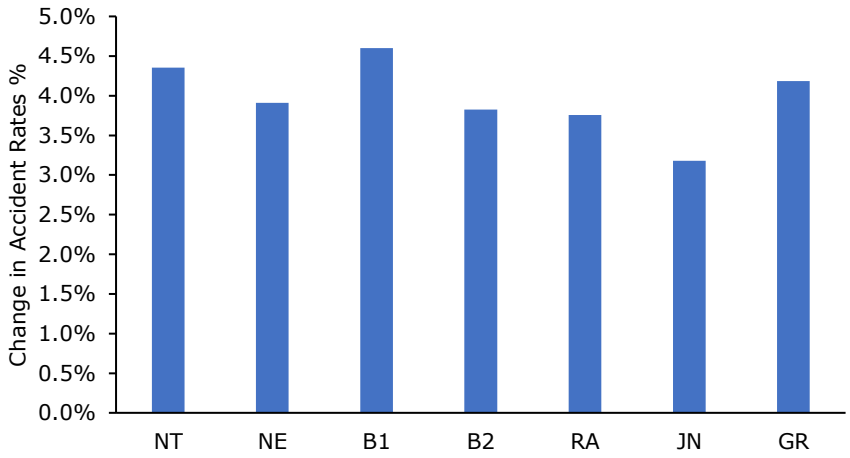


Figure 6-1: Estimated elasticity effects of a 1% increase in Ln AADF on total accident rates across NT level and all site categories in 3C network

- Heavy vehicles percentage

According to the RPT model for TAR accident rates (Table 6-2), the heavy vehicles percentage coefficients were significant factor for all models. Interestingly, a negative correlation was found between heavy vehicles percentage and total accident rates for NT roadway segments and NE site category. Regarding the model for NT roadway segments and NE site category, the estimated coefficient of heavy vehicles percentage varied across roadway segments, with a mean value of -19.767 and -12.613 and standard deviation of 64.707 and 20.502, respectively. Given these distribution parameters that 62% and 73% of the distribution was less than 0, and 38% and 27% was greater than 0, for NT and NE site categories, respectively. These results indicated that for 62% of NT roadway segments and 73% of NE roadway segments, an increase in heavy vehicles percentage was associated with a decrease in total accident rates. On the other hand, for 38% and 27% of NT and NE roadway segments, respectively, the opposite was true. However, heavy vehicles percentage

was correlated positively with total accident rates for other site categories models. The expected change in total accident rates for all site categories was due to a 10% increase in heavy vehicles percentage (Figure 6-2).

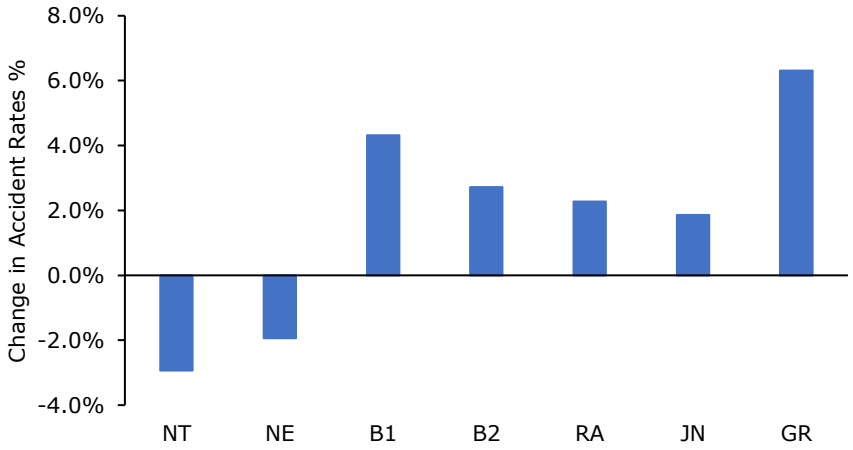


Figure 6-2: Estimated elasticity effects of a 10% increase in heavy vehicles percentage on total accident rates across NT level and all site categories in 3C network

- Speed limit

Increasing the speed limit for roadway segments was negatively correlated with total accident rates, in all site categories. The speed limit coefficient for the NT roadway segments was statistically significant and a random parameter, with a mean of -2.499 and a standard deviation of 1.693. This finding indicated that increasing speed limit was associated with decreases in total accident rates, for 93% of roadway segments. On the other hand, for only 7% of roadway segments, increasing speed limit was associated with increased total accident rates. Figure 6-3 provides an overview of percentage change in total accident rates in all site categories due to a 10% increase in speed limit. For example, for the NT site category, total accident rates were decreased by 8.43%, due to an increase in speed limit of 10%.

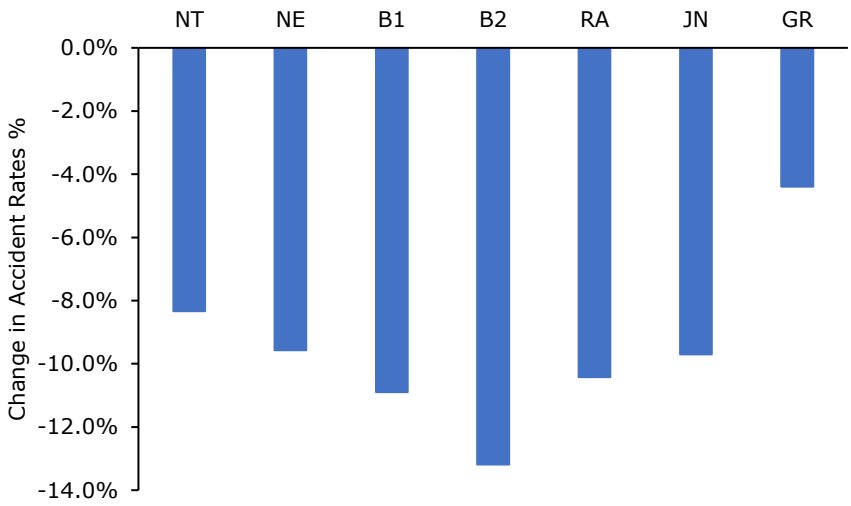


Figure 6-3: Estimated elasticity effects of a 10% increase in speed limit on total accident rates across NT level and all site categories in 3C network

6.2.2.2 Geometric characteristics

- Radius of curvature

In terms of geometric characteristics, radius of curvature for roadway segments was a significant factor, with a negative sign for total accident rates, in all site categories models, suggesting that increased radius of curvature would decrease total accident rates. For the NT roadway segments model, radius of curvature was a random parameter, with a mean of -0.111 and a standard deviation of 0.098. These distribution parameters indicated that 87% of the distribution was less than zero, whereas 13% of the distribution was greater than zero. These distribution parameters suggested that the majority of NT roadway segments, increasing radius of curvature decrease total accidents rates. Figure 6-4 compares the changes in total accident rates in all site categories, due to a 10% increase in radius of curvature. Regarding the NT roadway segments, the expected total accident rate was decreased by 0.73%, due to a 10% increase in radius of curvature.

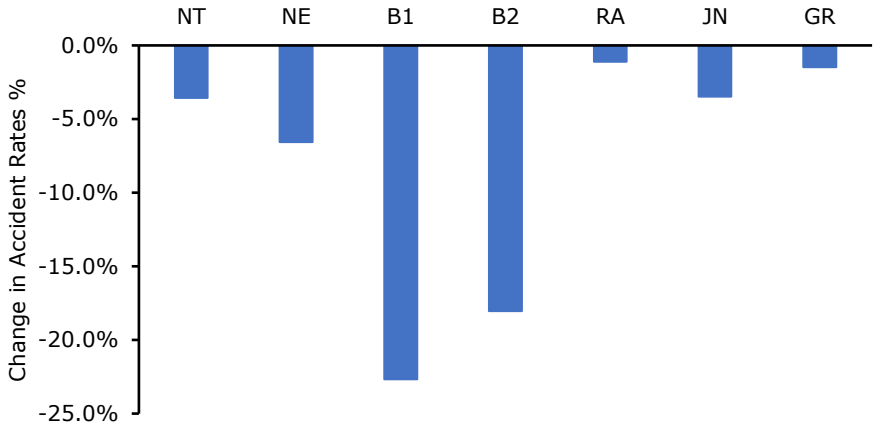


Figure 6-4: Estimated elasticity effects of a 10% increase in radius of curvature on total accident rates across NT level and all site categories in 3C network

- Gradient

The gradient coefficient was statistically significant and positively correlated with total accident rates for all site categories models. For the NT roadway segments, the gradient parameter was random, with a mean of 16.226 and a standard deviation of 64.051. The parameter distribution indicated that for 40% of roadway segments, increasing gradient increased expected total accident rates. However, for 60% of roadway segments, increasing gradient decreased the expected total accident rates. Figure 6-5 represents the elasticity effects of gradient on the expected total accident rates, for all site categories. A 10% increase in gradient was expected to increase total accident rates by 0.83 %, for NT roadway segments.

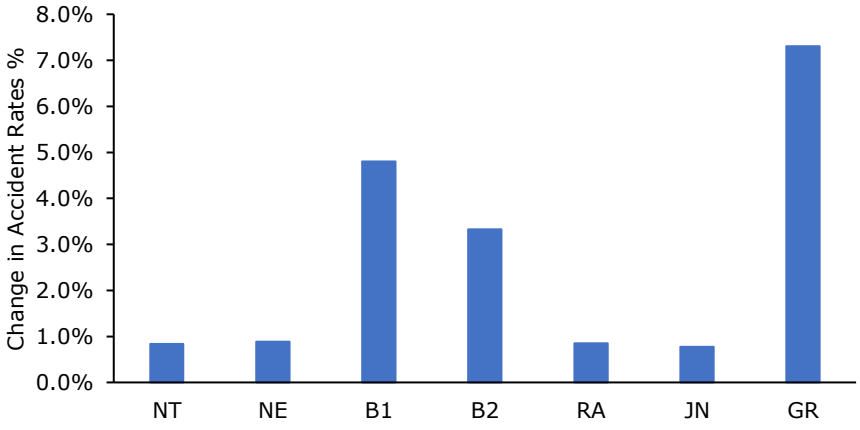


Figure 6-5: Estimated elasticity effects of a 10% increase in gradient on total accident rates across NT level and all site categories in 3C network

- Number of lanes

The variable NL was included in RPT models. Increasing number of lanes for roadway segments tended to decrease total accident rates for the majority of roadway segments at all site categories. Figure 6-6 represents the elasticity effects of number of lanes on total accident rates. The data represents the percentage changes in total accident rates, due to a 100% increase in number of lanes.

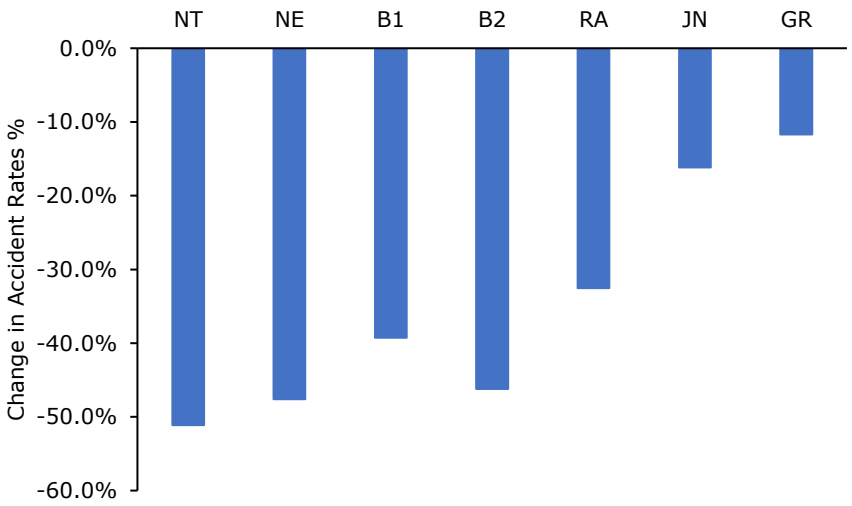


Figure 6-6: Estimated elasticity effects of a 100% increase in number of lanes on total accident rates across NT level and all site categories in 3C network

- Number of minor access

In addition to the abovementioned geometric characteristics, number of minor access had significant fixed effects on total accident rates, for all site categories. The positive sign of this factor indicated that high number of minor access in all roadway segments was associated with increasing total accident rates for all site categories. Figure 6-7 provides an overview for the elasticity effects of number of minor access on total accident rates for all site categories. In respect of the NT roadway segments, a 100% increase in number of minor access increased total accident rates by 10.61%.

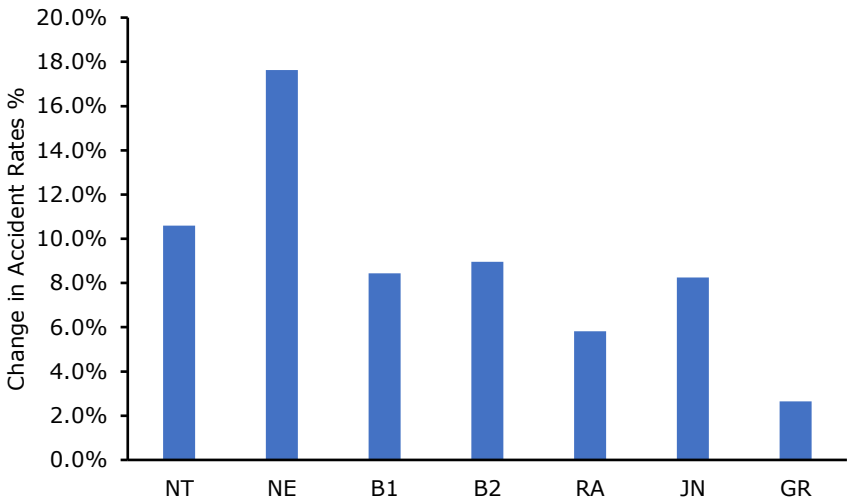


Figure 6-7: Estimated elasticity effects of a 100% increase in number of minor access on total accident rates across NT level and all site categories in 3C network

6.2.2.3 Pavement characteristics

- Skid resistance

Turning to the effects of pavement characteristics on total accident rates, the skid resistance for pavement surfaces was a significant factor in decreasing total accident rates for all site categories models. The NT roadway segments was a random parameter, normally distributed, with a mean of -604.825 and a standard deviation of 451.108. Given these distributional parameters, for 91% of roadway segments, skid resistance had a negative effect on total accident rates, while for 9% of roadway segments, skid resistance had a positive effect on total accident rates. This implied that for the majority of NT roadway segments, total accident rates decreased with increasing skid resistance. Figure 6-8 compares the average elasticity effects of skid resistance on the expected total accident rates for all site categories. Regarding the NT roadway segments, a 10% increase in skid resistance led to a decreased total accident rate of 6.32%.

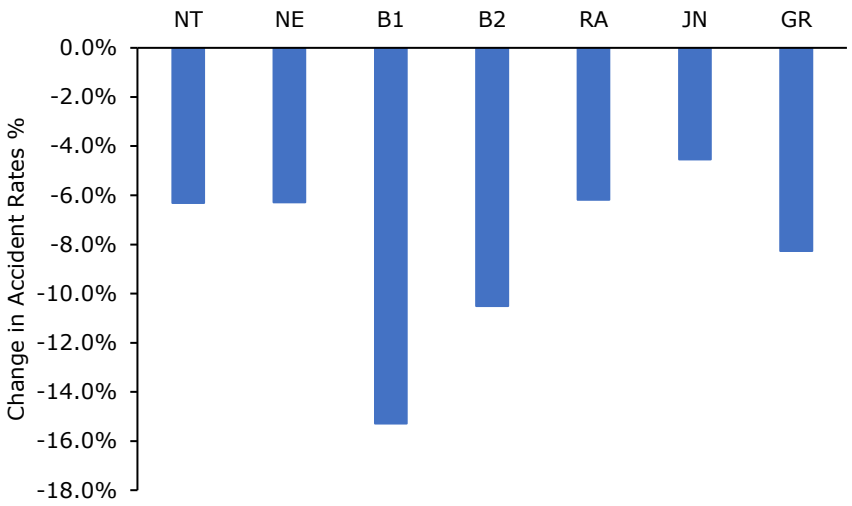


Figure 6-8: Estimated elasticity effects of a 10% increase in skid resistance on total accident rates across NT level and all site categories in 3C network

- Rut depth

The modelling RPT results indicated that increasing rut depth for roadway segments increased total accident rates in all site categories. Figure 6-9 represents the percentage changes in total accident rates in all site categories, due to a 10% increase in rut depth.

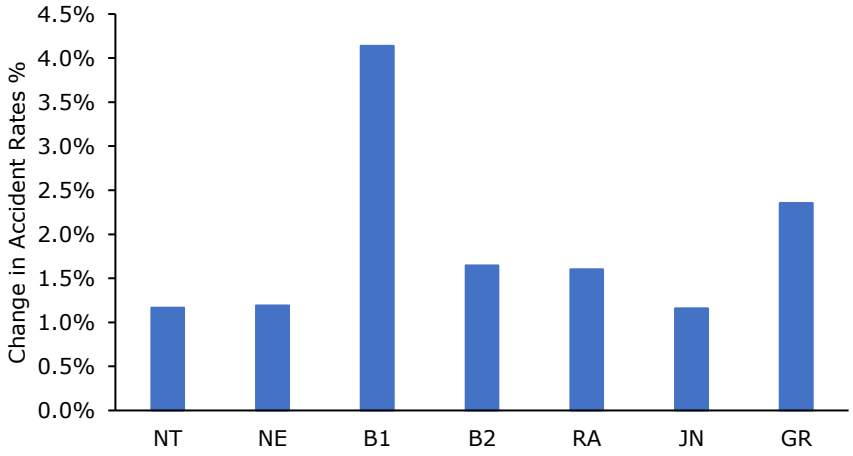


Figure 6-9: Estimated elasticity effects of a 10% increase in rut depth on total accident rates across NT level and all site categories in 3C network

- Texture depth

Texture depth was a significant parameter with a negative sign for total accident rates for all models. Texture depth was a random parameter for all site category models, expect for NE and JN, where it was a fixed parameter. The modelling results for total accident rates in the NT roadway segments had a mean of -51.139 and a standard deviation of 15.784, according to the normal distribution assumption, increasing the texture depth in 99% of roadway segments was leads to decrease total accidents rate. Figure 6-10 shows the average elasticity effects of texture depth on total accident rates in all site categories. Regarding the NT roadway segments, a 10% increase in texture depth led to decreases in total accident rates by 1.69%.

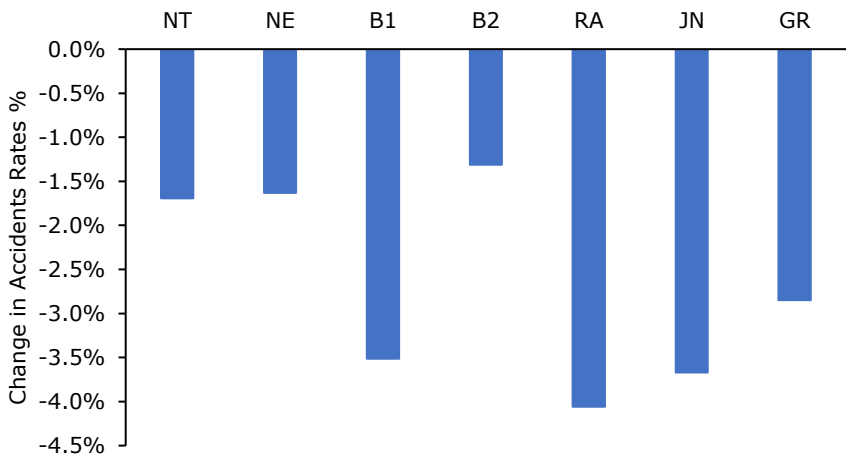


Figure 6-10: Estimated elasticity effects of a 10% increase in texture depth on total accident rates across NT level and all site categories in 3C network

6.2.2 Dry (DAR) and wet (WAR) accident rate models

Tables 6-3 and 6-4 present the FPT and RPT model estimation results for dry accident rates, while Tables 6-5 and 6-6 present the FPT and RPT model estimation results for wet accident rates at different site categories for 3C network.

6.2.2.1 Traffic characteristics

- Ln AADF

Regardless of differences in accident rate types and site categories, the variable Ln AADT was a fixed parameter in all models. As shown in Tables 6-4 and 6-6, the RPT results suggested that Ln AADF, on roadway segments, positively contributed to both dry and wet accident rates. Figure 6-11 shows the elasticity effects of Ln AADF on both DAR and WAR accident rates, in all site categories. With respect to the NT roadway segments, a 1% increase in Ln AADF led to an increase in the expected dry and wet accident rates, by 3.23% and 1.68%, respectively.

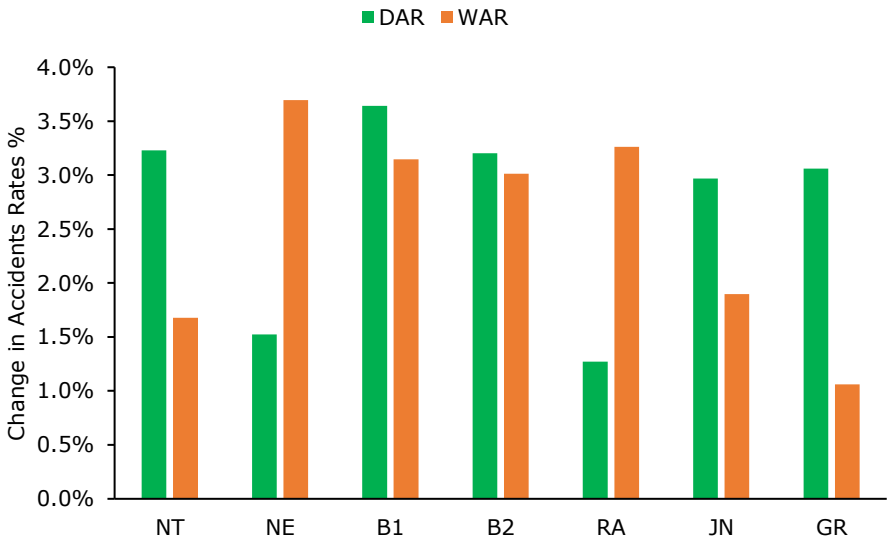


Figure 6-11: Estimated elasticity effects of a 1% increase in Ln AADF on dry and wet accident rates across NT level and all site categories in 3C network

- Heavy vehicles percentage

With regard to the RPT results for the dry and wet accident rate models, the heavy vehicles percentage resulted as a significant parameter with a negative sign in dry and wet accident rates for NT and NE site categories. On the other hand, heavy vehicles percentage was a significant parameter with a positive sign in other site categories. The results from the elasticity effects of heavy vehicles percentage on both dry and wet accident rates, in all site category are presented in Figure 6-12.

Table 6-3: FPT models estimation results for dry accident rates for 3C site categories

Variables	NT		NE		B1		B2		RA		JN		GR	
	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t
Constant	-1088.480	-14.06	-1029.240	-10.81	-1127.560	-4.33	-1113.870	-4.87	-839.353	-3.47	-1038.770	-7.92	-1505.740	-2.81
Ln AADF	113.001	14.10	118.393	11.81	134.500	4.82	140.586	6.06	35.420	1.61	113.353	8.72	149.695	2.65
%HV	17.859	13.39	10.257	7.10	10.417	1.49	1.065	0.26	13.221	2.88	11.243	3.46	31.632	2.79
SPL	-3.936	-16.95	-3.483	-11.96	-5.937	-7.24	-2.767	-4.89	-1.199	-1.74	-1.178	-2.84	-0.340	-0.23
RC	-0.006	-1.48	-0.018	-3.04	-0.577	-2.28	-0.185	-1.22	-0.024	-1.67	-0.193	-34.03	-0.012	-0.57
%G	10.543	3.90	9.572	1.65	1.609	0.20	1.117	0.16	9.222	1.09	12.287	2.76	8.347	0.43
NL	-61.817	-9.92	-23.342	-2.79	-85.479	-3.24	-20.191	-1.09	-69.292	-3.57	-68.838	-6.74	-101.054	-3.19
NMA	140.012	22.14	92.388	9.56	75.436	2.89	97.830	5.04	160.703	10.12	77.196	9.02	171.276	6.93
SR	-765.218	-7.91	-902.760	-7.70	-205.084	-0.63	-767.578	-3.17	-914.171	-3.24	-8.743	-0.05	-1524.800	-2.82
RD	-0.003	0.00	-2.994	-1.15	-4.753	-1.32	-3.266	-0.66	-4.637	-0.78	-2.160	-0.61	-3.792	-0.33
TX	-10.350	-0.43	-54.783	-1.90	-147.565	-1.55	-43.419	-0.74	-46.974	-0.58	-28.121	-0.60	-67.190	-0.41

Table 6-4: RPT models estimation results for dry accident rates for 3C site categories

Variables	NT		NE		B1		B2		RA		JN		GR	
	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t
Constant	-1096.48	-14.11	-1039.45	-11.15	-1134.67	-4.39	-879.808	-5.62	-946.661	-4.84	-1296	-6.76	-1308.09	-14.32
Ln AADF	115.434	14.33	125.605	12.74	137.803	4.98	152.208	9.32	34.135	1.95	141.431	7.18	147.843	16.10
Std.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
%HV	-18.222	-13.63	-10.389	-7.33	10.552	3.52	9.648	2.98	14.694	4.05	14.033	2.98	36.981	20.39
Std.	-	-	-	-	-	-	21.000	13.32	33.402	2.80	-	-	-	-
SPL	-3.983	-17.10	-3.964	-13.88	-5.949	-7.33	-6.547	-14.33	-1.502	-2.77	-1.546	-2.57	-2.285	-10.39
Std.	2.421	-	-	-	-	-	4.658	32.21	-	-	-	-	4.049	55.42
RC	-0.007	-1.55	-0.015	-2.55	-0.524	-2.09	-0.402	-3.62	-0.029	-2.47	-0.371	-26.15	-0.005	-1.68
Std.	0.005	8.32	0.032	10.92	-	-	0.492	20.98	0.059	7.66	0.205	22.83	0.03	15.85
%G	11.301	4.16	9.737	1.71	4.608	0.55	2.225	0.44	7.172	1.08	15.327	2.39	3.828	1.52
Std.	-	-	-	-	24.633	4.77	16.498	5.37	17.611	4.57	-	-	4.802	8.70
NL	-62.621	-10.02	-24.427	-2.98	-85.962	-3.29	-23.586	-1.96	-80.754	-4.99	-85.882	-5.76	-70.26	-13.79
Std.	-	-	-	-	-	-	15.771	4.62	65.39	17.87	-	-	204.252	64.79
NMA	141.417	22.21	90.619	9.59	71.667	2.77	84.152	6.30	153.801	11.44	96.312	6.85	158.371	21.75
Std.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SR	-812.49	-8.37	-937.027	-8.16	-215.658	-5.67	-549.932	-3.26	-904.985	-4.21	-10.908	-2.04	-592.136	-7.69
Std.	-	-	-	-	-	-	155.393	7.57	-	-	-	-	349.178	34.37
RD	-0.289	-1.18	-2.493	-2.98	-4.641	-3.30	-5.498	-1.55	-1.367	-0.28	-2.687	-2.51	-3.044	-1.90
Std.	0.472	5.22	-	-	-	-	5.762	2.70	30.609	21.73	-	-	10.282	20.19
TX	-8.537	-4.35	-51.641	-1.83	-150.752	-2.60	-62.581	-2.46	-28.688	-0.46	-35.083	-3.53	-32.108	-1.44
Std.	-	-	54.893	5.61	-	-	-	-	10.457	2.51	-	-	17.43	2.30

Table 6-5: FPT models estimation results for wet accident rates for 3C site categories

Variables	NT		NE		B1		B2		RA		JN		GR	
	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t
Constant	-1200.890	-12.47	-111.678	-8.95	-2293.600	-4.32	-1484.430	-4.29	-827.618	-5.27	-239.580	-1.16	-1735.830	-2.17
Ln AADF	51.916	5.12	17.004	13.58	42.663	0.78	102.272	2.75	122.787	9.07	70.206	3.47	23.297	0.30
%HV	21.598	12.77	0.988	4.37	21.307	1.78	2.643	0.40	5.241	1.72	19.706	4.21	34.377	2.12
SPL	-2.331	-8.70	-0.534	-16.01	-3.055	-2.14	-2.311	-2.47	-0.811	-1.91	-0.905	-1.65	-1.556	-0.71
RC	$0.3*10^{-4}$	-0.09	-0.013	-22.73	-0.114	-0.26	-0.022	-0.10	-0.101	-14.36	-0.002	-0.19	-0.029	-1.08
%G	17.022	5.53	0.380	0.55	20.402	1.43	15.091	1.47	8.865	1.65	22.331	3.77	18.086	0.66
NL	-108.941	-15.73	-3.186	-2.68	-141.179	-3.40	-42.421	-1.64	-24.482	-2.06	-108.130	-8.29	-188.435	-4.32
NMA	91.105	9.96	6.314	5.06	78.013	1.53	60.091	1.84	32.824	2.76	40.113	2.53	52.714	0.63
SR	-369.319	-3.28	-54.822	-3.88	-900.645	-1.39	-484.952	-1.31	-406.868	-2.42	-266.865	-1.18	-355.893	-0.43
RD	11.318	5.536	0.767	2.410	11.297	1.370	3.981	0.520	6.059	1.530	24.356	5.010	20.025	1.350
TX	-28.032	-1.01	-4.561	-1.32	-261.988	-1.61	-73.788	-0.78	-115.415	-2.71	-42.581	-0.70	-193.600	-0.81

Table 6-6: RPT models estimation results for wet accident rates for 3C site categories

Variables	NT		NE		B1		B2		RA		JN		GR	
	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t
Constant	-1089.140	-12.19	-798.786	-6.96	-1757.450	-4.74	-1178.230	-4.09	827.618	5.27	-206.075	-3.14	-1094.070	-2.18
Ln AADF	56.175	5.92	92.375	7.43	78.902	2.02	108.422	3.49	-122.787	-9.07	-58.559	-3.29	43.705	4.89
Std.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
%HV	-21.641	-13.54	-13.636	-7.92	58.928	5.76	7.549	1.25	5.241	1.72	19.968	4.80	36.272	3.38
Std.	-	-	-	-	67.818	14.60	17.676	6.64	-	-	-	-	56.381	3.53
SPL	-3.681	-14.25	-5.745	-16.64	-3.093	-2.85	-4.346	-5.13	-0.811	-1.91	-1.227	-2.48	-1.004	-0.70
Std.	2.872	49.68	4.007	45.28	2.011	7.19	3.649	17.66	-	-	1.867	14.43	2.494	8.02
RC	-0.002	-0.34	-0.019	-2.97	-0.454	-1.34	-0.010	-0.05	-0.101	-14.36	-0.004	-0.39	-0.023	-1.34
Std.	0.002	3.92	0.023	7.29	1.005	7.24	0.140	3.70	0.149	5.02	0.008	1.38	0.019	1.75
%G	12.832	-0.09	10.192	1.65	15.806	1.28	14.786	1.66	8.865	1.65	4.536	0.72	22.794	1.25
Std.	53.910	30.27	12.721	4.15	76.102	11.10	29.819	3.25	-	-	77.985	22.78	19.183	5.09
NL	-106.348	-16.40	-23.559	-2.53	-103.350	-3.51	-35.420	-1.63	-24.482	-2.06	-104.423	-9.03	-145.219	-4.69
Std.	-	-	-	-	60.876	7.13	17.039	2.80	-	-	-	-	77.386	7.94
NMA	88.923	10.46	64.788	5.66	61.265	1.69	59.441	2.19	32.824	2.76	31.533	2.16	51.831	0.97
Std.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SR	-366.840	-3.47	-1050.150	-8.12	-674.513	-2.45	-729.834	-2.26	-406.868	-2.42	-242.197	-1.19	-939.992	-1.72
Std.	-	-	-	-	-	-	613.270	16.07	-	-	118.285	4.86	787.272	11.21
RD	10.825	5.39	3.542	1.24	28.824	3.98	4.736	2.71	6.059	3.53	23.048	5.29	30.556	2.85
Std.	53.617	19.33	13.292	16.09	73.937	22.17	-	-	-	-	-	-	63.856	15.95
TX	-31.375	-1.19	-0.674	-3.02	-124.826	-1.02	-205.557	-2.33	-115.415	-2.71	-22.741	-0.42	-205.737	-1.28
Std.	27.064	3.06	0.492	4.05	407.225	10.23	339.469	11.98	-	-	70.069	3.91	79.106	2.54

As shown, a 10% increase in heavy vehicles percentage resulted in a decrease for dry and wet accident rates at NT site categories, by 3.38% and 2.42%, respectively.

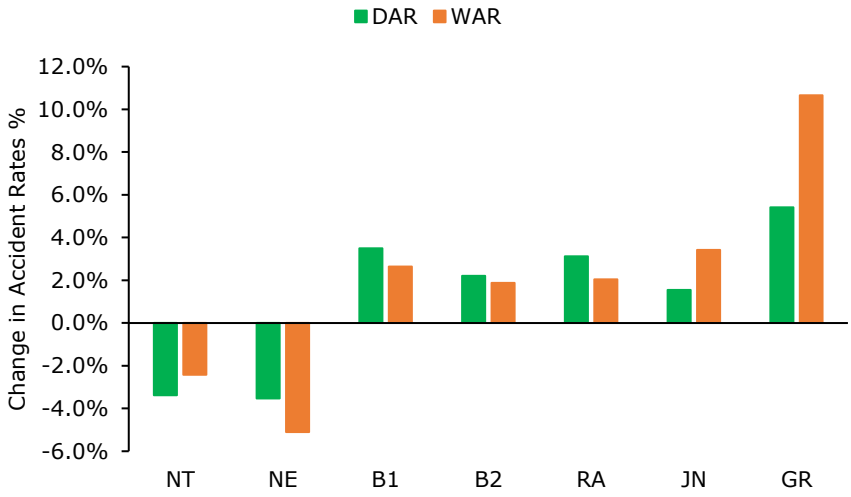


Figure 6-12: Estimated elasticity effects of a 10% increase in heavy vehicles percentage on dry and wet accident rates across NT level and all site categories in 3C network

- Speed limit

Regarding traffic characteristics, roadway segments with higher speed limit were associated with decreases in both dry and wet accident rates, in all site categories. As shown in Tables 6-4 and 6-6, under the NT roadway segments, speed limit resulted in a normally distributed random parameter, with a mean of -3.983 and a standard deviation of 2.421 for the dry accident rate model, and a mean of -3.681 and standard deviation of 2.872 for the wet accident rate model. Given these estimated distributional parameters, for 95% and 90% of NT roadway segments, increasing speed limit led to decreases in both dry and wet accident rates, respectively. Figure 6-13 shows the elasticity effects of speed limit on both dry and wet accident rates across all site categories. For the NT roadway segments, a 10% increase in speed limit decreased both dry and wet accident rates by 6.65% and 4.43%, respectively.

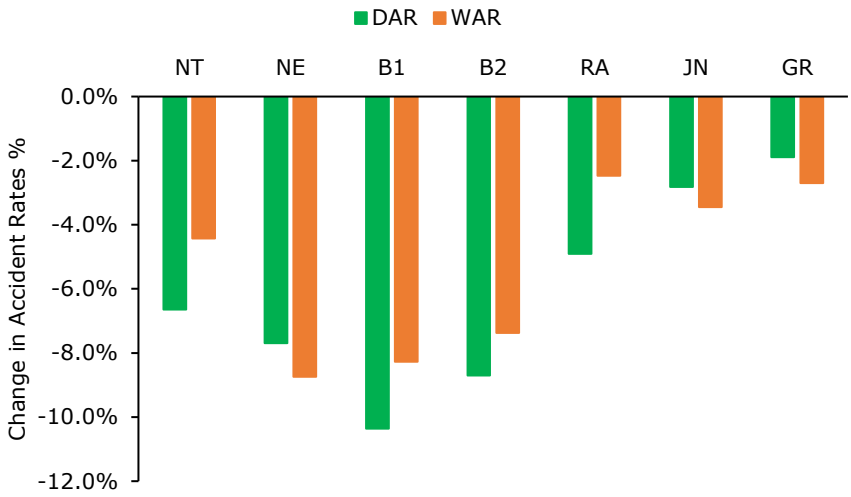


Figure 6-13: Estimated elasticity effects of a 10% increase in speed limit on dry and wet accident rates across NT level and all site categories in 3C network

6.2.2.2 Geometric characteristics

- Radius of curvature

Radius of curvature was statistically significant and negatively associated with both dry and wet accident rate models. The coefficient of radius of curvature for the NT roadway segments was a random parameter that is normally distributed with a mean of -0.007 and -0.002 and a standard deviation of 0.005 and 0.012 for dry and wet accident rate models, respectively. These distribution parameters given that 92% and 84% of the distributions were less than 0. On the other hand, for 8% and 16% of the distributions were greater than 0, for dry and wet, respectively. Thus, for the majority of roadway segments, both dry and wet accident rates were expected to decrease with increasing radius of curvature. The average elasticity effects of radius of curvature on the expected dry and wet accident rates is shown in Figure 6-14. This figure indicates that increasing radius of curvature for roadway segments by 10 % for NT site categories, decreased both dry and wet accident rates by an average of 1.28% and 1.12%, respectively.

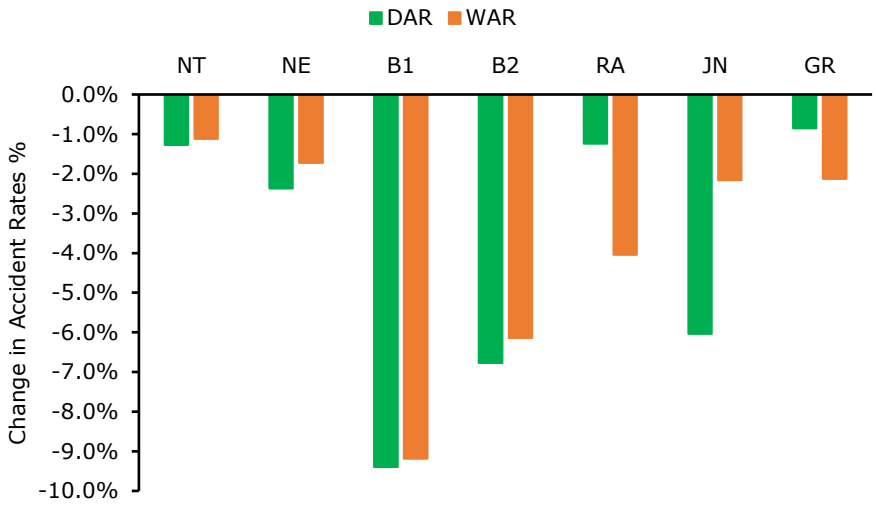


Figure 6-14: Estimated elasticity effects of a 10% increase in radius of curvature on dry and wet accident rates across NT level and all site categories in 3C network

- Gradient

In terms of geometric characteristics, gradient was a significant factor for increasing both dry and wet accident rates, in all site categories. Regarding the NT roadway segments, the coefficient of gradient was a random parameter, normally distributed, with a mean of 11.301 and 12.832 and a standard deviation of 89.932 and 255.854 for dry and wet accident rate models, respectively. These distribution parameters given that 45% and 48% of the distributions were less than 0. On the other hand, for 55% and 52% of the distributions were greater than 0, for dry and wet, respectively. Thus, for the half of roadway segments, both dry and wet accident rates were expected to increase with increasing gradient. Figure 6-15 represents the elasticity effects of gradient on both DAR and WAR accident rates, for all site categories. Regarding the NT roadway segments, a 10% increase in gradient led to increases in both dry and wet accident rates by 0.73% and 1.28%, respectively.

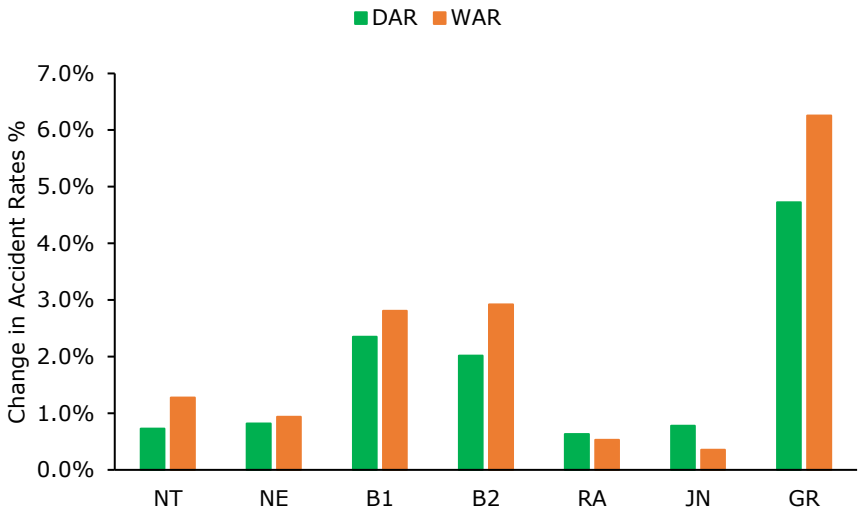


Figure 6-15: Estimated elasticity effects of a 10% increase in gradient on dry and wet accident rates across NT level and all site categories in 3C network

- Number of lanes

A negative correlation was found between both dry and wet accident rates and number of lanes. The negative coefficient for number of lanes indicated that roadway segments, with more lanes, were generally associated with lower dry and wet accident rates. Figure 6-16 represents the elasticity effects of number of lanes on dry and wet accident rates. For the NT roadway segments, a 100% increase in number of lanes led to deceased dry and wet accident rates by 27.15 and 25.21%, respectively.

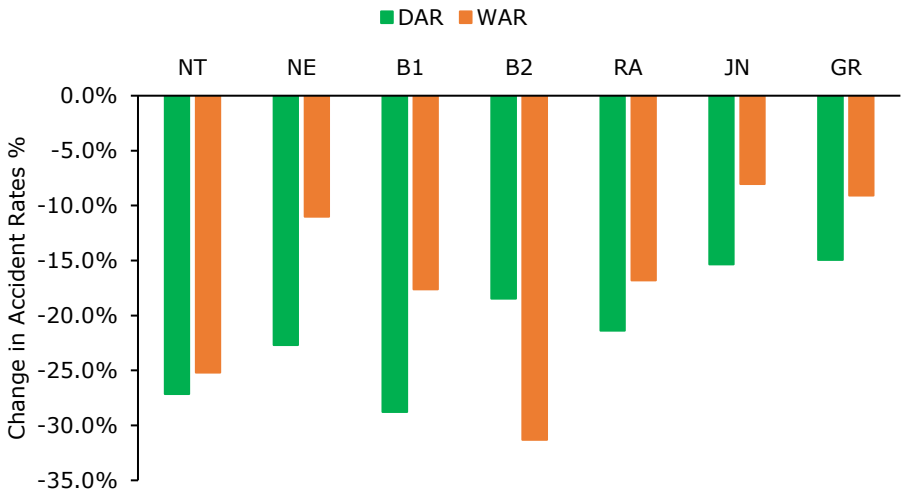


Figure 6-16: Estimated elasticity effects of a 100% increase in number of lanes on dry and wet accident rates across NT level and all site categories in 3C network

- Number of minor access

According to the estimation results of the RPT model for all site categories, number of minor access had a fixed significant positive effect on both dry and wet accident rates. Figure 6-17 provides an overview of the elasticity effects of number of minor access on both dry and wet accident rates. Regarding the NT roadway segments, a 100% increase in number of minor access increased both dry and wet accident rates by 5.53 and 3.97%, respectively.

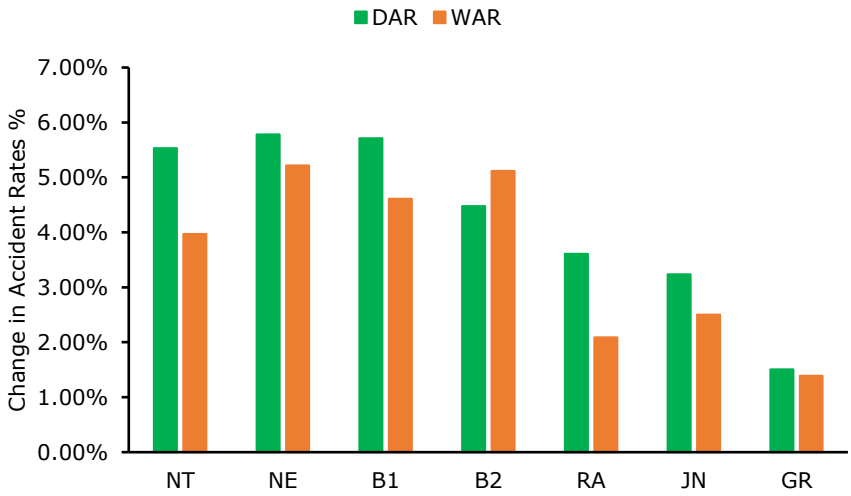


Figure 6-17: Estimated elasticity effects of a 100% increase in number of minor access on dry and wet accident rates across NT level and all site categories in 3C network

6.2.2.3 Pavement characteristics

- Skid resistance

Regarding the effects of skid resistance on accident rates, a negative correlation was found between skid resistance and both dry and wet accident rates at all site categories. The majority of roadway segments with high skid resistance had significantly lower dry and wet accident rates, in all site categories. Figure 6-18 compares the changes in the expected dry and wet accident rates for all site categories, due to a 10% increase in skid resistance.

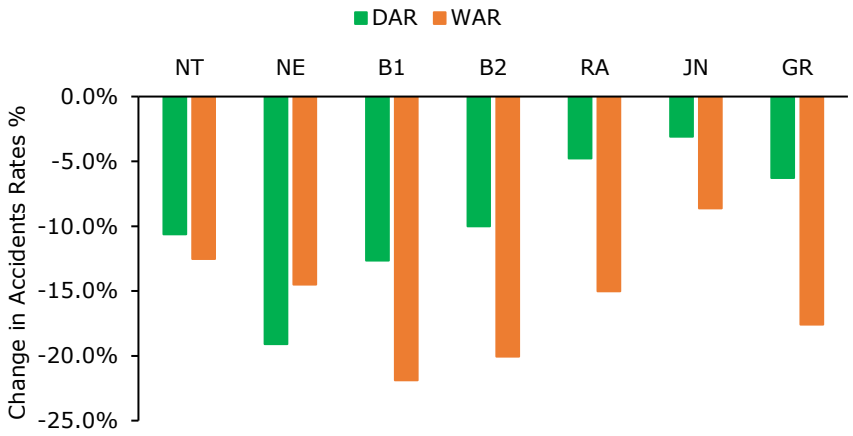


Figure 6-18: Estimated elasticity effects of a 10% increase in skid resistance on dry and wet accident rates across NT level and all site categories in 3C network

- Rut depth

The result of RPT models for dry and wet accident rates revealed that rut depth was negatively correlated with dry accident rates, while it was positively correlated with wet accident rates for all site categories. For the NT roadway segments, rut depth was a random parameter, the mean and standard deviation of the random parameter of rut depth for dry accident were -0.289 and 0.472, respectively, whereas those for wet accidents were 10.825 and 53.617, respectively. Given these distributional parameters increased the rut depth in 73% of roadway segments, would decrease the rate of dry accidents, while increase rut depth in 42% of roadway segments will increase the rate of wet accidents. Figure 6-19 provides an overview of the elasticity effects of rut depth on both dry and wet accident rates, in all site categories.

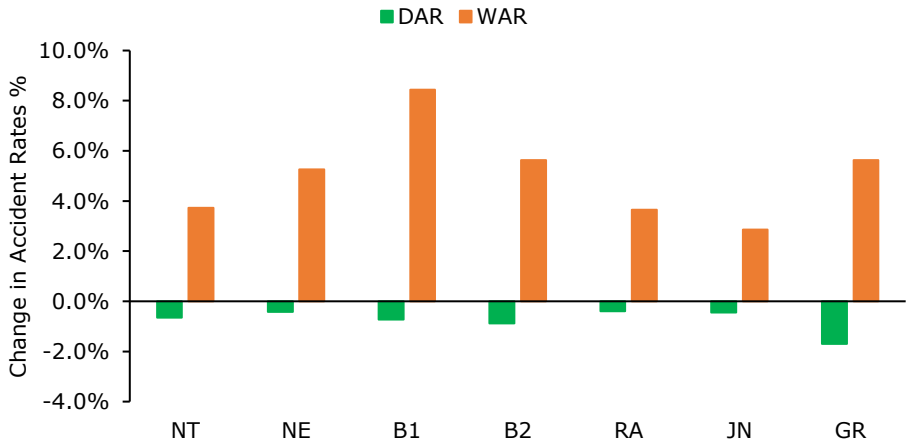


Figure 6-19: Estimated elasticity effects of a 10% increase in rut depth on dry and wet accident rates across NT level and all site categories in 3C network

- Texture depth

The result of RPT models for dry and wet accident rates revealed that texture depth was negatively correlated with both dry and wet accident rates for all site categories. The modelling results for dry and wet accident rates, for NT site categories, showed that texture depth was a fixed parameter for dry accident rates, while it resulted as a random parameter, with a mean of -31.375 and a standard deviation of 27.064 for WAR accident rates. According to the normal distribution assumption, increasing texture depth in 88% of NT roadway segments led to decreased rates of wet accident. On the other hand, on 12% % of roadway segments, there was a positive effect of texture depth on wet accident rates. Figure 6-21 shows the average elasticity effects of texture depth on dry and wet accident rates, in all site categories.

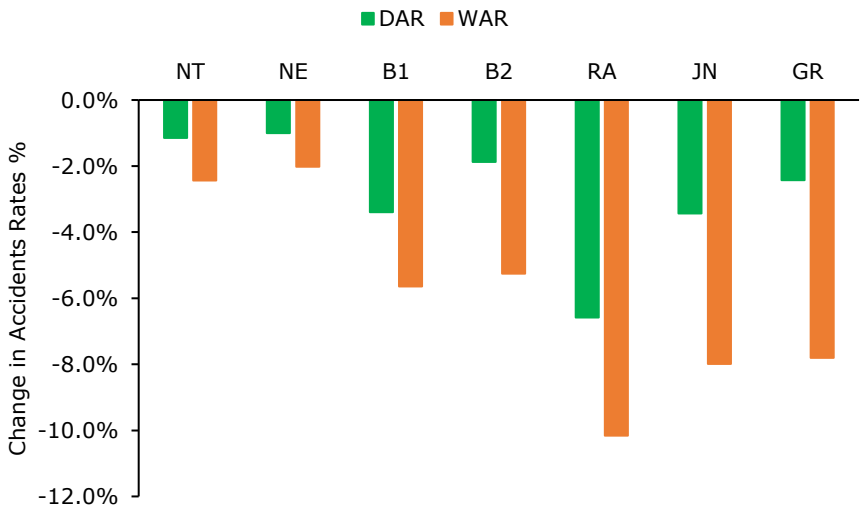


Figure 6-20: Estimated elasticity effects of a 10% increase in texture depth on dry and wet accident rates across NT level and all site categories in 3C network

6.2.3 Slight (SLAR) and serious and fatal (SFAR) accident rate models

Tables 6-7 and 6-8 present the FPT and RPT model estimation results for slight accident rates, while Tables 6-9 and 6-10 present the FPT and RPT model estimation results for serious and fatal accident rates at different site categories for 3C network.

6.2.3.1 Traffic characteristics

- Ln AADF

The coefficient of Ln AADF was a fixed parameter in all models, and its effect was highly significant and positively associated with higher slight and serious and fatal accident rates. The elasticity effects of Ln AADF on slight and serious and fatal accident rates is shown in Figure 6-21. For example, a 1% increase in Ln AADF, led to increased slight and serious and fatal accident rates on the NT roadway segments by 1.96% and 3.14%, respectively.

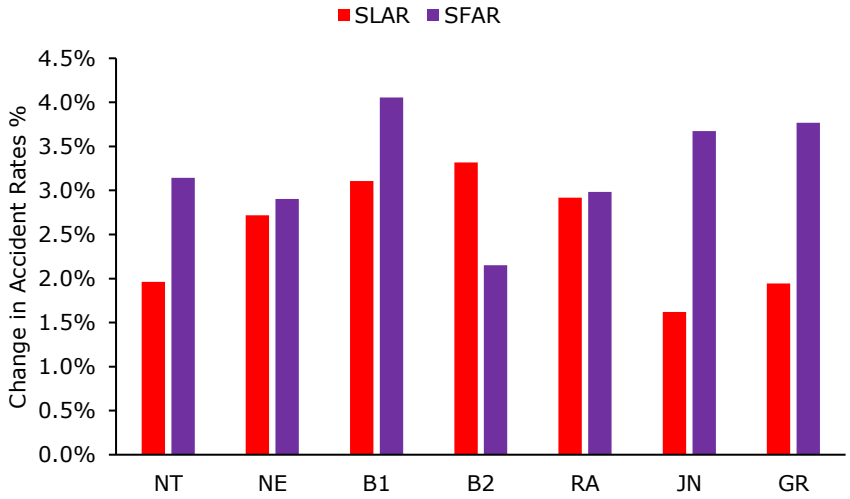


Figure 6-21: Estimated elasticity effects of a 1% increase in Ln AADF on slight and serious and fatal accident rates across NT level and all site categories in 3C network

- Heavy vehicles percentage

The heavy vehicles percentage was negatively related to both slight and serious and fatal accident models for NT and NE site categories. On the other hand, heavy vehicles percentage was a significant parameter with a positive sign in other site categories. Figure 6-22 compares the average elasticity effects of heavy vehicles percentage on the rate of slight and serious and fatal accidents, at all site categories for 3C.

Table 6-7: FPT models estimation results for slight accident rates for 3C site categories

Variables	NT		NE		B1		B2		RA		JN		GR	
	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t
Constant	-1008.690	-12.13	-964.668	-9.53	-933.872	-3.33	-605.766	-2.95	-1287.430	-3.98	-441.701	-2.63	-1345.410	-2.02
Ln AADF	82.721	10.03	113.010	10.81	41.224	3.39	46.925	2.25	131.058	4.74	36.769	3.25	63.955	0.96
%HV	20.417	14.15	11.980	7.77	0.950	2.82	3.598	0.83	20.175	3.37	9.133	2.75	36.204	2.50
SPL	-3.744	-15.54	-3.681	-11.97	-2.977	-2.06	-1.150	-1.99	-0.244	-0.28	-3.341	-1.52	-0.829	-0.43
RC	-0.019	-4.10	-0.020	-3.32	-0.030	-1.45	-1.844	-12.14	-0.041	-2.37	-1.968	-0.98	-0.027	-1.06
%G	15.971	5.72	10.195	1.68	11.277	0.55	5.124	0.73	20.825	1.85	7.345	0.77	26.954	1.09
NL	-99.261	-15.75	-33.586	-3.73	-74.234	-0.97	-28.414	-1.70	-42.513	-1.68	-34.786	-0.56	-180.088	-4.43
NMA	134.570	19.23	96.362	9.28	88.125	0.44	51.656	2.51	170.087	7.97	54.679	0.67	180.024	4.53
SR	-575.600	-5.65	-1051.340	-8.42	-211.430	-3.36	-151.513	-0.63	-333.981	-0.97	-257.123	-2.65	-1251.590	-1.70
RD	5.220	2.690	1.350	0.500	4.537	0.26	1.841	0.390	15.951	2.040	3.471	0.51	12.225	0.880
TX	-16.794	-0.67	-27.160	-0.90	-12.428	-1.25	-34.672	-0.59	-164.978	-1.76	-30.939	-0.81	-169.775	-0.84

Table 6-8: RPT model estimation results for slight accidents rates for 3C site categories

Variables	NT		NE		B1		B2		RA		JN		GR	
	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t
Constant	-998.593	-11.60	-963.835	-9.52	-1346.170	-4.70	-605.766	-2.95	-1307.480	-4.88	-1131.090	-5.20	-947.261	-2.01
Ln AADF	83.695	9.77	113.312	10.82	111.242	3.88	46.925	2.25	122.329	5.32	123.061	5.22	77.611	2.65
Std.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
%HV	-21.555	-14.50	-11.974	-7.76	30.091	3.84	3.598	3.83	20.385	4.10	2.212	0.56	46.770	4.28
Std.	-	-	-	-	27.472	7.73	-	-	5.723	2.46	12.388	6.24	32.249	6.61
SPL	-3.939	-15.77	-3.682	-11.96	-8.349	-9.08	-1.150	-1.99	-0.747	-1.03	-4.387	-6.56	-0.618	-0.45
Std.	-	-	-	-	5.663	23.91	-	-	2.548	17.90	4.298	23.40	2.200	7.10
RC	-0.027	-5.44	-0.019	-3.25	-0.535	-1.95	-1.844	-12.14	-0.045	-3.01	-0.140	-6.70	-0.027	-2.48
Std.	0.049	15.28	-	-	0.388	3.41	-	-	0.023	2.24	0.126	10.57	-	-
%G	17.159	5.92	10.088	1.66	2.486	0.26	5.124	1.73	18.515	2.01	0.841	0.09	52.781	2.88
Std.	-	-	-	-	43.326	7.58	-	-	40.366	9.04	125.829	24.16	45.117	12.02
NL	-103.996	-15.92	-33.634	-3.73	-19.779	-0.77	-28.414	-1.70	-43.296	-2.05	-92.353	-5.61	-116.108	-3.60
Std.	-	-	-	-	19.709	2.76	-	-	22.514	4.98	-	-	146.155	15.06
NMA	142.651	19.50	96.055	9.24	66.571	2.21	51.656	2.51	168.805	8.95	65.026	3.57	121.806	2.69
Std.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SR	-667.359	-6.33	-1058.340	-8.47	-521.473	-1.42	-151.513	-2.63	-383.459	-1.33	-45.693	-1.22	-1116.000	-2.12
Std.	-	-	-	-	235.399	5.29	-	-	225.092	6.78	194.710	6.55	-	-
RD	5.904	2.94	1.382	0.51	2.715	0.56	1.841	2.39	13.625	2.07	0.538	1.07	5.218	0.51
Std.	-	-	1.164	1.89	39.003	17.13	-	-	20.395	12.11	11.876	6.20	36.190	10.75
TX	-19.204	-0.74	-27.909	-0.93	-250.658	-2.52	-34.672	-3.59	-144.187	-1.85	-24.751	-0.41	-156.459	-1.07
Std.	50.909	5.74	-	-	181.183	5.49	42.994	11.25	107.825	4.30	110.952	5.72	53.024	3.10

Table 6-9: FPT model estimation results for serious and fatal accidents rate for 3C site categories

Variables	NT		NE		B1		B2		RA		JN		GR	
	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t
Constant	-996.645	-9.85	-895.970	-5.74	-1189.830	-2.72	-1431.530	-3.32	-263.984	-1.50	-222.805	-1.05	-1438.810	-1.86
Ln AADF	50.880	4.89	61.683	3.68	104.547	2.12	123.130	2.73	44.552	2.73	63.443	3.16	100.811	1.38
%HV	12.936	9.13	11.684	5.74	0.834	0.12	0.695	0.13	7.256	2.25	0.722	0.21	30.851	2.70
SPL	-1.327	-5.96	-1.385	-3.94	-1.866	-2.05	-1.177	-1.62	-0.187	-0.40	-0.259	-0.53	-1.909	-1.52
RC	-0.005	-1.22	0.000	0.00	-0.462	-1.69	-0.321	-1.69	-0.021	-2.34	-0.015	-1.64	0.000	0.00
%G	3.622	1.31	8.281	1.17	4.303	0.50	14.508	1.39	1.382	0.25	3.821	0.66	0.000	0.00
NL	-40.934	-6.56	-2.273	-0.22	-41.821	-1.49	-64.357	-2.23	-14.680	-1.16	-60.871	-4.92	-67.377	-2.57
NMA	75.668	10.23	56.713	4.37	58.410	2.08	89.117	3.51	26.713	2.18	56.576	4.11	26.782	0.63
SR	-294.966	-3.27	-695.387	-4.94	-757.769	-2.16	-124.971	-0.41	-2.623	-0.01	-222.909	-1.10	-448.683	-1.19
RD	1.088	0.720	2.227	0.700	6.839	2.010	0.542	0.080	3.791	0.940	2.580	0.590	5.725	0.660
TX	-36.738	-1.55	-31.460	-0.91	-40.566	-0.39	-27.996	-0.36	-131.105	-2.40	-119.666	-2.13	-5.726	-0.04

Table 6-10: RPT model estimation results for serious and fatal accidents rates for 3C site categories

Variables	NT		NE		B1		B2		RA		JN		GR	
	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t
Constant	-800.371	-9.35	-552.604	-4.54	-178.660	-3.28	-891.623	-4.45	-330.328	-2.62	-60.467	-5.48	-914.166	-11.36
Ln AADF	53.872	5.95	62.859	4.65	89.767	5.28	133.793	6.02	34.362	2.86	43.388	3.46	120.941	13.84
Std.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
%HV	-12.802	-9.72	-12.247	-6.75	10.434	2.88	12.191	3.23	8.023	3.33	10.690	4.02	79.655	28.07
Std.	-	-	-	-	30.157	14.76	26.471	12.62	5.586	4.72	25.184	17.72	-	-
SPL	-3.646	-16.83	-4.845	-14.09	-10.626	-16.20	-5.904	-10.19	-0.008	-1.02	-0.658	-2.00	-2.957	-19.22
Std.	3.083	41.90	3.515	28.76	6.625	22.47	4.186	18.48	0.483	5.61	2.046	20.74	-	-
RC	-0.034	-7.54	-0.083	-3.55	-0.453	-3.62	-0.843	-6.93	-0.028	-3.95	-0.004	-0.67	-0.081	-3.22
Std.	0.066	22.22	-	-	0.551	9.58	0.584	16.62	0.030	5.84	0.046	10.76	-	-
%G	3.699	1.38	4.512	0.74	35.933	6.67	13.438	2.23	25.731	4.86	50.591	9.81	31.087	14.37
Std.	26.271	16.64	26.628	8.34	48.225	14.22	-	-	57.858	18.38	97.075	31.60	-	-
NL	-39.470	-7.16	-4.048	-0.46	-87.035	-6.53	-78.368	-4.81	-19.488	-2.01	-57.446	-7.52	-81.386	-23.49
Std.	-	-	9.665	3.96	53.661	13.29	40.708	9.53	20.017	8.29	-	-	-	-
NMA	69.319	10.63	49.214	4.49	49.447	4.21	77.535	5.68	15.133	1.55	43.991	4.93	5.233	0.94
Std.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SR	-252.254	-3.08	-632.103	-5.24	-916.653	-5.84	-15.798	-1.09	-52.773	-1.38	-76.713	-0.58	-1663.500	-24.65
Std.	85.531	8.32	-	-	-	-	197.882	8.49	16.893	3.01	304.528	17.65	654.799	32.08
RD	0.102	0.07	16.332	5.55	2.590	1.56	1.775	0.49	8.783	2.82	4.546	1.52	17.288	14.82
Std.	5.041	9.00	23.172	23.24	19.675	15.60	4.395	3.67	15.757	15.31	22.499	22.21	12.442	25.74
TX	-34.079	-1.58	-41.031	-1.36	-0.162	-1.49	-104.830	-2.17	-124.274	-3.18	-106.987	-3.04	-328.348	-15.27
Std.	46.720	6.29	53.633	4.93	102.231	6.86	191.255	10.32	-	-	84.721	7.20	-	-

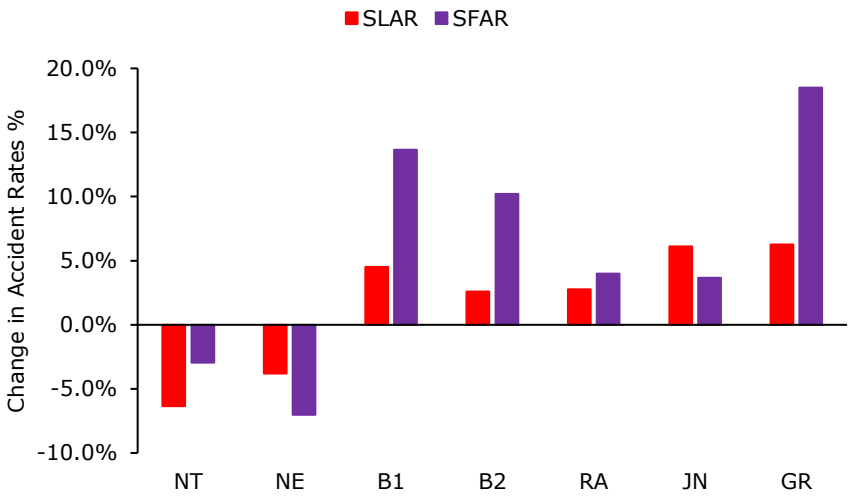


Figure 6-22: Estimated elasticity effects of a 10% increase in heavy vehicles percentage on slight and serious and fatal accident rates across NT level and all site categories in 3C network

- Speed limit

Both slight and serious and fatal accidents were negatively influenced by increasing speed limit for roadway segments. For slight accident rates the effects of speed limit fixed across the NT roadway segments. On the other hand, for serious and fatal accident rates this variable varied across the NT roadway segments, with a mean of -3.646 and standard deviation of 3.083. These parameters resulting that increasing of speed limit for 88% of NT roadway segments were associated with increasing the accident rates for serious and fatal. On the other hand, for 12% of roadway segments, the opposite was true. Figure 6-23 represents the elasticity effects of speed limit on both slight and serious and fatal accident rates, at all site categories. Within the NT roadway segments, a 10% increase in speed limit led to decreases in both slight and serious and fatal accident rates by 3.82% and 4.31%, respectively.

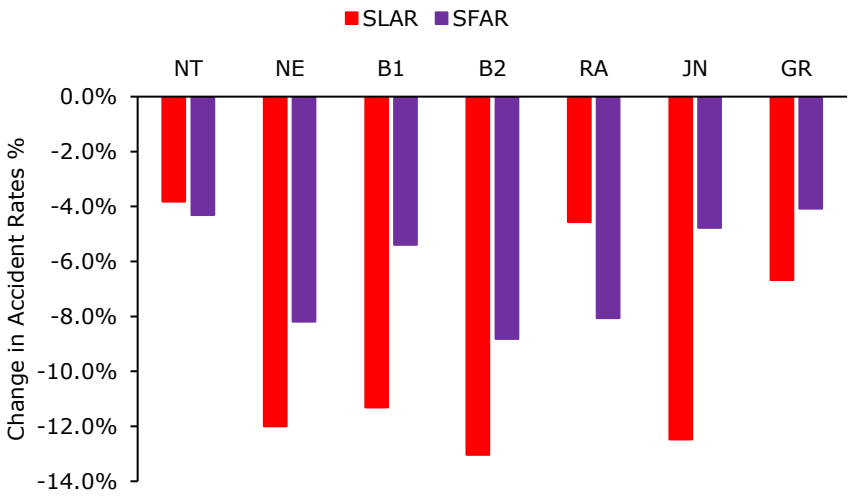


Figure 6-23: Estimated elasticity effects of a 10% increase in speed limit on slight and serious and fatal accident rates across NT level and all site categories in 3C network

6.2.3.2 Geometric characteristics

- Radius of curvature

The radius of curvature coefficient was statistically significant and negatively associated with the rate of accident severity, suggesting that increased radius of curvature would decrease the rate of both slight and serious and fatal accidents, in all models. Regarding the NT roadway segments, the radius of curvature for road segments was a random parameter, normally distributed, with a mean of -0.027 and -0.034, and a standard deviation of 0.049 and 0.066, for slight and serious and fatal accident rates, respectively. These parameters suggested that for 70% and 71% of roadway segments, both slight and serious and fatal accident rates were expected to decrease, with increasing radius of curvature. The average elasticity effects of a10% increase in radius of curvature on the rates of slight and serious and fatal accident is shown in Figure 6-24.

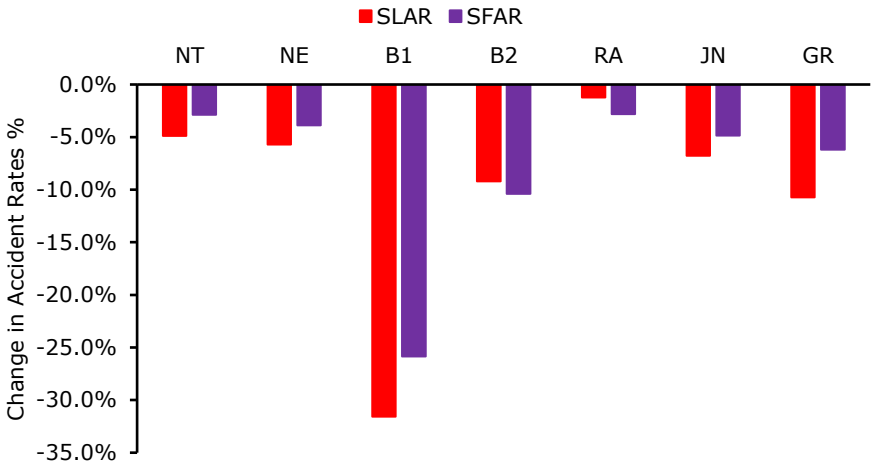


Figure 6-24: Estimated elasticity effects of a 10% increase in radius of curvature on slight and serious and fatal accident rates across NT level and all site categories in 3C network

- Gradient

The gradient was statistically significant and positively correlated with the rates of slight and serious and fatal accidents, for all site categories. For the NT roadway segments, the gradient parameter was fixed for slight accident rates. On the other hand, the gradient parameter was random, with a mean of 3.699 and a standard deviation of 26.271 for SFAR accident rates, respectively. The distribution parameters suggested that increasing the gradient for 44% of roadway segments, increased the rate of serious and fatal accident rates. Figure 6-25 represents the elasticity effects of gradient on both slight and serious and fatal accident rates, for all site categories.

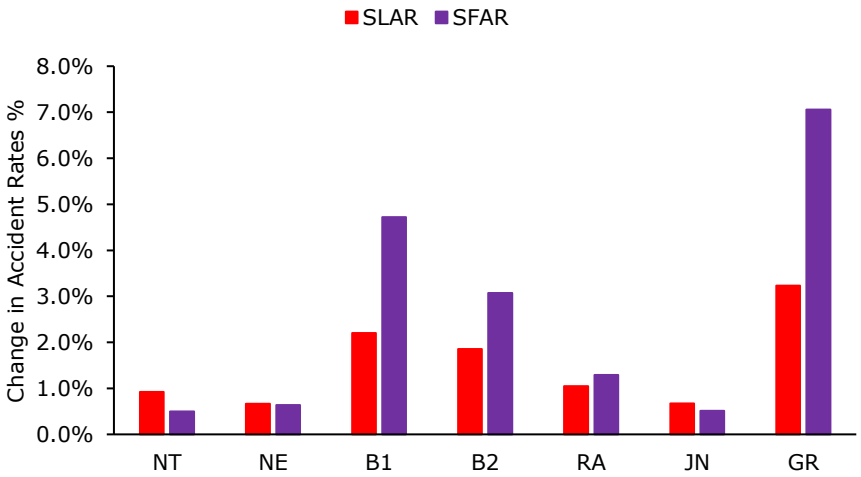


Figure 6-25: Estimated elasticity effects of a 10% increase in gradient on slight and serious and fatal accident rates across NT level and all site categories in 3C network

- Number of lanes

Tables 6-8 and 6-10 illustrated a decreasing trend in the rates of slight and serious and fatal accident in all site categories, due to increasing number of lanes in roadway segments. Its estimated coefficient resulted in a fixed parameter, across roadway segments for all slight and serious and fatal models. Figure 6-26 represents the elasticity effects of number of lanes on the rates of slight and serious and fatal accidents. With respect to the NT roadway segments, a 100% increase in number of lanes contributed to a 43.31% and 25.47% decrease in the rates of slight and serious and fatal accidents, respectively.

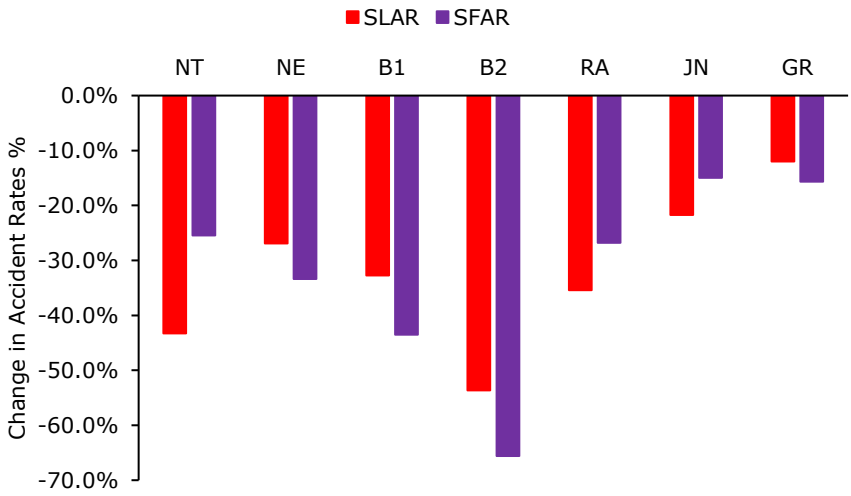


Figure 6-26: Estimated elasticity effects of a 100% increase in number of lanes on slight and serious and fatal accident rates across NT level and all site categories in 3C network

- Number of minor access

The positive correlation between number of minor access in roadway segments and slight and serious and fatal accident rates, indicated that an increase in number of minor access led to increases in both slight and serious and fatal accident rates. The number of minor access coefficient produced a fixed parameter in all site categories, for both slight and serious and fatal models. The results of the elasticity effects of number of minor access on accident rates for both slight and serious and fatal are shown in Figure 6-27. Regarding the NT roadway segments, a 100% increase in

number of minor access resulted in an 10.64% and 12.42% increase in the expected accident rates for slight and serious and fatal, respectively.

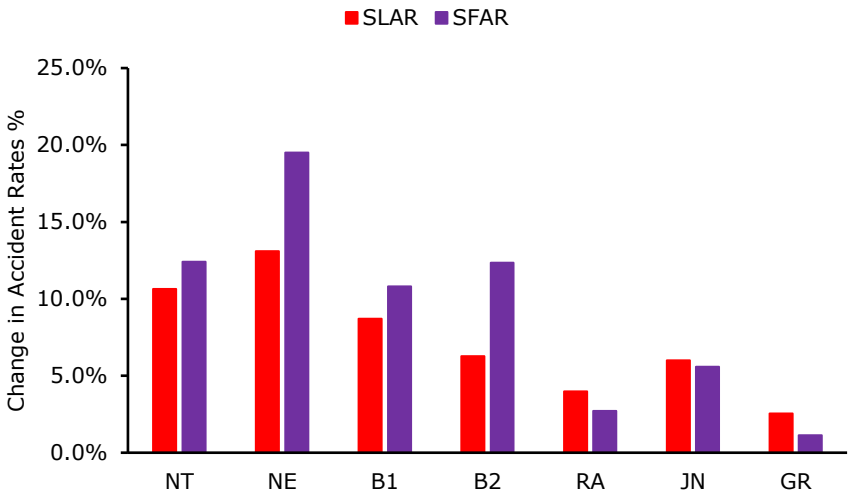


Figure 6-27: Estimated elasticity effects of a 100% increase in number of minor access on slight and serious and fatal accident rates across NT level and all site categories in 3C network

6.2.3.3 Pavement characteristics

- Skid resistance

Skid resistance was significantly negative in all slight and serious and fatal models. This indicated that both slight and serious and fatal accident rates significantly decreased, with increasing skid resistance at roadway segments, for all site categories. For the NT roadway segments, this variable produced a fixed parameter for slight accident rates, while for serious and fatal accident rates it produced a random parameter, with means of –252.254 and standard deviations of 85.531. These parameters given that 99% less than 0, while 1% are greater than 0. This implied that for the vast majority of roadway segments, the rates of both slight and serious and fatal accidents were expected to decrease, with increasing skid resistance values of roadway segments. Figure 6-28 shows the elasticity effects of skid resistance on both slight and serious and fatal accident rates. For example, a 10% increase in skid resistance can decrease the rates of slight and serious and fatal accident by 3.31% and 4.87%, respectively.

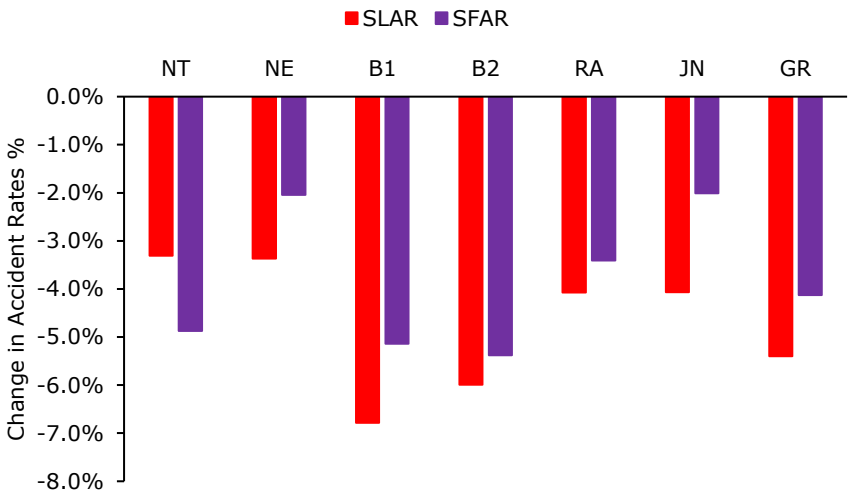


Figure 6-28: Estimated elasticity effects of a 10% increase in skid resistance on slight and serious and fatal accident rates across NT level and all site categories in 3C network

- Rut depth

Rut depth was positively associated with slight and serious and fatal rate outcomes, suggesting that roadway segments with high rut depth values were associated with higher slight and serious and fatal accident rates. For the NT roadway segments, this variable produced a fixed parameter for slight accident rates, while it resulted as a random parameter, with means of 0.102 and standard deviations of 5.041. These parameters given that 49% less than 0, while 51% are greater than 0. This implied, that for 49% of roadway segments, the rates of serious and fatal accidents were expected to increase, with increasing rut depth values of roadway segments. This result can also be derived from the elasticity effects of rut depth on the rates of slight and serious and fatal accidents (Figure 6-29). In relation to the elasticity effects of rut depth on the NT roadway segments, a 10% increase in rut depth led to increased slight and serious and fatal accident rates, by 1.11% and 2.05%, respectively.

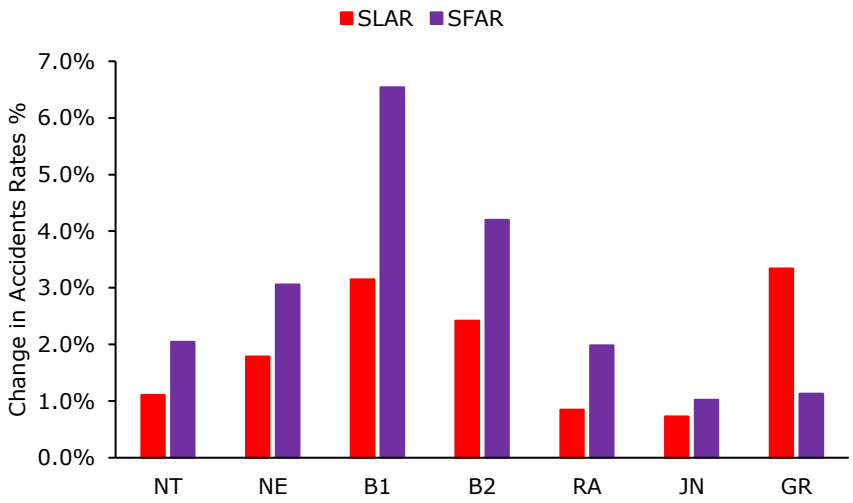


Figure 6-29: Estimated elasticity effects of a 10% increase in rut depth on slight and serious and fatal accident rates across NT level and all site categories in 3C network

- Texture depth

The texture depth coefficient was significantly negative in all severity accident models, indicating that the rate for both slight and serious and fatal accidents significantly decreased with texture depth increases in roadway segments. For the NT roadway segments, texture depth was a random parameter, with means of -19.204 and -34.079 standard deviations of 50.909 and 46.720, for slight and serious and fatal accident rates, respectively. These parameters given that 65% and 77% less than 0, while 35% and 23% are greater than 0. This implied that for 65% and 77% of roadway segments, the rates of both slight and serious and fatal accidents were expected to decrease, with increasing texture depth values of roadway segments. The results from the elasticity effects of texture depth on the rates of slight and serious and fatal accidents for all site categories are shown in Figure 6-32.

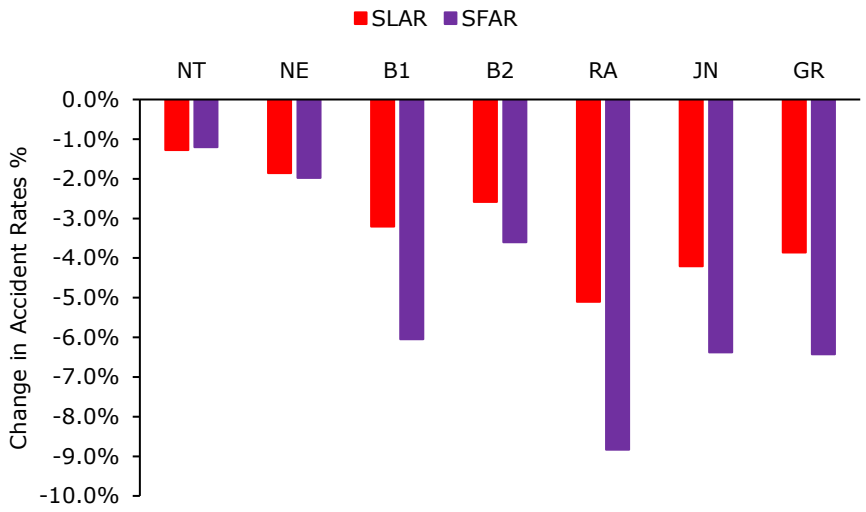


Figure 6-30: Estimated elasticity effects of a 10% increase in texture depth on slight and serious and fatal accident rates across NT level and all site categories in 3C network

6.3 Summary

This chapter examines the factors contributing to total, dry, wet, slight and serious and fatal accident rates that occurred in NT, NE, B1, B2, RA, JN and GR site categories in A – roads networks in 3C network from 2005-2010, using RPT model which was considered as an appropriate approach because its ability to account the unobserved heterogeneity that can be raised from the independent variables. Three types of independent variables: traffic characteristics (Ln AADF, heavy vehicles percentage and speed limit), geometric characteristics (radius of curvature, gradient, number of lanes and number of minor access), and pavement characteristics (skid resistance, rut depth and texture depth) were considered. Regarding the parameter estimation results of the RPNB models, our findings suggest that:

6.3.1 Traffic characteristics

- Ln AADF

Table 6-11 provides an overview of Ln AADF effect on total, dry, wet, slight and serious and fatal accident rates at all site categories. The Ln AADF was found to be a significant factor with positive sign, indicating that for all roadway segments total,

dry, wet, slight and serious and fatal accident rates increased with the Ln AADF at all site categories.

Table 6-11: The effect of Ln AADF on total, dry, wet, slight and serious and fatal accident rates using RPT model for 3C site categories

Site category	TAR		DAR		WAR		SLAR		SFAR	
	Ln AADF effect	Positive effect (%)	Ln AADF effect	Positive effect (%)	Ln AADF effect	Positive effect (%)	Ln AADF effect	Positive effect (%)	Ln AADF effect	Positive effect (%)
NT	↑	100 (F)	↑	100 (F)	↑	100 (F)	↑	100 (F)	↑	100 (F)
NE	↑	100 (F)	↑	100 (F)	↑	100 (F)	↑	100 (F)	↑	100 (F)
B1	↑	100 (F)	↑	100 (F)	↑	100 (F)	↑	100 (F)	↑	100 (F)
B2	↑	100 (F)	↑	100 (F)	↑	100 (F)	↑	100 (F)	↑	100 (F)
RA	↑	100 (F)	↑	100 (F)	↑	100 (F)	↑	100 (F)	↑	100 (F)
JN	↑	100 (F)	↑	100 (F)	↑	100 (F)	↑	100 (F)	↑	100 (F)
GR	↑	100 (F)	↑	100 (F)	↑	100 (F)	↑	100 (F)	↑	100 (F)

- Heavy vehicles percentage

Table 6-12 provides an overview of heavy vehicles percentage effect on total, dry, wet, slight and serious and fatal in all site categories. The heavy vehicles percentage in traffic stream is found to be significant factor in all RPT models. A positive correlation was found between heavy vehicles percentage and total, dry, wet, slight and serious and fatal accident rates for NT and NE site categories. On the other hand, there was a significant positive correlation between heavy vehicles percentage and total, dry, wet, slight and serious and fatal accident rates for other site categories.

Table 6-12: The effect of heavy vehicles percentage on TAR, DAR, WAR, SLAR and SFAR accident rates using RPT model for 3C site categories

Site category	TAR		DAR		WAR		SLAR		SFAR	
	%HV effect	Positive effect (%)	%HV effect	Positive effect (%)	%HV effect	Positive effect (%)	%HV effect	Positive effect (%)	%HV effect	Positive effect (%)
NT	↓	38 (R)	↓	0 (F)	↓	0 (F)	↓	0 (F)	↓	0 (F)
NE	↓	27 (R)	↓	0 (F)	↓	0 (F)	↓	0 (F)	↓	0 (F)
B1	↑	17 (R)	↑	100 (F)	↑	19 (R)	↑	14 (R)	↑	36 (R)
B2	↑	37 (R)	↑	32 (R)	↑	33 (R)	↑	100 (F)	↑	32 (R)
RA	↑	100 (F)	↑	33 (R)	↑	100 (F)	↑	1 (R)	↑	8 (R)
JN	↑	100 (F)	↑	100 (F)	↑	100 (F)	↑	43 (R)	↑	34 (R)
GR	↑	100 (F)	↑	100 (F)	↑	26 (R)	↑	7 (R)	↑	100 (F)

- Speed limit

Table 6-13 provides an overview of heavy vehicles percentage effect on total, dry, wet, slight and serious and fatal in all site categories. The analysis of speed limit effect on accident rates revealed an interesting result in that roadway segments with higher speed limit were associated with reduced total, dry, wet, slight and serious and fatal accident rates for the majority of roadway segments at all sit categories.

Table 6-13: The effect of SPL on total, dry, wet, slight and serious and fatal accident rates using RPT model for 3C site categories

Site category	TAR		DAR		WAR		SLAR		SFAR	
	SPL effect	Positive effect (%)	SPL effect	Positive effect (%)	SPL effect	Positive effect (%)	SPL effect	Positive effect (%)	SPL effect	Positive effect (%)
NT	↓	7 (R)	↓	5 (R)	↓	10 (R)	↓	0 (F)	↓	12 (R)
NE	↓	0 (F)	↓	0 (F)	↓	8 (R)	↓	0 (F)	↓	8 (R)
B1	↓	8 (R)	↓	0 (F)	↓	6 (R)	↓	7 (R)	↓	5 (R)
B2	↓	12 (R)	↓	8 (R)	↓	12 (R)	↓	0 (F)	↓	8 (R)
RA	↓	43 (R)	↓	0 (F)	↓	0 (F)	↓	38 (R)	↓	49 (R)
JN	↓	0 (F)	↓	0 (F)	↓	26 (R)	↓	15 (R)	↓	37 (R)
GR	↓	6 (R)	↓	29 (R)	↓	34 (R)	↓	39 (R)	↓	0 (F)

6.3.2 Geometric characteristics

- Radius of curvature

Table 6-14 shows the effect of radius of curvature on total, dry, wet, slight and serious and fatal accident rates at all site categories. There was a significant negative correlation between radius of curvature and accident rates at all site categories, which indicates that sharp curvatures (reduction of the radius of curvature at roadway segments) were associated with more total, dry, wet, slight and serious and fatal accident rates in the majority of roadway segments at all site categories.

Table 6-14: The effect of radius of curvature on total, dry, wet, slight and serious and fatal accident rates using RPT model for 3C site categories

Site category	TAR		DAR		WAR		SLAR		SFAR	
	RC effect	Positive effect (%)	RC effect	Positive effect (%)	RC effect	Positive effect (%)	RC effect	Positive effect (%)	RC effect	Positive effect (%)
NT	↓	13 (R)	↓	8 (R)	↓	16 (R)	↓	29 (R)	↓	30 (R)
NE	↓	22 (R)	↓	32 (R)	↓	20 (R)	↓	0 (F)	↓	0 (F)
B1	↓	0 (F)	↓	0 (F)	↓	33 (R)	↓	8 (R)	↓	21 (R)
B2	↓	30 (R)	↓	21 (R)	↓	47 (R)	↓	0 (F)	↓	7 (R)
RA	↓	0 (F)	↓	31 (R)	↓	25 (R)	↓	3 (R)	↓	18 (R)
JN	↓	13 (R)	↓	4 (R)	↓	31 (R)	↓	13 (R)	↓	47 (R)
GR	↓	0 (F)	↓	43 (R)	↓	11 (R)	↓	0 (F)	↓	0 (F)

- Gradient

Table 6-15 shows an overview effect of gradient on total, dry, wet, slight and serious and fatal accident rates in all site categories. This table illustrates that gradient was significantly associated with accident rates. Roadway segments with steep slope experienced more total, dry, wet, slight and serious and fatal accident rates. This is practically true for GR roadway segments.

Table 6-15: The effect of gradient on total, dry, wet, slight and serious and fatal accident rates using RPT model for 3C site categories

Site category	TAR		DAR		WAR		SLAR		SFAR	
	%G effect	Positive effect (%)	%G effect	Positive effect (%)	%G effect	Positive effect (%)	%G effect	Positive effect (%)	%G effect	Positive effect (%)
NT	↑	40 (R)	↑	45 (R)	↑	48 (R)	↑	100 (F)	↑	44 (R)
NE	↑	100 (F)	↑	100 (F)	↑	21 (R)	↑	100 (F)	↑	43 (R)
B1	↑	17 (R)	↑	43 (R)	↑	42 (R)	↑	48 (R)	↑	23 (R)
B2	↑	35 (R)	↑	45 (R)	↑	31 (R)	↑	100 (F)	↑	100 (F)
A	↑	37 (R)	↑	34 (R)	↑	100 (F)	↑	32 (R)	↑	33 (R)
JN	↑	100 (F)	↑	100 (F)	↑	48 (R)	↑	50 (R)	↑	30 (R)
GR	↑	100 (F)	↑	21 (R)	↑	12 (R)	↑	12 (R)	↑	100 (F)

- Number of lanes

Table 6-16 provides an overview of the effect of number of lanes on total, dry, wet, slight and serious and fatal accident rates in all site categories. Number of lanes was observed to show a negative relation with all accident rate models. This indicates that increasing number of lanes leads to decrease total, dry, wet, slight and serious and fatal accident rates for the majority of roadway segments.

Table 6-16: The effect of number of lanes on total, dry, wet, slight and serious and fatal accident rates using RPT model for 3C site categories

Site category	TAR		DAR		WAR		SLAR		SFAR	
	NL effect	Positive effect (%)	NL effect	Positive effect (%)	NL effect	Positive effect (%)	NL effect	Positive effect (%)	NL effect	Positive effect (%)
NT	↓	0 (F)	↓	0 (F)	↓	0 (F)	↓	0 (F)	↓	0 (F)
NE	↓	0 (F)	↓	0 (F)	↓	0 (F)	↓	0 (F)	↓	34 (R)
B1	↓	5 (R)	↓	0 (F)	↓	4 (R)	↓	16 (R)	↓	5 (R)
B2	↓	38 (R)	↓	7 (R)	↓	2 (R)	↓	0 (F)	↓	3 (R)
RA	↓	2 (R)	↓	11 (R)	↓	0 (F)	↓	3 (R)	↓	17 (R)
JN	↓	0 (F)	↓	0 (F)	↓	0 (F)	↓	0 (F)	↓	0 (F)
GR	↓	32	↓	37 (R)	↓	3 (R)	↓	21	↓	0 (F)

- Number of minor access

Table 6-17 provides an overview of the effect of number of minor access on total, dry, wet, slight and serious and fatal accident rates in all site categories. From the data in Table 6-17, it was found that number of minor access is positively associated with the rate of total, dry, wet, slight and serious and fatal accidents. The effect of number of minor access was found to be fixed across roadway segments for all site categories. This indicates that increasing number of minor access leads to increase total, dry, wet, slight and serious and fatal accident rates at all site categories.

Table 6-17: The effect of number of minor access on total, dry, wet, slight and serious and fatal accident rates using RPT model for 3C site categories

Site category	TAR		DAR		WAR		SLAR		SFAR	
	NMA effect	Positive effect (%)	NMA effect	Positive effect (%)	NMA effect	Positive effect (%)	NMA effect	Positive effect (%)	NMA effect	Positive effect (%)
NT	↑	100 (F)	↑	100 (F)	↑	100 (F)	↑	100 (F)	↑	100 (F)
NE	↑	100 (F)	↑	100 (F)	↑	100 (F)	↑	100 (F)	↑	100 (F)
B1	↑	100 (F)	↑	100 (F)	↑	100 (F)	↑	100 (F)	↑	100 (F)
B2	↑	100 (F)	↑	100 (F)	↑	100 (F)	↑	100 (F)	↑	100 (F)
RA	↑	100 (F)	↑	100 (F)	↑	100 (F)	↑	100 (F)	↑	100 (F)
JN	↑	100 (F)	↑	100 (F)	↑	100 (F)	↑	100 (F)	↑	100 (F)
GR	↑	100 (F)	↑	100 (F)	↑	100 (F)	↑	100 (F)	↑	100 (F)

6.3.3 Pavement characteristics

- Skid resistance

Table 6-18 provides an overview of the effect of skid resistance on total, dry, wet, slight and serious and fatal accident rates at all site categories. From the data in Table 6-18, it is apparent that all accident rates were negatively associated with skid resistance. This indicates that the majority of roadway segments at all site categories have lower total, dry, wet, slight and serious and fatal accident rates when roadway segments have higher skid resistance values.

Table 6-18: The effect of skid resistance on total, dry, wet, slight and serious and fatal accident rates using RPT model for 3C site categories

Site category	TAR		DAR		WAR		SLAR		SFAR	
	SR effect	Positive effect (%)	SR effect	Positive effect (%)	SR effect	Positive effect (%)	SR effect	Positive effect (%)	SR effect	Positive effect (%)
NT	↓	9 (R)	↓	0 (F)	↓	0 (F)	↓	0 (F)	↓	1 (R)
NE	↓	0 (F)	↓	0 (F)	↓	0 (F)	↓	0 (F)	↓	0 (F)
B1	↓	11 (R)	↓	0 (F)	↓	0 (F)	↓	1 (R)	↓	0 (F)
B2	↓	0 (F)	↓	1 (R)	↓	12 (R)	↓	0 (F)	↓	47 (R)
RA	↓	9 (R)	↓	0 (F)	↓	0 (F)	↓	4 (R)	↓	1 (R)
JN	↓	19 (R)	↓	0 (F)	↓	2 (R)	↓	41 (R)	↓	40 (R)
GR	↓	1 (R)	↓	4 (R)	↓	12 (R)	↓	0 (F)	↓	1 (R)

- Rut depth

Table 6-19 provides an overview of the effect of rut depth on total, dry, wet, slight and serious and fatal accident rates at all site categories. Based on the results from Table 6-19, it can be concluded that rut depth has a mixed effect on accident rates. Increased rut depth has a positive correlation with total, wet, slight and serious and fatal accident rates all site categories. On the other hand, it however has a negative correlation with dry accident rates at all site categories.

Table 6-19: The effect of rut depth on total, dry, wet, slight and serious and fatal accident rates using RPT model for 3C site categories

Site category	TAR		DAR		WAR		SLAR		SFAR	
	RD effect	Positive effect (%)	RD effect	Positive effect (%)	RD effect	Positive effect (%)	RD effect	Positive effect (%)	RD effect	Positive effect (%)
NT	↑	100 (F)	↓	27 (R)	↑	42 (R)	↑	100 (F)	↑	49 (R)
NE	↑	24 (R)	↓	0 (F)	↑	39 (R)	↑	12 (R)	↑	24 (R)
B1	↑	100 (F)	↓	0 (F)	↑	35 (R)	↑	47 (R)	↑	45 (R)
B2	↑	38 (R)	↓	17 (R)	↑	100 (F)	↑	100 (F)	↑	34 (R)
RA	↑	32 (R)	↓	48 (R)	↑	100 (F)	↑	25 (R)	↑	29 (R)
JN	↑	100 (F)	↓	0 (F)	↑	100 (F)	↑	48 (R)	↑	42 (R)
GR	↑	100 (F)	↓	38 (R)	↑	32 (R)	↑	44 (R)	↑	8 (R)

- Texture depth

Table 6-20 provides an overview of the effect of texture depth on total, dry, wet, slight and serious and fatal accident rates at all site categories. The results, as shown in Table 1, indicate that roadway segments with high texture depth values tended to experience less total, dry, wet, slight and serious and fatal accident rates. This practically true for the majority of roadway segments at all site categories.

Table 6-20: The effect of texture depth on total, dry, wet, slight and serious and fatal accident rates using RPT model for 3C site categories

Site category	TAR		DAR		WAR		SLAR		SFAR	
	TX effect	Positive effect (%)	TX effect	Positive effect (%)	TX effect	Positive effect (%)	TX effect	Positive effect (%)	TX effect	Positive effect (%)
NT	↓	1 (R)	↓	0 (F)	↓	12 (R)	↓	35 (R)	↓	23 (R)
NE	↓	0 (F)	↓	17 (R)	↓	9 (R)	↓	0 (F)	↓	22 (R)
B1	↓	11(R)	↓	0 (F)	↓	38 (R)	↓	8 (R)	↓	50 (R)
B2	↓	38 (R)	↓	0 (F)	↓	27 (R)	↓	21 (R)	↓	29 (R)
RA	↓	0 (F)	↓	1 (R)	↓	0 (F)	↓	9 (R)	↓	0 (F)
JN	↓	0 (F)	↓	0 (F)	↓	37 (R)	↓	41 (R)	↓	10 (R)
GR	↓	49 (R)	↓	3 (R)	↓	1 (R)	↓	1 (R)	↓	0 (F)

CHAPTER SEVEN

DISSCUSION THE RESULTS OF

FREQUENCY AND RATE MODELS

CHAPTER SEVEN: DISSCUSION THE RESULTS OF FREQUENCY AND RATE MODELS

7.1 Overview

This thesis discovers the relationship between traffic (Ln AADF, heavy vehicles percentage and speed limit), geometric (radius of curvature, gradient, number of lanes and number of minor access) and pavement characteristics (skid resistance, rut depth and texture depth); and road accidents at NT, NE, B1, B2, RA, JN and GR site categories. This has been achieved by examining the effects of traffic, geometric, and pavement characterises on accident frequency; and on accident rate. The main aim of this chapter was to compare the effect of traffic, geometric and pavement characteristics on both accidents frequency (the results obtained from Chapter 5 using RPNB model) and rate (the results obtained from Chapter 6 using RPT model). This is for more understanding if the results obtained from frequency models are maybe different with these which are obtained from rate models.

7.2 Traffic characteristics

7.2.1 Ln AADF

- Frequency models

Regarding the parameter estimations of traffic characteristics, Ln AADF was an important independent variable in accident frequency model estimations. The coefficient of Ln AADT was significantly affected in all RPNB models, at the 99% confidence level. The coefficient of Ln AADT was a fixed parameter, regardless of the differences in model types and site categories. The findings indicated that increasing Ln AADF on roadway segments, positively contributed to the frequency of total, dry, wet, slight and serious and fatal accidents, in all site categories. These were expected results, seeing that increasing Ln AADF led to the higher likelihood of movement conflicts between vehicles. These findings were consistent with several previous studies (Poch and Mannering, 1996; Abdel-Aty and Radwan, 2000; Chin and Quddus, 2003).

The elasticity effects of Ln AADF on total, dry, wet, slight and serious and fatal accident frequencies, in different site categories are presented in Figure 7-1. The estimated elasticity effects of Ln AADF were consistent for all types of accident, but it varied in the magnitude of elasticity effects. This figure compared the changes in accident frequencies, due to a 1% increase in Ln AADF.

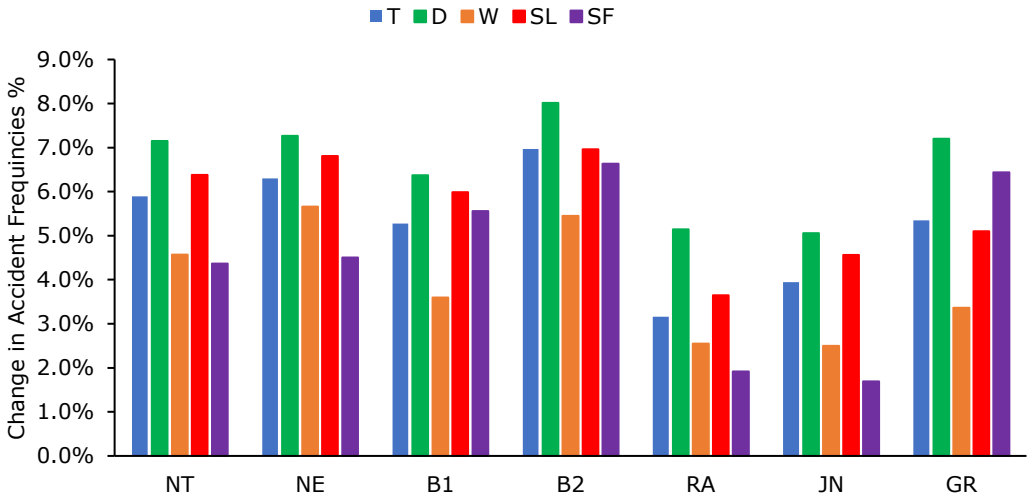


Figure 7-1: Estimated elasticity effects of a 1% increase in Ln AADF on total, dry, wet, slight and serious and fatal accident frequencies across NT level and all site categories in 3C network

- Rate models

The coefficient of Ln AADT resulted as a fixed parameter regardless of the differences in accident rate types and site categories. The findings indicate that increasing Ln AADF on roadway segments contribute positively to the rate of total, dry, wet, slight and serious and fatal accidents in all site categories. These results support the idea that increasing Ln AADF at roadway segments leads to increase the prospective conflicts among vehicles (Milton and Mannering, 1998), therefore; it increases the likelihood of accidents occurrence. These findings are consistent with a wide range of previous studies (Abdel-Aty and Haleem, 2011; Das and Abdel-Aty, 2011). The elasticity effects of Ln AADF on total, dry, wet, slight and serious and fatal accident rates in different site categories is presented in Figure 7-2. The estimated elasticity effects of Ln AADF were consistent for all types of accident, but it was varying in the

magnitude of the elasticity effects. This figure compared the change in accidents rate due to 1% increase in Ln AADF.

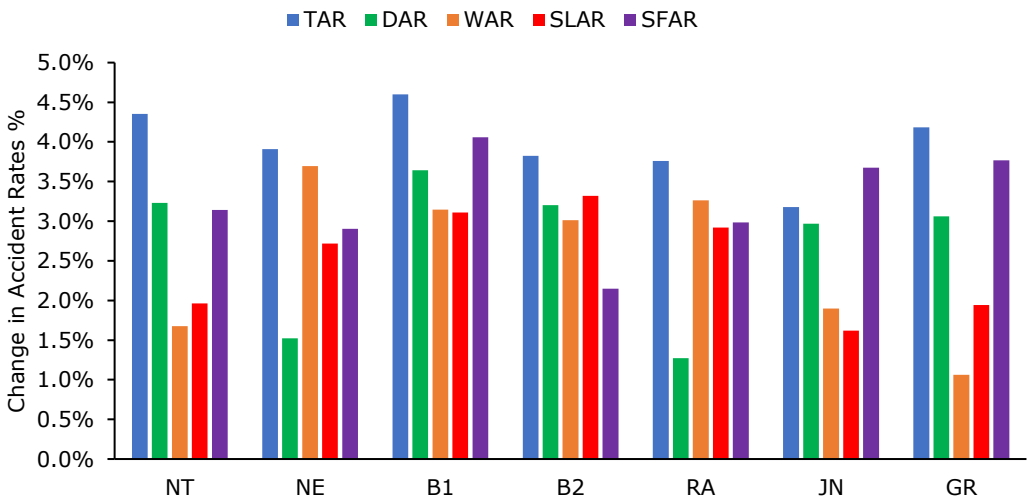


Figure 7-2: Estimated elasticity effects of a 1% increase in Ln AADF on total, dry, wet, slight and serious and fatal accident rates across NT level and all site categories in 3C network

7.2.2 Heavy vehicles percentage

- Frequency models

Despite the lower heavy vehicles percentage in traffic flows, prior study noted the significant effects of heavy vehicles percentage on traffic safety, because of physical (length and size) effects and operation (acceleration/deceleration) characteristics (Moridpour *et al.*, 2015). In general, the roadway segments with high heavy vehicles percentage was associated with higher frequency of total, dry, wet, slight and serious and fatal accidents. This finding was also reported by Dong *et al.*, (2015) who found that heavy vehicles percentage was positive and statistically significant with accident frequencies. The finding of the RPNB models for this variable, supports the idea that increasing heavy vehicles percentage in traffic streams increased the number of lanes changing manoeuvres (overtaking) by other vehicles, which led to the increased likelihood of accidents, especially from opposite direction traffic. The majority of roadway segments in this study were two-lane two-way undivided roadways;

therefore, this finding is intuitively reasonable. This finding is also consistent with (Zheng *et al.*, 2013), these authors observed that increasing heavy vehicles percentage from 2% to 4%, increased lane changes for other vehicles by 32% on a 610 m long section, over a 45-minute period. As shown in Figure 7-3, it was interesting to note that in B1, B2 and GR site categories, more accidents (especially for serious and fatal accident frequencies) are expected when there was a high heavy vehicles percentage in the traffic stream. Travelling along sharp curves and steep downgrade roadways forced heavy vehicles to use continuous braking, reducing braking system capability by over-heating (Ahmed *et al.*, 2012). It is possible to hypothesise that these conditions increased the likelihood of accident occurrence. In addition, heavy vehicle involvement in traffic accidents increased the level of accident severity, due to their size and weight. Qin *et al.*, (2013) showed that accidents involving heavy vehicles were generally more severe. The elasticity effects showed that increasing heavy vehicles percentage by 10% led to increased SF accident frequencies at GR site category by 11.96%.

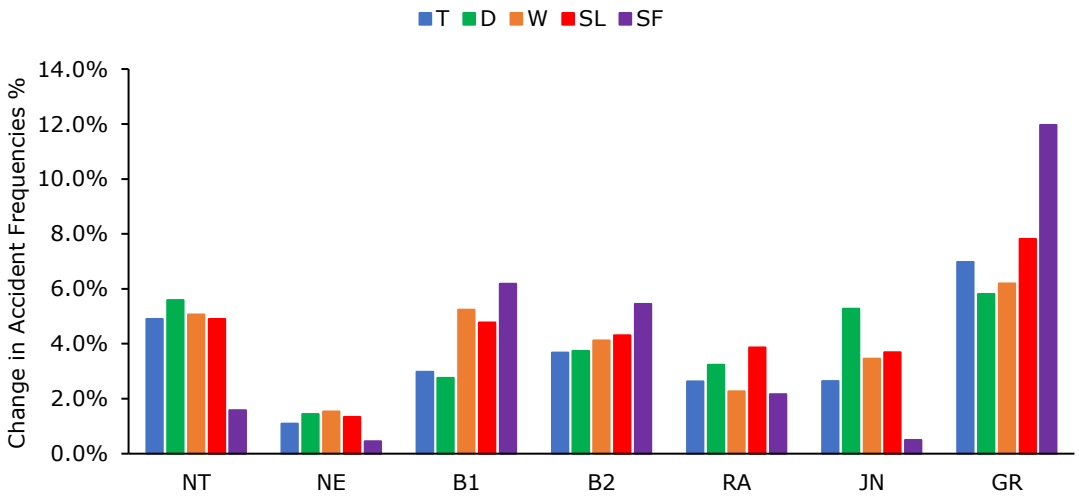


Figure 7-3: Estimated elasticity effects of a 10% increase in heavy vehicles percentage on total, dry, wet, slight and serious and fatal accident frequencies across NT level and all site categories in 3C network

- Rate models

Heavy vehicles percentage was negatively associated with total, dry, wet, slight and serious and fatal accident rates for NT and NE site categories. The outcome of RPT models for NT and NE site categories supported the idea that the number of other vehicle types (passenger vehicles) that will change lane and overtake is reduced in traffic streams with higher numbers of heavy vehicles, leading to lower accident rates (Miaou, 1994; Milton and Mannering; 1998; Anastasopoulos *et al.,* 2008, 2012). However, the heavy vehicles percentage was observed to be positively associated with total, dry, wet, slight and serious and fatal accident rates for other site categories. This result may be explained by the fact that increasing heavy vehicles percentage, effects other driver behaviour, increasing lane changing and overtaking (Dong *et al.*, 2015). Figure 7-4 provides an overview of the elasticity effects of heavy vehicles percentage on the rate of accident types in all site categories.

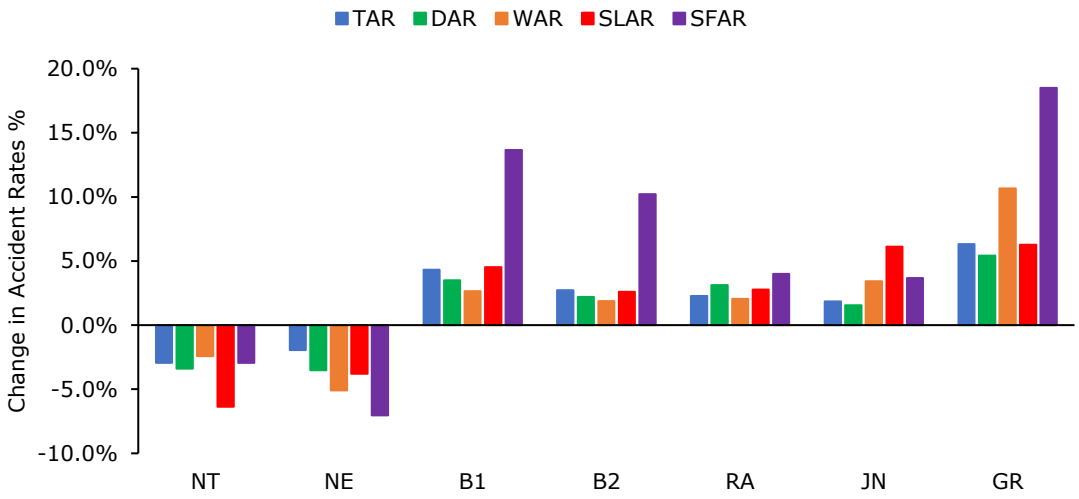


Figure 7-4: Estimated elasticity effects of a 10% increase in heavy vehicles percentage on total, dry, wet, slight and serious and fatal accident rates across NT level and all site categories in 3C network

7.2.3 Speed limit

- Frequency models

In terms of RPNB model estimation results for traffic characteristics, the majority of roadway segments with higher speed limit, had fewer total, dry, wet, slight and serious and fatal accident frequencies, for all site category models. This finding was

reported by Hosseinpour *et al.* (2014) who found that speed limit was negatively associated with accident frequencies. In addition, this finding was consistent with Liu *et al.* (2018) who found that roadway segments with an speed limit of 45 mph had fewer accidents than those with an speed limit of 30 and 35 mph. Some authors have claimed that for higher speed limit the roadway segments are usually well-planned, constructed, and managed (Milton and Mannering, 1998; Zeng *et al.*, 2016), thus, the highway safety performances improves due to these features. In general, caution should be derived from the relationship between speed limits and accident frequencies. Increase speed limit should not be considered by highway agencies as a recommended policy to improve safety on A road networks. The results of elasticity effects of speed limit on aggregate traffic accident frequencies is summarised in Figure 7-5. This figure shows a significant reduction in accident frequencies for all site categories, due to a 10% increase in speed limit.

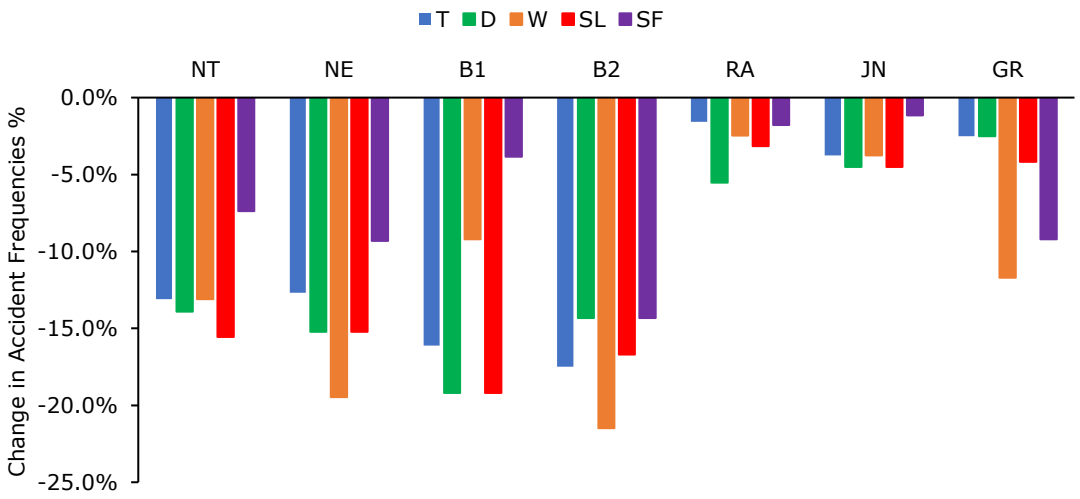


Figure 7-5: Estimated elasticity effects of a 10% increase in speed limit on total, dry, wet, slight and serious and fatal accident frequencies across NT level and all site categories in 3C network

- Rate models

With regard to traffic characteristics, speed limit was considered one of the important factors for traffic safety; the parameter ranged from 32 kph to 118 kph for the roadway segments. Speed limit was negatively related to the aggregate accident rate

in all site categories. It was important to note that speed limit was different from the average travel speed. The RPT result indicated that increasing speed limit for the majority of all site categories, contributed negatively to the rate of total, dry, wet, slight and serious and fatal accidents. This finding was highlighted by several previous studies (Milton and Mannering, 1998; Donnell *et al.* , 2010; Lao *et al.*, 2014; Li *et al.*, 2015). There are several possible explanations for this result. Firstly, highway agencies fix a lower speed limit to roadway segments with high accident rates as a safety policy to reduce the likelihood of accidents. Secondly, roads with higher speed limit are considered safer designs. However, these results would not encourage highway agencies to increase speed limit, to reduce accident rates on A-road networks in the UK. The elasticity effects of speed limit on total, dry, wet, slight and serious and fatal accident rates in different site categories is presented in Figure 7-6. The estimated elasticity effects of speed limit were consistent for all types of accident, but it varied in magnitude in terms of elasticity effects. This figure compared the changes in accident rates due to a 10% increase in speed limit.

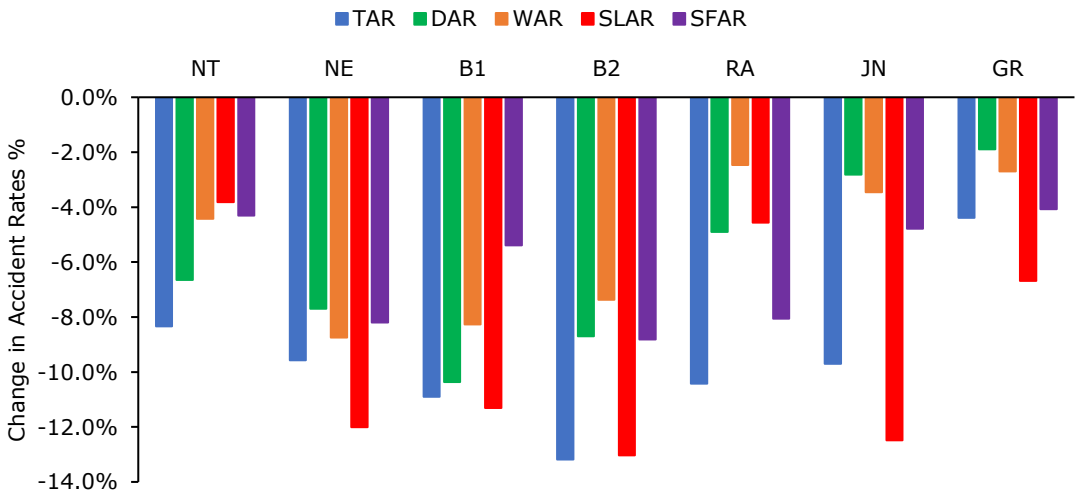


Figure 7-6: Estimated elasticity effects of a 10% increase in speed limit on total, dry, wet, slight and serious and fatal accident rates across NT level and all site categories in 3C network

7.3 Geometric characteristics

7.3.1 Radius of curvature

- Frequency models

A wider horizontal curve radius provides a smoother transition between tangent sections and reduces the centrifugal forces on vehicles negotiating curves, thereby reducing the likelihood of accidents. The negative coefficient on RPNB of all models corresponding to radius of curvature for roadway segments, indicated that roadway segments with higher radius of curvature were associated with lower frequencies of total, dry, wet, slight and serious and fatal accidents, in all site categories. Accident frequency increased significantly as the curve radius decreased, which is consistent with several previous studies (Glennon, 1987; Zegeer *et al.*, 1990, 1991). Figure 7-7 shows the results from the elasticity effects of radius of curvature on total, dry, wet, slight and serious and fatal accident frequencies, in all site categories.

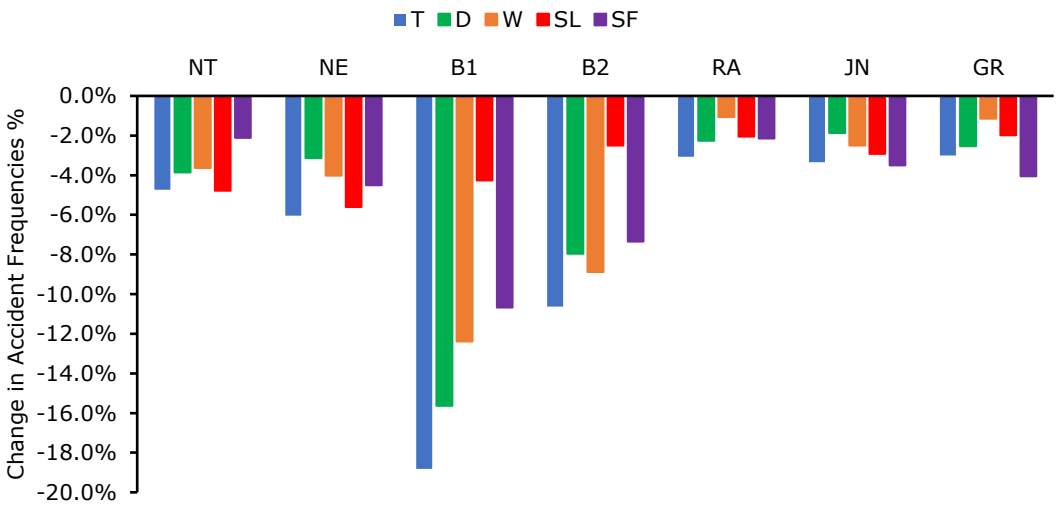


Figure 7-7: Estimated elasticity effects of a 10% increase in radius of curvature on total, dry, wet, slight and serious and fatal accident frequencies across NT level and all site categories in 3C network

- Rate models

Previous studies noted that sharp bend roadway segments experienced more accident rates than on milder roadway segments (Aram, 2010; Vayalamkuzhi and Amirthalingam, 2016). The RPT results suggested that roadway segments with higher

radius of curvature experienced fewer accident rates, which was consistent with expectation. Roadway segments with high radius of curvature provided smoother transitions between tangent sections and reduced the centrifugal force on vehicles negotiating the curve. According to data from the RPT outcomes, there was an obvious decrease in accident rates, in the majority of roadway segments at all site categories, due to increasing radius of curvature. However, for a small percentage of roadway segments, the opposite was true. Figure 7-8 compares the changes in all accidents rates, at different site categories, due to a 10% increase in radius of curvature. As expected, the most effective radius of curvature increases on total, dry, wet, slight and serious and fatal accident rates, in all site categories, was recorded at the B1 and B2 site categories.

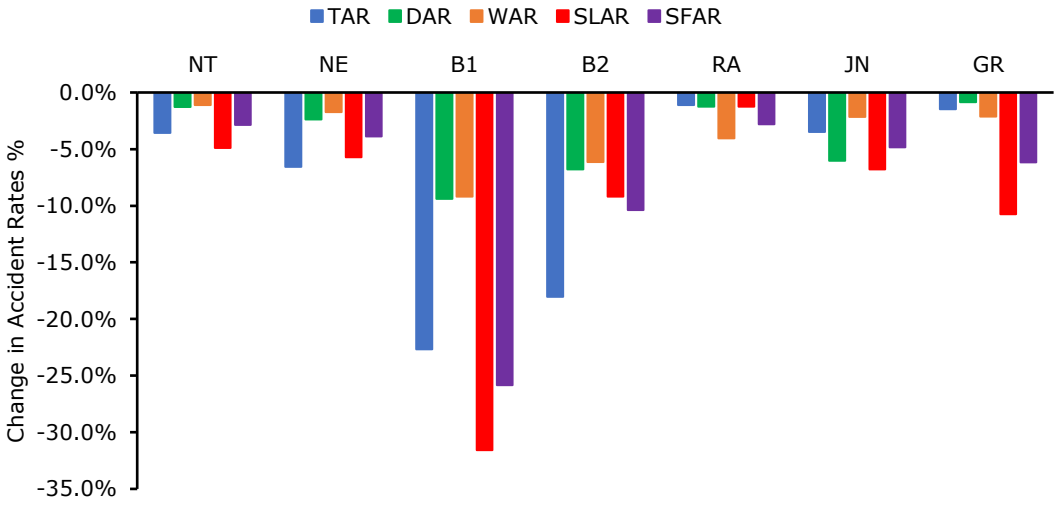


Figure 7-8: Estimated elasticity effects of a 10% increase in radius of curvature on total, dry, wet, slight and serious and fatal accident rates across NT level and all site categories in 3C network

7.3.2 Gradient

- Frequency models

Generally, the trends in RPNB models show that gradient for roadway segments was correlated positively with accident frequencies. This finding supports evidence from previous studies (Shankar *et al.*, 1995; Chang and Chen, 2005). In Figure 7-9, an increasing trend was observed for all types of accident frequency at GR site categories

(gradient > 5%), due to a 10% increase in gradient. This finding was supported by other studies, for example, Ahmed *et al.* (2012) reported a roadway segment with a gradient of 6–8% was more hazardous, when compared to 4–6% and 2–4% gradients. Similarly, Yu et al., (2015) concluded that the presence of a steep grade slope, increased accident frequencies. This result may be explained by the fact that continuous braking up and down roads is likely to increase temperatures on brake pads, which may significantly effects on the efficiency of vehicle brakes and increase the likelihood of accidents (Rusli *et al.*, 2017). Regarding the elasticity effects of gradient on accident frequencies, Figure 7-9, illustrates increases in accident frequency were due to a 10% increase in the gradient of a roadway segment.

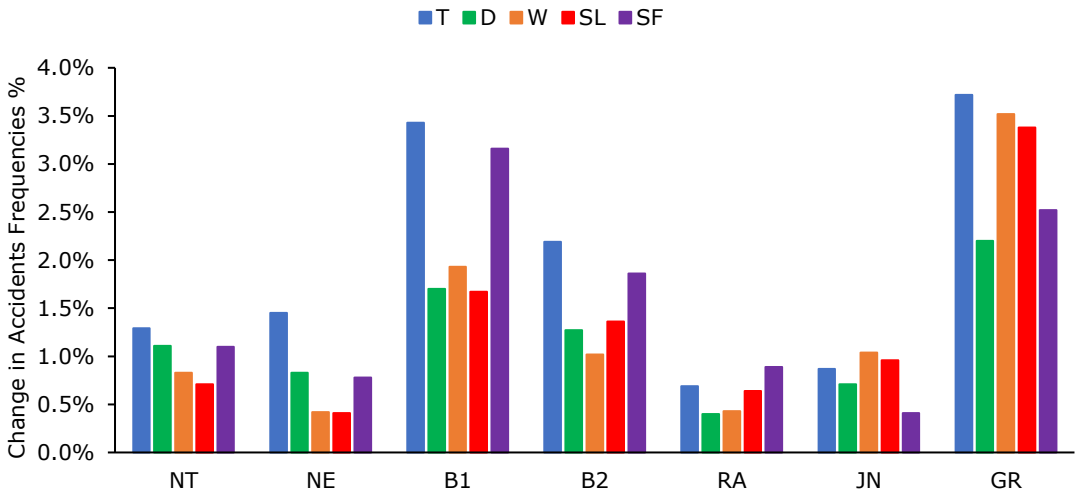


Figure 7-9: Estimated elasticity effects of a 10% increase in gradient on total, dry, wet, slight and serious and fatal accident frequencies across NT level and all site categories in 3C network

- Rate models

The outcome of the RPT model for all site categories indicated a positive relationship between all accident rates and the gradient of roadway segments in all site categories. This finding was consistent with previous studies (Shankar *et al.,* 1995; Chang and Chen, 2005) who argued that steep grades may increase the likelihood of accidents.

Figure 6-33 compares the changes in all accident rates at different site categories due to a 10% increase in gradient. As seen in Figure 7-10 for all accident rates, a

10% increase in the gradient was most effective at the GR site category, practically for serious and fatal accident rates. These results were consistent with the finding of Fu *et al.*, (2011), who concluded that accident rates increased exponentially, with the gradient of roadway segments.

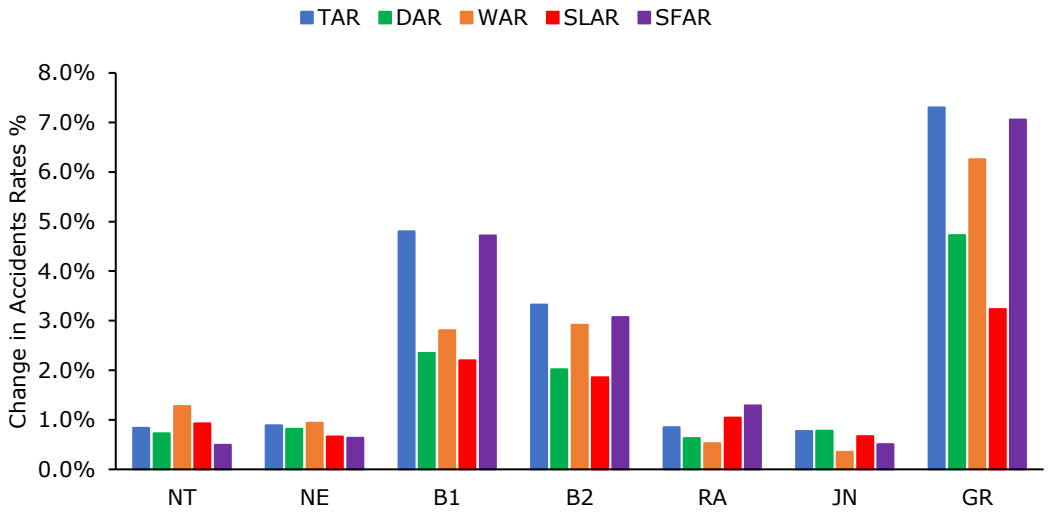


Figure 7-10: Estimated elasticity effects of a 10% increase in gradient on total, dry, wet, slight and serious and fatal accident rates across NT level and all site categories in 3C network

7.3.3 Number of lanes

- Frequency models

The RPNB model result indicated that increasing number of lanes for the majority of roadway segments decreased all accident types, for all site categories. These results were consistent with a previous study by Ma and Kockelman (2006). These authors found that increasing the number of lanes led to decreased accident frequencies. In addition, Park *et al.* (2010) found that four-lane freeways experienced higher accident occurrences, when compared with six lane freeways. This relationship may be explained by the fact that wider roads allow drivers to make more manoeuvres, avoiding contact between vehicles. Figure 7-11 represents the results obtained from the elasticity effects of number of lanes on aggregate accident frequencies, in all site categories. From this figure, the greatest reduction in accident frequencies was due to a 100% increase in number of lanes, from the GR site category. Increasing the number of lanes on GR site categories may support the hypothesis that minimising

the effects of slower moving vehicles, especially heavy vehicles on downgrade segments, can be provided by improving overtaking opportunities. Milton and Mannering (1998) found that for significantly long grades, heavy vehicles often slow to 15 km/hr, this reduction in speed is associated with increased numbers of passing vehicles. Thus, it will potentially increase conflicts between passing vehicles and vehicles travelling in the opposite direction.

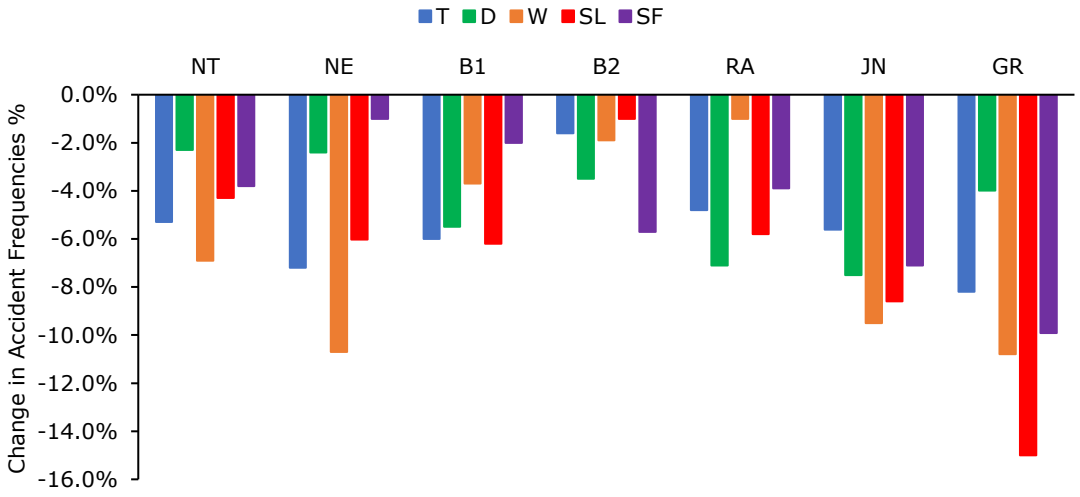


Figure 7-11: Estimated elasticity effects of a 100% increase in number of lanes on total, dry, wet, slight and serious and fatal accident frequencies across NT level and all site categories in 3C network

- Rate models

With regard to number of lanes, from the RPT models for all site categories, a significant negative relationship was determined between number of lanes and total, dry, wet, slight and serious and fatal accident rates in all models. These results were consistent with a previous study by Ma and Kockelman (2006) who found that increasing lane numbers led to decreased accident rates. In addition, Park *et al.* (2010) found that four-lane freeways had higher accidents when compared with six lanes. This relationship may be explained as, in wider roads, drivers can make more manoeuvres thereby avoiding vehicle conflict. Figure 7-12 represents the results from the elasticity effects of number of lanes on total, dry, wet, slight and serious and fatal accident rates, in all site categories.

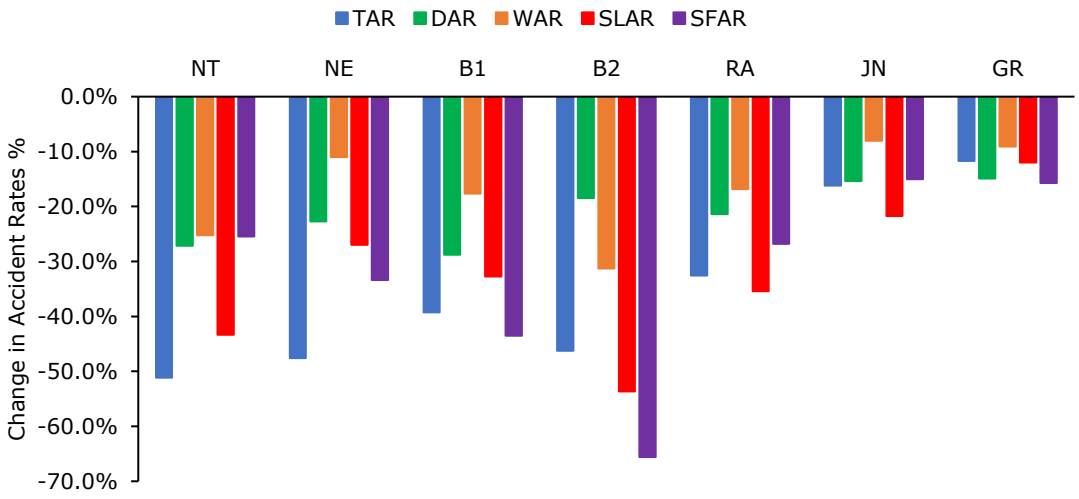


Figure 7-12: Estimated elasticity effects of a 100% increase in number of lanes on total, dry, wet, slight and serious and fatal accident rates across NT level and all site categories in 3C network

7.3.4 Number of minor access

- Frequency models

The geometric characteristics of number of minor access, which refer to the number of minor accesses in roadway segments, was found to be a fixed significant parameter in all RPNB models, with a positive sign. This meant increased number of minor access on roadway segments consistently demonstrated increased total, dry, wet, slight and serious and fatal accident frequencies, in all site categories. These finding were consistent with data obtained by Baek and Hummer (2008) ; Ackaah and Salifu (2011). These studies concluded that higher number of minor access in roadway segments, led to more accidents, due to conflicts between vehicles travelling in major direction and vehicles travelling from minor directions. The elasticity effects of number of minor access on total, dry, wet, slight and serious and fatal accident frequencies at different site categories are presented in Figure 7-13. This figure compared the changes in accident frequencies from to a 100% increase in number of minor access.

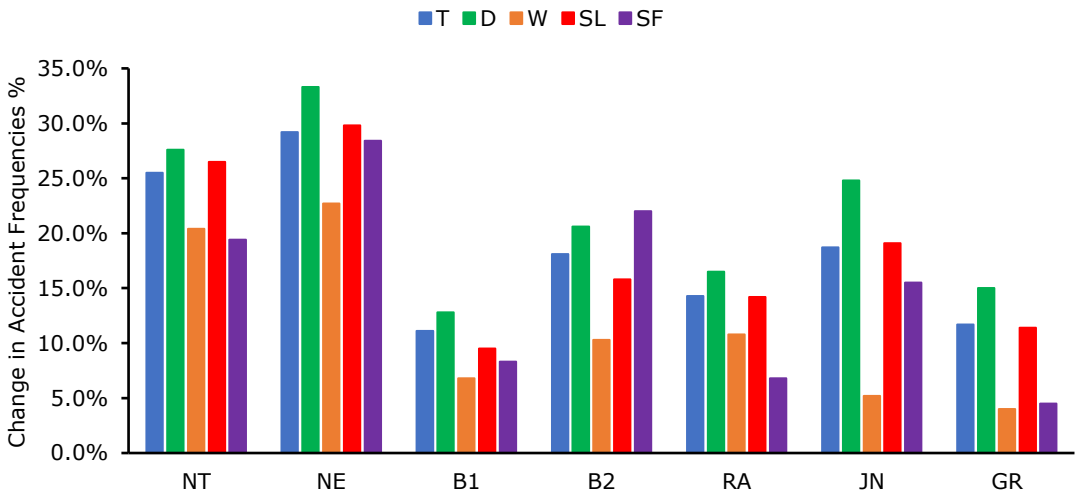


Figure 7-13: Estimated elasticity effects of a 100% increase in number of minor access on total, dry, wet, slight and serious and fatal accident frequencies across NT level and all site categories in 3C network

- Rate models

The effect of number of minor access in each roadway segment was fixed random and positively correlated with aggregate accident rates, in all site categories. This indicated that roadway segments with higher number of minor access were likely to experience more accident rates, when compared with roadway segments with lower number of minor access. This finding was consistent with findings from previous studies (Peng, 2004; Eisele and Frawley, 2005). This finding may be explained by the fact that roadway segments, with high number of minor access, attract greater traffic volumes, increasing the conflict between vehicles, in major and minor directions. Figure 7-14 represents the results from the elasticity effects of number of minor access on total, dry, wet, slight and serious and fatal accident rates, in all site categories.

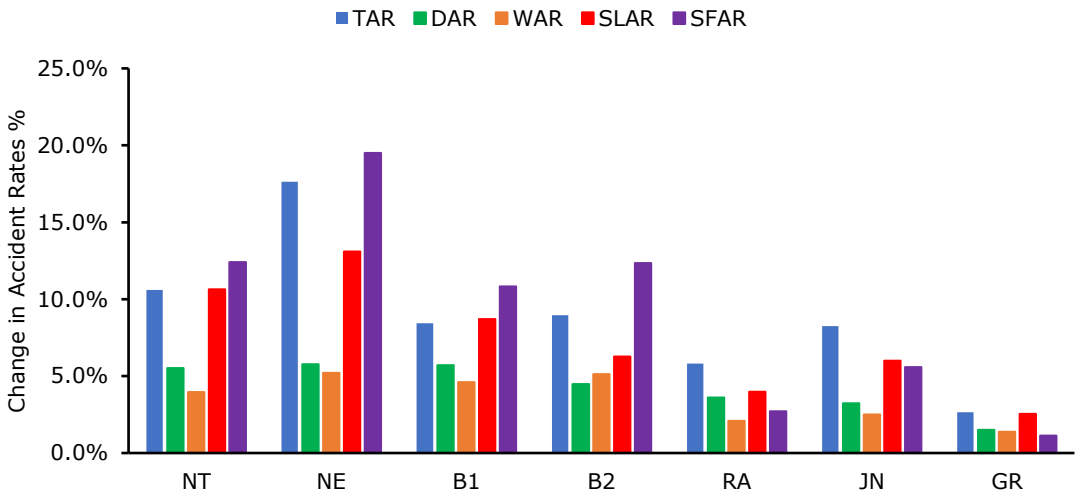


Figure 7-14: Estimated elasticity effects of a 100% increase in number of minor access on total, dry, wet, slight and serious and fatal accident rates across NT level and all site categories in 3C network

7.4 Pavement characteristics

7.4.1 Skid resistance

- Frequency models

The effects of skid resistance were observed to be significantly variable on the frequency of all type of accidents. Increasing skid resistance coefficients were found to be beneficial to safety, by decreasing the frequency of total, dry, wet, slight and serious and fatal accidents in the majority of roadway segments, for all site categories. These results appeared to be consistent with other studies, that found that skid resistance was a significant parameter that could include in the accident models (Abdel-Aty *et al.*, 2009; Anastasopoulos and Mannering, 2009; Hou *et al.*, 2018). Figure 7-15 compares the average elasticity effects of skid resistance on the expected total, dry, wet, slight and serious and fatal accident frequencies, for all site categories. As expected in all site categories, the significant reduction in all types of accident was due to increases in skid resistance was obtained for wet accidents frequency. Previous research has concluded significant negative correlations between skid resistance values and wet accidents (Xiao, *et al.*, 2000; Mayora and Piña, 2009).

From Figure 7-15, depicting W accidents, a 10 % increase in skid resistance appeared to be more obvious at B1 and B2 site categories. This indicated a significant negative correlation between skid resistance and curve roadway segments, suggesting that increasing skid resistance on bend roadway segments decreased the frequency of total, dry, wet, slight and serious and fatal accidents. The observed correlation between skid resistance and curve roadway segments may be explained whereby, a large skid resistance helps drivers cross curves safely, especially for sharp curves (Hou *et al.*, 2018).

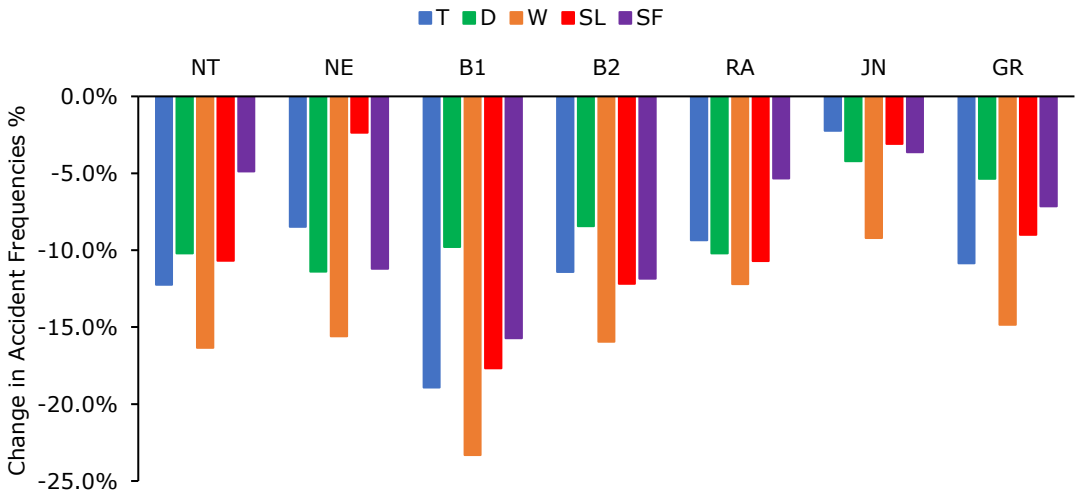


Figure 7-15: Estimated elasticity effects of a 10% increase in skid resistance on total, dry, wet, slight and serious and fatal accident frequencies across NT level and all site categories in 3C network

- Rate models

The effect of skid resistance was a significant variable on the rate of total, dry, wet, slight and serious and fatal accidents, in all site categories. Regarding RPT outcomes, skid resistance was a random parameter for all accident types, in all site categories. The results indicated that increasing skid resistance in the majority of all site category roadway segments, contributed negatively to the rates of total, dry, wet, slight and serious and fatal accidents. This result was expected and may be explained by the fact that roadway segments with higher skid resistance, contributed significantly to accident prevention when drivers used their brakes, particularly on wet surfaces.

Previous studies, evaluating the effects of skid resistance on wet accident rates, showed strong negative relationships between skid resistance and wet accident rates (Kuttesch, 2004; Najafi *et al.*, 2017). However, few studies have evaluated the effects of skid resistance on other accident rate types. It was interesting to note that for all site categories, an improvement of skid resistance resulted in significant reductions in all accident rates. Figure 7-16 compares the changes in all accident rates at different site categories, due to a 10% increase in skid resistance. As expected, such an increase appeared to be more effective for wet accident rates, in the majority of site categories. From Figure 7-16, the greatest reduction in all accident rate types was due to a 10% increase in skid resistance, for the B1 site category. This finding confirmed that skid resistance was negatively associated with all accident rates, at sharp bends. This finding was reported by Hall *et al.,* (2009), who showed that roadway segments, with small curvature radius, required high skid resistance levels to help drivers safely navigate sharp curves, by overcoming centrifugal forces that developed during through the sharp curve.

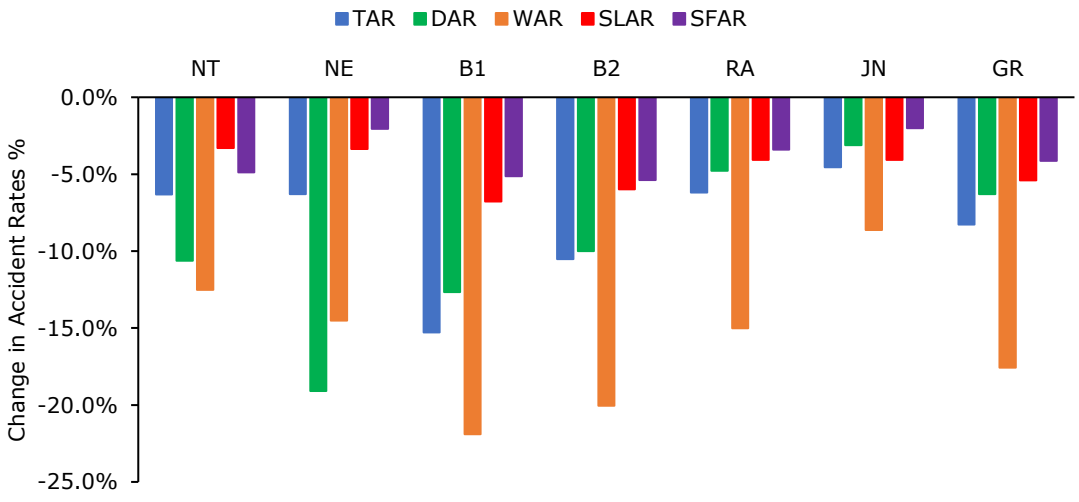


Figure 7-16: Estimated elasticity effects of a 10% increase in skid resistance on total, dry, wet, slight and serious and fatal accident rates across NT level and all site categories in 3C network

7.4.2 Rut depth

- Frequency models

The results of RPNB models for all types of accidents, confirmed that roadway segments with high frequency accidents were associated with high rut depth. From Figure 7-17, it was interesting to note that in all site categories, the most obvious effects of rut depth were observed for wet accident frequencies. This result was in agreement with Anastasopoulos, and Mannering, (2009) who argued that roadway segments with high rut depth increased the chances of hydroplaning when moisture was present and could therefore contribute to vehicle tracking and loss of control, during lane changes and manoeuvring. Regarding the elasticity effects of rut depth on accident frequencies, Figure 7-17 shows the change in total, dry, wet, slight and serious and fatal accident frequencies, due to a 10% increase in rut depth of roadway segments.

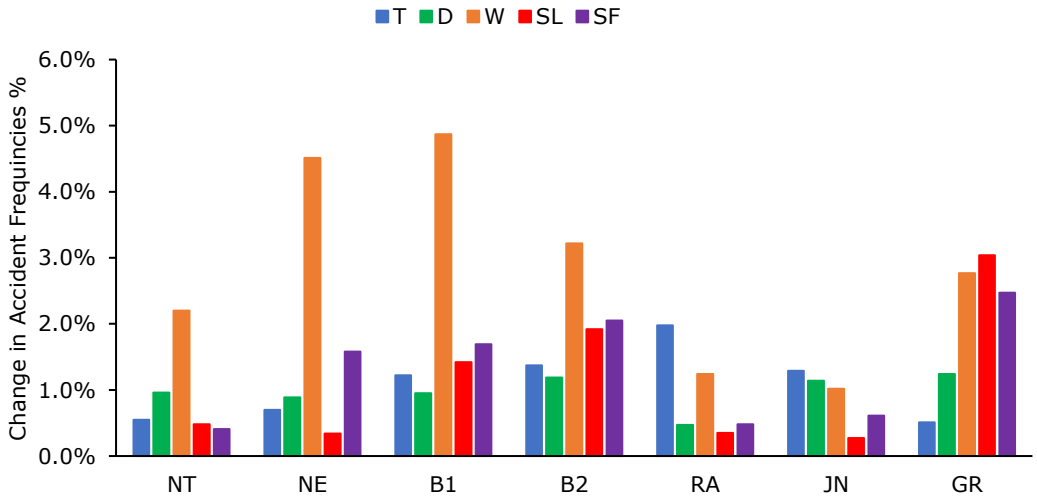


Figure 7-17: Estimated elasticity effects of a 10% increase in rut depth on total, dry, wet, slight and serious and fatal accidents frequency across NT level and all site categories in 3C network

- Rate models

The results of the RPT model confirmed that roadway segments, with high rut depth, were associated with high accident rates, except for dry accident rates. However, rut depth was negatively related to dry accident rates, in all site categories. A possible

explanation for this could be that rut depth is more obvious during normal weather. Thus, drivers can control their vehicles to safely manoeuvre through the rutted zones (Chan *et al.*, 2009). However, as shown in Figure 7-18, rut depth was correlated positively with total, wet, slight and serious and fatal accident rates, in all site categories. This result agreed with Anastasopoulos and Mannering, (2009) who argued that roadway segments with high rut depth, increased the chances of hydroplaning when moisture was present and could therefore contribute to vehicle tracking and loss of control during lane changes and manoeuvring. Figure 7-18 shows the change in total, dry, wet, slight and serious and fatal accident rates, due to a 10% increase in rut depth of roadway segments.

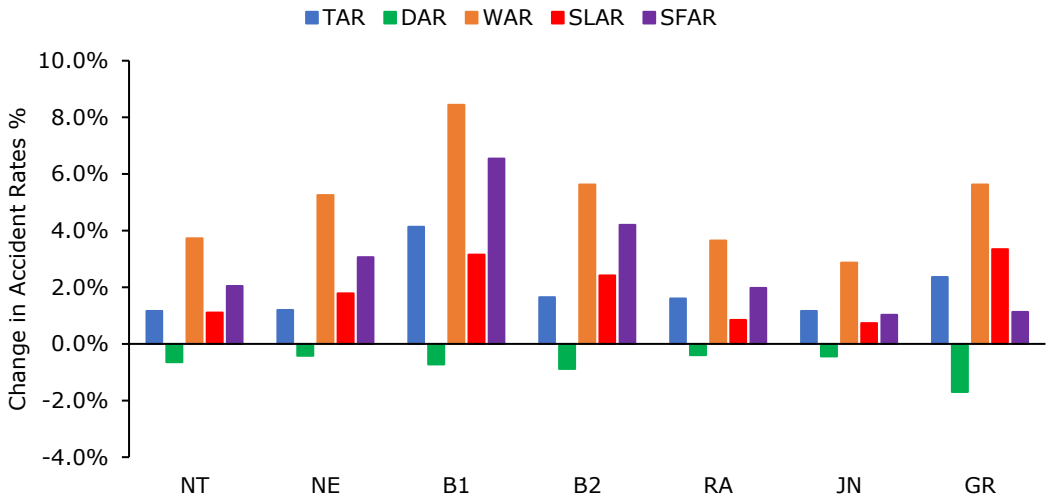


Figure 7-18: Estimated elasticity effects of a 10% increase in rut depth on total, dry, wet, slight and serious and fatal accident rates across NT level and all site categories in 3C network

7.4.3 Texture depth

- Frequency models

Regarding RPNB model results, the texture depth coefficient was significantly negative in all models, indicating all accident frequencies in the majority of roadway segments, decreased with increases in texture depth. This finding is consistent with that of Pulugurtha *et al.*, (2010) who demonstrated a significant relationship between different types of accident and texture depth. The elasticity effect results are shown in Figure 7-19, and suggest for total, dry, wet, slight and serious and fatal accident

frequencies, a 10% increase in texture depth was obvious for wet accidents at B2, RA, JN and GR site categories. This result may be explained by the fact that pavement surfaces with sufficient texture depth delayed hydroplaning, due to increases in hydroplaning speeds of up to 20% (Ong, *et al.,* 2005).

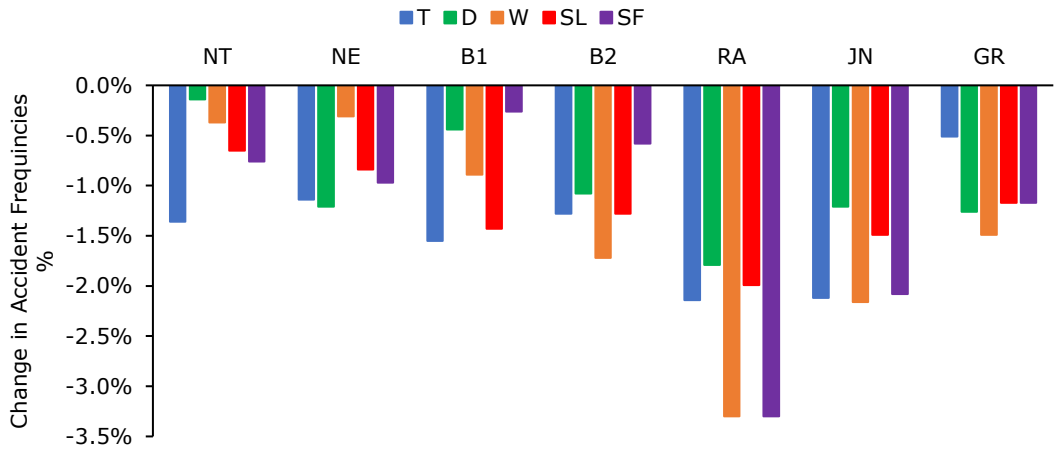


Figure 7-19: Estimated elasticity effects of a 10% increase in texture depth on total, dry, wet, slight and serious and fatal accidents frequency across NT level and all site categories in 3C network

- Rate models

Regarding RPT outcomes, the texture depth coefficient was significantly negative in all models, this indicated that increasing texture depth, in the majority of roadway segments, led to decrease total, dry, wet, slight and serious and fatal accident rates, in all site categories. These findings support evidence from previous studies (Roe *et al.*, 1991; Gothie, 1993; Cairney and Styles, 2005). These authors concluded that texture depth was an important pavement characteristic that contributed to accident prevention. Figure 6-33 provides an overview of a 10% increase in texture depth on the expected total, dry, wet, slight and serious and fatal accident rates for all site categories.

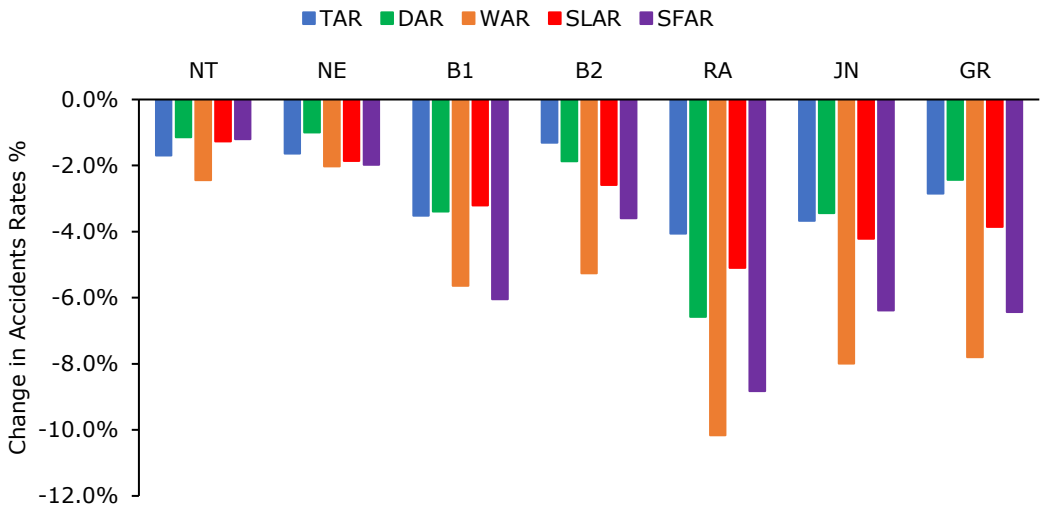


Figure 7-20: Estimated elasticity effects of a 10% increase in texture depth on total, dry, wet, slight and serious and fatal accident rates across NT level and all site categories in 3C network

The most obvious finding from this figure was that a 10% increase in texture depth was most effective for wet accident rates, in the majority of site categories. Previous studies have demonstrated the importance of texture depth in accident reduction especially for wet accident rates (Wambold *et al.,* 1986; Hall *et al.,* 2009). Another important finding from Figure 6-33 suggested that with respect to all accident rates, a 10% increase in texture depth was most effective at the RA and JN site categories. This finding was similar to a previous study, which suggested that texture depth should be considered an important factor, contributing to decreased accident likelihoods, especially for roadway segments where braking manoeuvres are more common (Fernandes and Neves, 2013).

7.5 Summary

This chapter showed the main factors influencing accident frequency (total, dry, wet, slight and serious and fatal accident frequencies) based on RPNB models that were presented in Chapter 5); and accident rates (total, dry, wet, slight and serious and fatal accident rates) based on RPT models that were presented in Chapter 6. The following sections show that main point identified:

7.5.1 Traffic characteristics

- LN AADF

The coefficient estimates of RPNB and RPT models demonstrate that Ln AADF was an important independent variable in accident frequencies and rates models. Ln AADF had significant positive effects on all accidents frequencies and rates. Table 7-1 indicates that increased traffic (Ln AADT) leads to increase accident frequencies and rates at all roadway segments for all site categories. Regarding NT roadway segments a 1% increase in Ln AADF would increase total, dry, wet, slight and serious and fatal accident frequencies by 5.89, 7.15, 4.57, 6.38 and 4.36%. While a 1% increase in Ln AADF would increase total, dry, wet, slight and serious and fatal accident rates by 4.35, 3.23, 1.68, 1.96 and 3.14%; respectively.

Table 7-1: Effect of Ln AADF on accident frequencies and rates at different site categories in 3C network

Site category	Ln AADF effect									
	T	TAR	D	DAR	W	WAR	SL	SLAR	SF	SFAR
NT	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
NE	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
B1	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
B2	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
RA	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
JN	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
GR	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
Site category	Positive effect (%)									
	T	TAR	D	DAR	W	WAR	SL	SLAR	SF	SFAR
NT	100	100	100	100	100	100	100	100	100	100
NE	100	100	100	100	100	100	100	100	100	100
B1	100	100	100	100	100	100	100	100	100	100
B2	100	100	100	100	100	100	100	100	100	100
RA	100	100	100	100	100	100	100	100	100	100
JN	100	100	100	100	100	100	100	100	100	100
GR	100	100	100	100	100	100	100	100	100	100
Site category	Random (R) or Fixed (F)									
	T	TAR	D	DAR	W	WAR	SL	SLAR	SF	SFAR
NT	F	F	F	F	F	F	F	F	F	F
NE	F	F	F	F	F	F	F	F	F	F
B1	F	F	F	F	F	F	F	F	F	F
B2	F	F	F	F	F	F	F	F	F	F
RA	F	F	F	F	F	F	F	F	F	F
JN	F	F	F	F	F	F	F	F	F	F
GR	F	F	F	F	F	F	F	F	F	F
Site category	Elasticity effect (%) due to 1% increasing in Ln AADF									
	T	TAR	D	DAR	W	WAR	SL	SLAR	SF	SFAR
NT	5.89	4.35	7.15	3.23	4.57	1.68	6.38	1.96	4.36	3.14
NE	6.30	3.91	7.27	1.52	5.66	3.70	6.81	2.72	4.50	2.90
B1	5.28	4.60	6.38	3.64	3.60	3.15	5.99	3.11	5.56	4.06
B2	6.97	3.83	8.01	3.20	5.45	3.01	6.96	3.32	6.63	2.15
RA	3.16	3.76	5.15	1.27	2.55	3.26	3.65	2.92	1.92	2.98
JN	3.95	3.18	5.05	2.97	2.50	1.90	4.56	1.62	1.69	3.67
GR	5.35	4.18	7.20	3.06	3.36	1.06	5.10	1.94	6.44	3.77

- Heavy vehicles percentage

Table 7-2 summarises the effect of heavy vehicles percentage on accident frequencies and rates at different site categories based on RPNB and RPT models. From this table, it can be concluded that heavy vehicles percentage has a negative effect on road safety in terms of increased total, dry, wet, slight and serious and fatal accident frequencies at all site categories. On the other hand, RPT models showed that heavy vehicles percentage has a mixed effect on road safety, increased heavy vehicles percentage has a positive effect on road safety in terms of decreased all accident rates at NT and NE site categories, it however has a negative effect on road safety in terms of increased all accident rates at B1, B2, RA, JN and GR site categories. The result shown in Table 9-2 indicates that for all accident frequencies and rates a 10% increase in heavy vehicles percentage is the most effective at GR site category. Regarding GR roadway segments a 10% increase in heavy vehicles percentage would increase total, dry, wet, slight and serious and fatal accident frequencies by 6.98, 5.81, 6.20%, 7.81 and 11.96%. While a 10% increase in RC would decrease total, dry, wet, slight and serious and fatal accident rates by 6.31, 5.41, 10.66, 6.26 and 18.51%, respectively.

Table 7-2: Effect of heavy vehicles percentage on accident frequencies and rates at different site categories in 3C network

Site category	%HV effect									
	T	TAR	D	DAR	W	WAR	SL	SLAR	SF	SFAR
NT	↑	↓	↑	↓	↑	↓	↑	↓	↑	↓
NE	↑	↓	↑	↓	↑	↓	↑	↓	↑	↓
B1	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
B2	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
RA	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
JN	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
GR	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
Site category	Positive effect (%)									
	T	TAR	D	DAR	W	WAR	SL	SLAR	SF	SFAR
NT	25	38	37	0	30	0	41	0	45	0
NE	33	27	49	0	47	0	49	0	100	0
B1	48	17	43	100	16	19	34	14	17	36
B2	100	37	39	32	100	33	100	100	100	32
RA	47	100	41	33	45	100	45	1	25	8
JN	47	100	31	100	48	100	46	43	100	34
GR	100	100	100	100	100	26	100	7	100	100
Site category	Random (R) or Fixed (F)									
	T	TAR	D	DAR	W	WAR	SL	SLAR	SF	SFAR
NT	R	R	R	F	R	F	R	F	R	F
NE	R	R	R	F	R	F	R	F	F	F
B1	R	R	R	F	R	R	R	R	R	R
B2	F	R	R	R	F	R	F	F	F	F
RA	R	F	R	R	R	F	R	R	R	R
JN	R	F	R	F	R	F	R	R	F	R
GR	F	F	F	F	F	R	F	R	F	F
Site category	Elasticity effect (%) due to 10% increasing in %HV									
	T	TAR	D	DAR	W	WAR	SL	SLAR	SF	SFAR
NT	4.90	-2.93	5.59	-3.38	5.07	-2.42	4.90	-6.35	1.58	-2.96
NE	1.09	-1.94	1.44	-3.53	1.54	-5.10	1.34	-3.79	0.45	-7.03
B1	2.98	4.31	2.76	3.50	5.24	2.64	4.78	4.52	6.19	13.67
B2	3.68	2.72	3.74	2.21	4.12	1.88	4.31	2.59	5.45	10.21
RA	2.63	2.28	3.24	3.13	2.27	2.04	3.86	2.78	2.16	3.99
JN	2.64	1.86	5.28	1.56	3.46	3.42	3.69	6.11	0.50	3.66
GR	6.98	6.31	5.81	5.41	6.20	10.66	7.81	6.26	11.96	18.51

- Speed limit

Table 7-3 indicated that roadway segment with lower speed limit was associated with higher total, dry, wet, slight and serious and fatal accident frequencies; and total, dry, wet, slight and serious and fatal accident rates at all site categories. Regarding NT roadway segments a 10% increase in speed limit would decrease total, dry, wet, slight and serious and fatal accident frequencies by 13.10, 13.92, 13.10, 15.56 and 7.37%. While a 10% increase in speed limit would decrease total, dry, wet, slight

and serious and fatal accident rates by 8.34, 6.65, 4.43, 3.82 and 4.31%, respectively.

Table 7-3: Effect of speed limit on accident frequencies and rates at different site categories in 3C network

Site category	SPL effect									
	T	TAR	D	DAR	W	WAR	SL	SLAR	SF	SFAR
NT	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
NE	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
B1	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
B2	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
RA	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
JN	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
GR	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
Site category	Positive effect (%)									
	T	TAR	D	DAR	W	WAR	SL	SLAR	SF	SFAR
NT	4	7	2	5	9	10	7	0	10	12
NE	2	0	2	0	5	8	2	0	8	8
B1	4	8	1	0	0	6	R	7	0	5
B2	4	12	8	8	7	12	5	0	8	8
RA	15	43	1	0	27	0	9	38	0	49
JN	0	0	16	0	11	26	0	15	0	37
GR	0	6	0	29	24	34	29	39	0	0
Site category	Random (R) or Fixed (F)									
	T	TAR	D	DAR	W	WAR	SL	SLAR	SF	SFAR
NT	R	R	R	R	R	R	R	F	R	R
NE	R	F	R	F	R	R	R	F	R	R
B1	R	R	R	F	F	R	R	R	F	R
B2	R	R	R	R	R	R	R	F	R	R
RA	R	R	R	F	R	F	R	R	F	R
JN	F	F	R	F	R	R	F	R	F	R
GR	F	F	F	R	R	R	R	R	F	F
Site category	Elasticity effect (%) due to 10% increasing in SPL									
	T	TAR	D	DAR	W	WAR	SL	SLAR	SF	SFAR
NT	-13.10	-8.34	-13.92	-6.65	-13.10	-4.43	-15.56	-3.82	-7.37	-4.31
NE	-12.69	-9.57	-15.23	-7.69	-19.46	-8.74	-15.23	-12.01	-9.31	-8.19
B1	-16.12	-10.90	-19.19	-10.36	-9.21	-8.27	-19.19	-11.31	-3.84	-5.39
B2	-17.50	-13.19	-14.32	-8.70	-21.48	-7.38	-16.70	-13.04	-14.32	-8.82
RA	-1.58	-10.42	-5.53	-4.90	-2.47	-2.47	-3.16	-4.56	-1.79	-8.06
JN	-3.75	-9.70	-4.50	-2.82	-3.75	-3.45	-4.50	-12.48	-1.15	-4.78
GR	-2.51	-4.39	-2.51	-1.90	-11.71	-2.70	-4.18	-6.68	-9.20	-4.08

7.5.2 Geometric characteristics

- Radius of curvature

Roadway segment with higher radius of curvature results in lower accident frequencies and rate for the majority roadway segments at all site categories. Table 7-4 summarises the effect of radius of curvature on accident frequencies and rates at different site categories based on RPNB and RPT models. As expected the result shown in Table 7-4 suggests that for all accident frequencies and rates, a 10% increase in radius of curvature is most effective at B1 site category. Regarding B1 roadway segments a 10% increase in radius of curvature would decrease total, dry, wet, slight and serious and fatal accident frequencies by 18.82, 15.63, 12.39, 4.27 and 10.68%. While a 10% increase in radius of curvature would decrease total, dry, wet, slight and serious and fatal accident rates by 22.67, 9.40, 9.19, 31.59 and 25.85%, respectively.

Table 7-4: Effect of radius of curvature on accident frequencies and rates at different site categories in 3C network

Site category	RC effect									
	T	TAR	D	DAR	W	WAR	SL	SLAR	SF	SFAR
NT	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
NE	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
B1	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
B2	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
RA	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
JN	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
GR	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
Site category	Positive effect (%)									
	T	TAR	D	DAR	W	WAR	SL	SLAR	SF	SFAR
NT	14	13	16	8	1	16	35	29	30	30
NE	26	22	3	32	22	20	40	0	42	0
B1	2	0	0	0	0	33	0	8	0	21
B2	0	30	0	21	36	47	8	0	0	7
RA	34	0	36	31	0	25	0	3	7	18
JN	1	13	34	4	0	31	33	13	0	47
GR	0	0	0	43	0	11	0	0	18	0
Site category	Random (R) or Fixed (F)									
	T	TAR	D	DAR	W	WAR	SL	SLAR	SF	SFAR
NT	R	R	R	R	R	R	R	R	R	R
NE	R	R	R	R	R	R	R	F	R	F
B1	R	F	F	F	F	R	F	R	F	R
B2	F	R	F	R	R	R	R	F	F	R
RA	R	F	R	R	F	R	F	R	R	R
JN	R	R	R	R	F	R	R	R	F	R
GR	F	F	F	R	F	R	F	F	R	F
Site category	Elasticity effect (%) due to 10% increasing in RC									
	T	TAR	D	DAR	W	WAR	SL	SLAR	SF	SFAR
NT	-4.73	-3.56	-3.86	-1.28	-3.64	-1.12	-4.78	-4.89	-2.12	-2.87
NE	-6.04	-6.56	-3.14	-2.37	-4.02	-1.72	-5.60	-5.72	-4.51	-3.87
B1	-18.82	-22.67	-15.63	-9.40	-12.39	-9.19	-4.27	-31.59	-10.68	-25.85
B2	-10.63	-18.04	-7.97	-6.78	-8.88	-6.14	-2.50	-9.20	-7.35	-10.38
RA	-3.07	-1.11	-2.26	-1.24	-1.06	-4.04	-2.06	-1.24	-2.15	-2.81
JN	-3.35	-3.48	-1.87	-6.03	-2.50	-2.16	-2.93	-6.78	-3.50	-4.84
GR	-3.01	-1.48	-2.54	-0.86	-1.15	-2.13	-1.99	-10.74	-4.05	-6.18

- Gradient

Roadway segment with higher gradient results in higher accident frequencies and rate for approximately half of roadway segments at all site categories. Table 7-5 summarises the effect of gradient on accident frequencies and rates at different site categories based on RPNB and RPT models. As expected the result shown in Table 7-5 suggests that for all accident frequencies and rates, a 10% increase in gradient is

most effective at GR site category. Regarding GR roadway segments a 10% increase in gradient would increase total, dry, wet, slight and serious and fatal accident frequencies by 3.72, 2.20, 3.52, 3.38 and 2.52%. While a 10% increase in gradient would increase total, dry, wet, slight and serious and fatal accident rates by 7.30, 4.73, 6.26, 3.23 and 7.06%, respectively. However, the elasticity effect of gradient was not high for other site categories and is considered relatively low over 6 years period.

Table 7-5: Effect of gradient on accident frequencies and rates at different site categories in 3C network

Site category	%G effect									
	T	TAR	D	DAR	W	WAR	SL	SLAR	SF	SFAR
NT	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
NE	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
B1	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
B2	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
RA	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
JN	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
GR	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
Site category	Positive effect (%)									
	T	TAR	D	DAR	W	WAR	SL	SLAR	SF	SFAR
NT	20	40	21	45	65	48	19	100	28	44
NE	22	100	36	100	40	21	6	100	31	43
B1	30	17	43	43	100	42	38	48	25	23
B2	100	35	38	45	14	31	100	100	100	100
RA	45	37	100	34	34	100	15	32	30	33
JN	100	100	100	100	100	48	100	50	100	30
GR	100	100	100	21	100	12	100	12	100	100
Site category	Random (R) or Fixed (F)									
	T	TAR	D	DAR	W	WAR	SL	SLAR	SF	SFAR
NT	R	R	R	R	R	R	R	F	R	R
NE	R	F	R	F	R	R	R	F	R	R
B1	R	R	R	R	F	R	R	R	R	R
B2	F	R	R	R	R	R	F	F	F	F
RA	R	R	F	R	R	F	R	R	R	R
JN	F	F	F	F	F	R	F	R	F	R
GR	F	F	F	R	F	R	F	R	F	F
Site category	Elasticity effect (%) due to 10% increasing in %G									
	T	TAR	D	DAR	W	WAR	SL	SLAR	SF	SFAR
NT	1.29	0.83	1.11	0.73	0.83	1.28	0.71	0.93	1.10	0.50
NE	1.45	0.89	0.83	0.82	0.42	0.94	0.41	0.66	0.78	0.64
B1	3.43	4.80	1.70	2.35	1.93	2.81	1.67	2.20	3.16	4.72
B2	2.19	3.33	1.27	2.02	1.02	2.92	1.36	1.85	1.86	3.07
RA	0.69	0.85	0.40	0.63	0.43	0.53	0.64	1.05	0.89	1.29
JN	0.87	0.77	0.71	0.78	1.04	0.35	0.96	0.67	0.41	0.51
GR	3.72	7.30	2.20	4.73	3.52	6.26	3.38	3.23	2.52	7.06

- Number of lanes

Regarding geometric characteristics, increasing number of lanes was found to has a positive effect on road safety. The RPNB and RPT models' results revealed that roadway segments with fewer lanes expected more accidents frequencies and rates in comparison with roadway segments with higher number of lanes. Table 7-6 provides an overview of the effect of number of lanes on accidents frequencies and rates at all site categories. Regarding NT roadway segments a 100% increase in number of lanes would decrease total, dry, wet, slight and serious and fatal accident frequencies by 5.30, 2.30, 6.90, 4.30 and 3.80%. While a 100% increase in number of lanes would decrease total, dry, wet, slight and serious and fatal accident rates by 51.14, 27.15, 25.21, 43.31 and 25.47%, respectively.

Table 7-6: Effect of number of lanes on accident frequencies and rates at different site categories in 3C network

Site category	NL effect									
	T	TAR	D	DAR	W	WAR	SL	SLAR	SF	SFAR
NT	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
NE	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
B1	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
B2	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
RA	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
JN	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
GR	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
Site category	Positive effect (%)									
	T	TAR	D	DAR	W	WAR	SL	SLAR	SF	SFAR
NT	4	0	33	0	0	0	17	0	1	0
NE	5	0	32	0	0	0	24	0	48	34
B1	0	5	7	0	0	4	19	16	0	5
B2	40	38	3	7	32	2	32	0	0	3
RA	33	2	0	11	2	0	0	3	20	17
JN	3	0	0	0	0	0	3	0	0	0
GR	19	32	26	37	0	3	15	21	0	0
Site category	Random (R) or Fixed (F)									
	T	TAR	D	DAR	W	WAR	SL	SLAR	SF	SFAR
NT	R	F	R	F	F	F	R	F	R	F
NE	R	F	R	F	F	F	R	F	R	R
B1	F	R	R	F	F	R	R	R	F	R
B2	R	R	R	R	R	R	R	F	F	R
RA	R	R	F	R	R	F	F	R	R	R
JN	R	F	F	F	F	F	R	F	F	F
GR	R	R	R	R	F	R	R	R	F	F
Site category	Elasticity effect (%) due to 100% increasing in NL									
	T	TAR	D	DAR	W	WAR	SL	SLAR	SF	SFAR
NT	-5.30	-51.14	-2.30	-27.15	-6.90	-25.21	-4.30	-43.31	-3.80	-25.47
NE	-7.20	-47.61	-2.40	-22.69	-10.70	-11.02	-6.03	-26.94	-1.00	-33.39
B1	-6.00	-39.27	-5.50	-28.78	-3.70	-17.62	-6.20	-32.74	-2.00	-43.53
B2	-1.60	-46.23	-3.50	-18.48	-1.90	-31.31	-1.00	-53.64	-5.70	-65.58
RA	-4.80	-32.53	-7.10	-21.38	-1.00	-16.82	-5.80	-35.44	-3.90	-26.78
JN	-5.61	-16.16	-7.50	-15.35	-9.50	-8.04	-8.60	-21.72	-7.10	-15.00
GR	-8.20	-11.68	-3.99	-14.93	-10.80	-9.10	-15.00	-12.02	-9.91	-15.70

- Number of minor access

As can be seen in Table 7-7, number of minor access has statistically significant influence on accident frequencies and rates at all site categories. The results in Table 7-7 shows that increasing number of minor access at all roadway segments lead to increase total, dry, wet, slight and serious and fatal accident frequencies; and total, dry, wet, slight and serious and fatal accident rates. Regarding NT roadway segments a 100% increase in number of minor access would decrease total, dry, wet, slight

and serious and fatal accident frequencies by 25.50, 27.60, 20.40, 26.50 and 19.40%. While a 100% increase in number of minor access would decrease total, dry, wet, slight and serious and fatal accident rates by 10.60, 5.53, 3.97, 10.64 and 12.42%, respectively.

Table 7-7: Effect of number of minor access on accident frequencies and rates at different site categories in 3C network

Site category	NMA effect									
	T	TAR	D	DAR	W	WAR	SL	SLAR	SF	SFAR
NT	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
NE	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
B1	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
B2	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
RA	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
JN	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
GR	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
Site category	Positive effect (%)									
	T	TAR	D	DAR	W	WAR	SL	SLAR	SF	SFAR
NT	100	100	100	100	100	100	100	100	100	100
NE	100	100	100	100	100	100	100	100	100	100
B1	100	100	100	100	100	100	100	100	100	100
B2	100	100	100	100	100	100	100	100	100	100
RA	100	100	100	100	100	100	100	100	100	100
JN	100	100	100	100	100	100	100	100	100	100
GR	100	100	100	100	100	100	100	100	100	100
Site category	Random (R) or Fixed (F)									
	T	TAR	D	DAR	W	WAR	SL	SLAR	SF	SFAR
NT	F	F	F	F	F	F	F	F	F	F
NE	F	F	F	F	F	F	F	F	F	F
B1	F	F	F	F	F	F	F	F	F	F
B2	F	F	F	F	F	F	F	F	F	F
RA	F	F	F	F	F	F	F	F	F	F
JN	F	F	F	F	F	F	F	F	F	F
GR	F	F	F	F	F	F	F	F	F	F
Site category	Elasticity effect (%) due to 100% increasing in NMA									
	T	TAR	D	DAR	W	WAR	SL	SLAR	SF	SFAR
NT	25.50	10.60	27.60	5.53	20.40	3.97	26.50	10.64	19.40	12.42
NE	29.20	17.63	33.30	5.78	22.71	5.22	29.80	13.11	28.40	19.52
B1	11.10	8.44	12.80	5.71	6.80	4.61	9.50	8.71	8.30	10.82
B2	18.10	8.95	20.60	4.48	10.30	5.12	15.80	6.28	22.00	12.35
RA	14.30	5.82	16.50	3.61	10.80	2.09	14.20	3.98	6.80	2.71
JN	18.70	8.25	24.80	3.24	5.20	2.50	19.10	6.01	15.50	5.58
GR	11.70	2.65	15.00	1.51	4.00	1.39	11.40	2.55	4.50	1.14

7.5.3 Pavement characteristics

- Skid resistance

The effect of skid resistance was observed to have a negative effect on accident frequencies and rate at all site categories. As shown in Table 7-8, increasing the skid resistance for the majority of roadway segments leads to a significant decrease in all accident frequencies and rates in all site categories. As seen from Table 7-8, for all accident frequencies and rates, a 10% increase in skid resistance emerges to be more effective at B1 site category. Regarding B1 roadway segments a 10% increase in skid resistance would decrease total, dry, wet, slight and serious and fatal accident frequencies by 12.24, 10.21, 16.34, 10.68 and 4.87%. While a 10% increase in skid resistance would decrease total, dry, wet, slight and serious and fatal accident rates by 6.32, 10.62, 12.52, 3.31 and 4.87%, respectively.

Table 7-8: Effect of skid resistance on accident frequencies and rates at different site categories in 3C network

Site category	SR effect									
	T	TAR	D	DAR	W	WAR	SL	SLAR	SF	SFAR
NT	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
NE	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
B1	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
B2	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
RA	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
JN	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
GR	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
Site category	Positive effect (%)									
	T	TAR	D	DAR	W	WAR	SL	SLAR	SF	SFAR
NT	7	9	24	0	1	0	5	0	11	1
NE	21	0	1	0	1	0	1	0	2	0
B1	1	11	0	0	1	0	21	1	0	0
B2	16	0	1	1	10	12	3	0	19	47
RA	2	9	15	0	21	0	13	4	0	1
JN	17	19	3	0	5	2	32	41	0	40
GR	0	1	0	4	0	12	0	0	0	1
Site category	Random (R) or Fixed (F)									
	T	TAR	D	DAR	W	WAR	SL	SLAR	SF	SFAR
NT	R	R	R	F	R	F	R	F	F	R
NE	R	F	R	F	R	F	R	F	R	F
B1	R	R	F	F	R	F	R	R	F	F
B2	R	F	R	R	R	R	R	F	R	R
RA	R	R	R	F	R	F	R	R	F	R
JN	R	R	R	F	R	R	R	R	R	R
GR	F	R	F	R	F	R	F	F	F	R
Site category	Elasticity effect (%) due to 10% increasing in SR									
	T	TAR	D	DAR	W	WAR	SL	SLAR	SF	SFAR
NT	-12.24	-6.32	-10.21	-10.62	-16.34	-12.52	-10.68	-3.31	-4.87	-4.87
NE	-8.48	-6.29	-11.40	-19.10	-15.60	-14.51	-2.36	-3.37	-11.20	-2.04
B1	-18.92	-15.29	-9.78	-12.65	-23.31	-21.89	-17.68	-6.78	-15.72	-5.14
B2	-11.41	-10.51	-8.43	-10.00	-15.95	-20.05	-12.19	-5.99	-11.85	-5.38
RA	-9.36	-6.19	-10.21	-4.77	-12.20	-15.02	-10.70	-4.08	-5.34	-3.41
JN	-2.23	-4.55	-4.21	-3.11	-9.21	-8.63	-3.08	-4.07	-3.63	-2.01
GR	-10.85	-8.27	-5.36	-6.29	-14.85	-17.58	-8.99	-5.40	-7.14	-4.13

- Rut depth

Table 7-9 summarises the effect of rut depth on accident frequencies and rates at different site categories based on RPNB and RPT models. In terms of accident frequency models, relatively roadway segments with high rut depth was observed to higher accident frequencies. In terms of accident rate models, rut depth has a mixed effect on accident rates, increased rut depth was associated with increase total, dry,

wet, slight and serious and fatal accident rates at all site categories. On the other hand, increased rut depth was associated with decrease dry accident rates at all site categories. As seen in Table 7-9, the most effective of a 10% increase in rut depth be revealed for wet accident frequencies and rates at all site categories. Based on the elasticity effect of rut depth it can be concluded that its effect over 6 years is relatively low.

Table 7-9: Effect of rut depth on accident frequencies and rates at different site categories in 3C network

Site category	RD effect									
	T	TAR	D	DAR	W	WAR	SL	SLAR	SF	SFAR
NT	↑	↑	↓	↑	↑	↑	↑	↑	↑	↑
NE	↑	↑	↓	↑	↑	↑	↑	↑	↑	↑
B1	↑	↑	↓	↑	↑	↑	↑	↑	↑	↑
B2	↑	↑	↓	↑	↑	↑	↑	↑	↑	↑
RA	↑	↑	↓	↑	↑	↑	↑	↑	↑	↑
JN	↑	↑	↓	↑	↑	↑	↑	↑	↑	↑
GR	↑	↑	↓	↑	↑	↑	↑	↑	↑	↑
Site category	Positive effect (%)									
	T	TAR	D	DAR	W	WAR	SL	SLAR	SF	SFAR
NT	30	100	30	27	46	42	22	100	39	49
NE	35	24	14	0	100	39	45	12	15	24
B1	41	100	29	0	100	35	49	47	100	45
B2	100	38	100	17	27	100	6	100	26	34
RA	100	32	50	48	23	100	100	25	30	29
JN	21	100	10	0	100	100	31	48	100	42
GR	100	100	27	38	100	32	48	44	100	8
Site category	Random (R) or Fixed (F)									
	T	TAR	D	DAR	W	WAR	SL	SLAR	SF	SFAR
NT	R	F	R	R	R	R	R	F	R	R
NE	R	R	R	F	F	R	R	R	R	R
B1	R	F	R	F	F	R	R	R	F	R
B2	F	R	F	R	R	F	R	F	R	R
RA	F	R	R	R	R	F	F	R	R	R
JN	R	F	R	F	F	F	R	R	F	R
GR	F	F	R	R	F	R	R	R	F	R
Site category	Elasticity effect (%) due to 10% increasing in RD									
	T	TAR	D	DAR	W	WAR	SL	SLAR	SF	SFAR
NT	0.55	1.17	0.96	-0.65	2.20	3.73	0.48	1.11	0.41	2.05
NE	0.70	1.19	0.89	-0.42	4.51	5.26	0.34	1.79	1.58	3.06
B1	1.22	4.14	0.95	-0.73	4.87	8.44	1.42	3.15	1.69	6.54
B2	1.37	1.65	1.19	-0.89	3.22	5.63	1.92	2.42	2.05	4.20
RA	1.98	1.60	0.47	-0.40	1.24	3.65	0.35	0.85	0.48	1.98
JN	1.29	1.16	1.14	-0.44	1.02	2.87	0.27	0.73	0.61	1.02
GR	0.51	2.36	1.24	-1.69	2.77	5.62	3.04	3.34	2.47	1.13

- Texture depth

Table 7-10 illustrates the effect of texture depth on accident frequencies and rates at different site categories based on RPNB and RPT models. As shown in Table 7-10, increasing the texture depth for the majority of roadway segments leads to a significant decrease in all accident frequencies and rates in all site categories. As seen from Table 7-10, for all accident frequencies and rates, a 10% increase in texture depth appears to be more effective at RA site category. Regarding RA roadway segments a 10% increase in texture depth would decrease total, dry, wet, slight and serious and fatal accident frequencies by 2.14, 1.79, 3.30, 1.99 and 3.30%. While a 10% increase in texture depth would decrease total, dry, wet, slight and serious and fatal accident rates by 4.06, 6.58, 10.16, 5.10 and 8.83%, respectively.

Table 7-10: Effect of texture depth on accident frequencies and rates at different site categories in 3C network

Site category	TX effect									
	T	TAR	D	DAR	W	WAR	SL	SLAR	SF	SFAR
NT	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
NE	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
B1	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
B2	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
RA	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
JN	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
GR	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
Site category	Positive effect (%)									
	T	TAR	D	DAR	W	WAR	SL	SLAR	SF	SFAR
NT	13	1	35	0	26	12	43	35	1	23
NE	47	0	26	17	34	9	39	0	0	22
B1	0	11	4	0	44	38	19	8	41	50
B2	34	38	20	0	20	27	0	21	0	29
RA	0	0	48	1	0	0	0	9	0	0
JN	3	0	0	0	44	37	0	41	0	10
GR	13	49	0	3	18	1	0	1	21	0
Site category	Random (R) or Fixed (F)									
	T	TAR	D	DAR	W	WAR	SL	SLAR	SF	SFAR
NT	R	R	R	F	R	R	R	R	R	R
NE	R	F	R	R	R	R	R	F	F	R
B1	F	R	R	F	R	R	R	R	R	R
B2	R	R	R	F	R	R	F	R	F	R
RA	F	F	R	R	F	F	F	R	F	F
JN	R	F	F	F	R	R	F	R	F	R
GR	R	R	F	R	R	R	F	R	R	F
Site category	Elasticity effect (%) due to 10% increasing in TX									
	T	TAR	D	DAR	W	WAR	SL	SLAR	SF	SFAR
NT	-1.36	-1.69	-0.14	-1.14	-0.37	-2.44	-0.65	-1.27	-0.76	-1.20
NE	-1.14	-1.63	-1.21	-1.00	-0.31	-2.02	-0.84	-1.86	-0.97	-1.98
B1	-1.55	-3.51	-0.44	-3.39	-0.89	-5.64	-1.43	-3.21	-0.26	-6.04
B2	-1.28	-1.31	-1.08	-1.87	-1.72	-5.26	-1.28	-2.59	-0.58	-3.60
RA	-2.14	-4.06	-1.79	-6.58	-3.30	-10.16	-1.99	-5.10	-3.30	-8.83
JN	-2.12	-3.67	-1.21	-3.44	-2.16	-7.99	-1.49	-4.21	-2.08	-6.38
GR	-0.51	-2.85	-1.26	-2.43	-1.49	-7.80	-1.17	-3.86	-1.17	-6.43

7.5.4 RPNB vs RPT models

The process of evaluating the fitted performance of the RPNB and PRT models via the mean absolute deviation (MAD) (Xie *et al.,* 2007) as follows:

$$MAD = \frac{1}{n}\sum_{i=1}^{n}|Y_i - y_i| \qquad (7 - 1)$$

Where n is number of observations; Y_i is the predicted values for accident frequencies or rates; y_i are the actual values for accident frequencies or rates. The MAD values for both RPNB and RPT models for all site categories are presented in Table 7-11.

Table 7-11: Mean absolute deviation (MAD) for RPNB and RPT models

Accident type	Site Category	MAD for RPNB	MAD for RPT
T	NT	0.504	79.648
	NE	0.355	68.230
	B1	0.221	39.554
	B2	0.420	48.881
	RA	0.142	16.975
	JN	0.262	45.121
	GR	0.192	44.451
D	NT	0.117	18.982
	NE	0.230	23.249
	B1	0.261	17.184
	B2	0.264	46.488
	RA	0.204	52.468
	JN	0.117	21.512
	GR	0.235	43.583
W	NT	0.116	22.815
	NE	0.345	20.169
	B1	0.278	27.147
	B2	0.116	23.534
	RA	0.267	34.847
	JN	0.182	44.530
	GR	0.656	12.167
SL	NT	1.017	59.071
	NE	0.525	38.206
	B1	0.644	49.740
	B2	0.446	31.764
	RA	1.022	22.430
	JN	0.814	46.182
	GR	0.602	32.186
SF	NT	0.866	44.707
	NE	0.415	22.122
	B1	0.339	35.659
	B2	0.269	38.056
	RA	0.153	23.249
	JN	0.313	20.569
	GR	0.198	11.457

CHAPTER EIGHT

SKID RESISTANCE THRESHOLD

CHAPTER EIGHT: SKID RESISTANCE THRESHOLD

8.1 Overview

The skidding standard for strategic road network of the UK was introduced by the Department of Transport in 1988 in HD28/88 of the Design Manual for Roads and Bridges. The basis for the standard was the analysis conducted on determining the link between skidding resistance and risk of accidents according to definitions advanced by Rogers and Gargett (1991). On 2015 the Design Manual for Roads and Bridges published the newest version of the skid resistance policy for strategic roads as HD28/15 (Highways Agency, 2015). Although the highway agency (local authorities) in the UK used the skid resistance policy (HD 28/15) to define site categories and establish skid resistance thresholds for these site categories for the A-road networks, identifying the skid resistance thresholds for the local authority of A–road networks remains a problem, because the nature of local authority roads is different from strategic roads in terms of traffic flow, road geometry, and speed. Therefore, the definitions of skid resistance thresholds and site categories in strategic roads do not necessarily match those of the local authority of A-roads.

The main aim of this chapter is to establish skid resistance threshold for different site categories defined in section 3.5 and compare these threshold values with those in HD28/15.

This has been achieved through the following.

- An examination of the effect of skid resistance on the expected total, dry, wet, slight and serious and fatal accident frequencies, obtained using the RPNB model presented in Chapter 5; an examination of the effect of skid resistance on the expected total, dry, wet, slight and serious and fatal accident rates, obtained using the RPT model presented in Chapter 6.
- The application of accident prediction models (frequency and rate) in this thesis establishes the skid resistance thresholds for different accidents and site categories, by considering the expected traffic accident frequency and rate as functions of skid resistance. The analyses of accident frequency and

rate as functions of skid resistance make it possible to define the threshold values of skid resistance by identify the inflection point (required skid resistance threshold) below which the expected accident frequencies or rates would increase with the decrease in the selected skid resistance threshold.

8.2 Skid resistance and road safety

Chapter 5 presents the RPNB model estimation results of total, dry, wet, slight and serious and fatal accident frequencies for NT, NE, B1, B2, RA, JN, and GR site categories. Based on the analysis of data from the A-road networks of three counties in England—Norfolk, Oxfordshire, and Nottinghamshire (3C), it was found that the skid resistance is negatively associated with accident frequencies. Generally, RPNB model results suggest that for a majority of roadway segments increased skid resistance has a positive impact on road safety in terms of decreased total, dry, wet, slight and serious and fatal accident frequencies at all site categories. While Chapter 6 presents the RPT model estimation results of total, dry, wet, slight and serious and fatal accident rates for NT, NE, B1, B2, RA, JN, and GR site categories. It was found that skid resistance is negatively associated with accident rates. The RPT model results suggest that for a majority of roadway segments increased skid resistance has a positive impact on road safety in terms of decreased total, dry, wet, slight and serious and fatal accident rates at all site categories. Table 8-1 shows the elasticity effects of in skid resistance on both accident frequencies and rates at all site categories. A 10% increase in skid resistance was selected in thesis rather than other percentage because its more logical.

Table 8-1: Estimated elasticity effects of a 10% increase in skid resistance on both accident frequencies and rates at all site categories

Accident type	Site category	Reduction in accident frequencies (%)	Reduction in accident rates (%)
Total	NT	-12.24%	-6.32%
Total	NE	-8.48%	-6.29%
Total	B1	-18.92%	-15.29%
Total	B2	-11.41%	-10.51%
Total	RA	-9.36%	-6.19%
Total	JN	-2.23%	-4.55%
Total	GR	-10.85%	-8.27%
Dry	NT	-10.21%	-10.62%
Dry	NE	-11.40%	-19.10%
Dry	B1	-9.78%	-12.65%
Dry	B2	-8.43%	-10.00%
Dry	RA	-10.21%	-4.77%
Dry	JN	-4.21%	-3.11%
Dry	GR	-5.36%	-6.29%
Wet	NT	-16.34%	-12.52%
Wet	NE	-15.60%	-14.51%
Wet	B1	-23.31%	-21.89%
Wet	B2	-15.95%	-20.05%
Wet	RA	-12.20%	-15.02%
Wet	JN	-9.21%	-8.63%
Wet	GR	-14.85%	-17.58%
Slight	NT	-10.68%	-3.31%
Slight	NE	-2.36%	-3.37%
Slight	B1	-17.68%	-6.78%
Slight	B2	-12.19%	-5.99%
Slight	RA	-10.70%	-4.08%
Slight	JN	-3.08%	-4.07%
Slight	GR	-8.99%	-5.40%
Serious and Fatal	NT	-4.87%	-4.87%
Serious and Fatal	NE	-11.20%	-2.04%
Serious and Fatal	B1	-15.72%	-5.14%
Serious and Fatal	B2	-11.85%	-5.38%
Serious and Fatal	RA	-5.34%	-3.41%
Serious and Fatal	JN	-3.63%	-2.01%
Serious and Fatal	GR	-7.14%	-4.13%

Regarding, the elasticity effects of skid resistance on both accident frequencies and rates the following points can be concluded:

- With respect to total accident frequencies, a 10% increase in skid resistance is most effective at B1 site category (18.92% reduction) and least effective at JN site category (2.23% reduction). Regarding total accident rates a 10% increase in skid resistance is most effective at B1 site category (15.29% reduction) and least effective at JN site category (4.55% reduction).
- With respect to dry accident frequencies, a 10% increase in skid resistance is most effective at NE site category (11.40% reduction) and least effective at JN site category (4.21% reduction). Regarding dry accident rates a 10% increase in skid resistance is most effective at NE site category (19.10% reduction) and least effective at JN site category (3.11% reduction).
- With respect to wet accident frequencies, a 10% increase in skid resistance is most effective at B1 site category (23.31% reduction) and least effective at JN site category (9.21% reduction). Regarding wet accident rates a 10% increase in skid resistance is most effective at B1 site category (21.89% reduction) and least effective at JN site category (8.63% reduction).
- With respect to slight accident frequencies, a 10% increase in skid resistance is most effective at B1 site category (17.68% reduction) and least effective at NE site category (2.36% reduction). Regarding slight accident rates a 10% increase in skid resistance is most effective at B1 site category (6.78% reduction) and least effective at NT roadway segments (3.31% reduction).
- With respect to serious and fatal accident frequencies, a 10% increase in skid resistance is most effective at B1 site category (15.72% reduction) and least effective at JN site category (3.63% reduction). Regarding serious and fatal accident rates a 10% increase in skid resistance is most effective at B1 site category (5.38% reduction) and least effective at JN site category (2.01% reduction).

8.2.1 Network roadway segments (NT)

A network roadway segment is defined as any 50-m long roadway segment located at an A–road of the 3C network.

8.2.1.1 Frequency models

Table 8-2 summarises the estimated coefficients associated with the variable skid resistance for the expected total, dry, wet, slight and serious and fatal accident frequencies using the RPNB models for NT roadway segments. The results of RPNB models reveal that the skid resistance is negatively associated with total, dry, wet, slight and serious and fatal accident frequencies. As shown in Table 8-2, roadway segments with higher skid resistance values almost uniformly tends to decrease total, dry, wet, slight and serious and fatal accident frequencies. The decreasing effect is estimated to occur in the majority of NT road segments as indicated by the positive effect percentage. This implies that there is a significant effect of increasing skid resistance to reduce all accident frequencies, especially for total and wet accidents (see elasticity effect). A 10% increase in the skid resistance would decrease the total, dry, wet, slight and serious and fatal accident frequencies by 12.24, 9.60, 12.20, 10.68, and 4.87%, respectively.

Table 8-2: Statistical details of skid resistance coefficient for NT roadway segment frequency models

Model	SR effect	Fixed (F) or Random (R)	Positive effect %	Elasticity %	Note
T	⬇	R	7	-12.24	T, D, W, SL and SF accident frequencies decrease with increasing SR for the majority of NT roadway segments
D	⬇	R	2	-9.60	
W	⬇	R	1	-12.20	
SL	⬇	R	1	-10.68	
SF	⬇	F	0	-4.87	

Figure 8-1 shows the actual and expected total, dry, wet, slight and serious and fatal accident frequencies for the NT roadway segments of the 3C network as a function of skid resistance. The following points can be observed in Figure 8-3:

- There is an increase in the total, dry and serious and fatal accident frequencies when the skid resistance is below 0.45. On the other hand, dry and slight accident frequencies decline when the skid resistance is below 0.5.
- For NT roadway segments, the expected total, dry and slight accident frequencies reduce by 67, 74, and 67%, respectively, when the skid resistance is between 0.2 and 0.45; the expected wet and serious and fatal accident frequencies reduce by 59 and 49%, respectively, when the skid resistance increases from 0.2 to 0.5.

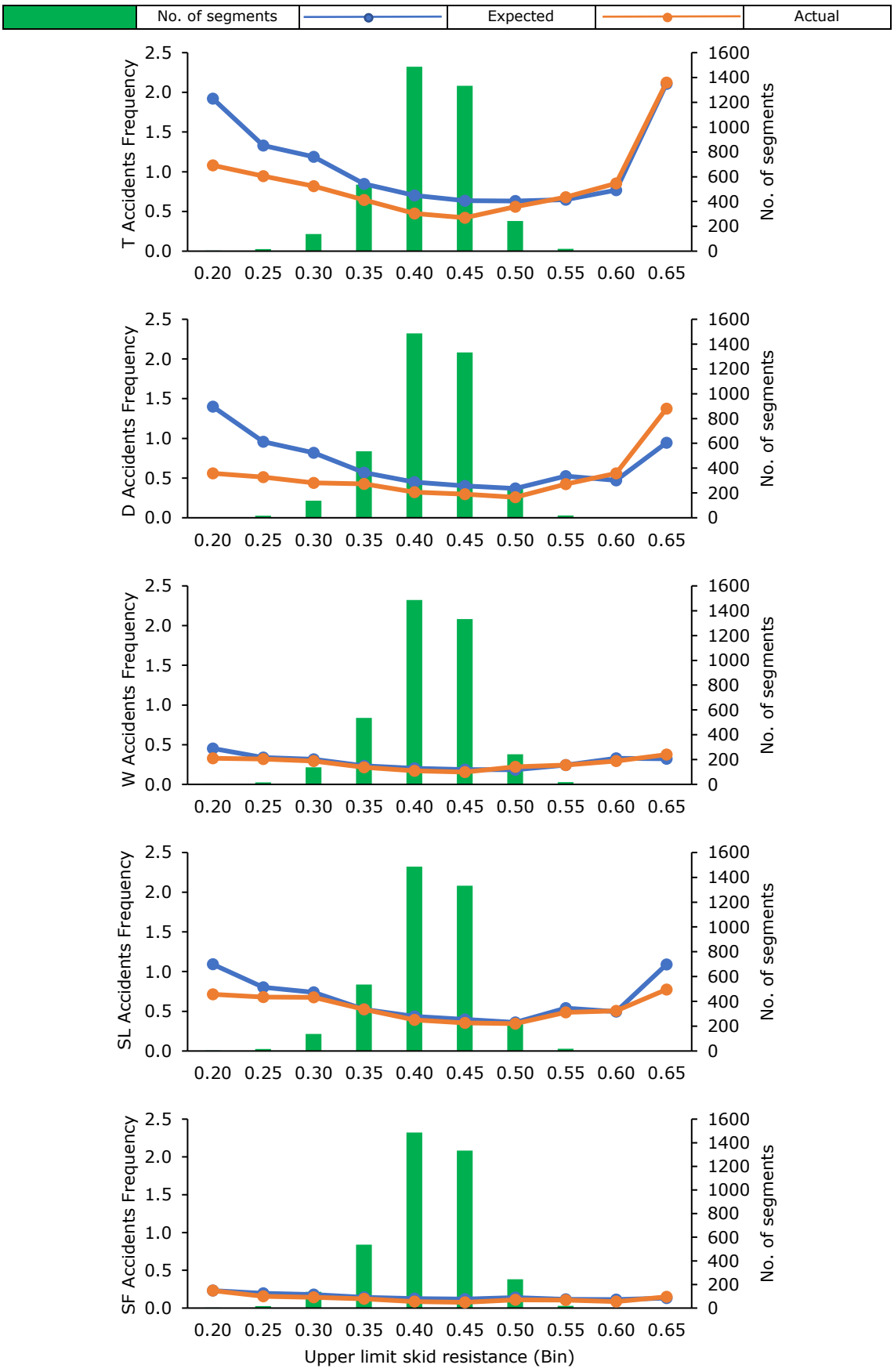


Figure 8-1: Actual and expected total, dry, wet, slight and serious and fatal accidents frequencies as a function of skid resistance for NT roadway segments for 3C network

8.2.1.2 Rate models

Table 8-3 summarises the estimated coefficient that is associated with the variable skid resistance for the expected total, dry, wet, slight and serious and fatal accident rates using RPT models for NT roadway segments. The RPT model results reveal that the skid resistance is negatively associated with total, dry, wet, slight and serious and fatal accident rates. As shown in Table 8-3, roadway segments with higher skid resistance values tends to decrease total, dry, wet, slight and serious and fatal accident rates. The decreasing effect is estimated to occur in all NT road segments for total, dry, wet and slight accident rates, while this effect is observed to be valid for the majority of roadway segments for serious and fatal accident rates as indicated by the positive effect percentage. A 10% increase in the skid resistance would decrease total, dry, wet, slight and serious and fatal accident rates by 6.32, 10.62, 12.52, 3.31, and 4.87%, respectively.

Table 8-3: Statistical details of SR coefficient for NT roadway segment rate models

Model	SR effect	Fixed (F) or Random (R)	Positive effect %	Elasticity %	Note
TAR	⬇	F	0	-6.32	TAR, DAR, WAR, SLAR and SFAR accidents rates decrease with increasing SR for the majority of NT roadway segments
DAR	⬇	F	0	-10.62	
WAR	⬇	F	0	-12.52	
SLAR	⬇	F	0	-3.31	
SFAR	⬇	R	1	-4.87	

Figure 8-2 shows the actual and expected total, dry, wet, slight and serious and fatal accident rates (RPT models results) for the NT roadway segments of the 3C network as a function of skid resistance. With regard to Figure 8-4, these points can be obtained:

- The relationship between total, dry and slight accident rates and skid resistance bins is considerably similar among the three cases, although total accident rates are slightly higher; the relationship between wet and serious and fatal accident rates, and the skid resistance is very similar.

- There is an increase in the total and dry accident rates when the skid resistance decreases below 0.45. On the other hand, wet, slight and serious and fatal accident rates decline when the skid resistance is below 0.5.
- For the NT roadway segments, the expected total and dry accident rates reduce by 53 and 60%, respectively, when the skid resistance is between 0.2 and 0.45; the expected wet, slight and serious and fatal accident rates reduce by 50, 48, and 57%, respectively, when the skid resistance increases from 0.2 to 0.5.

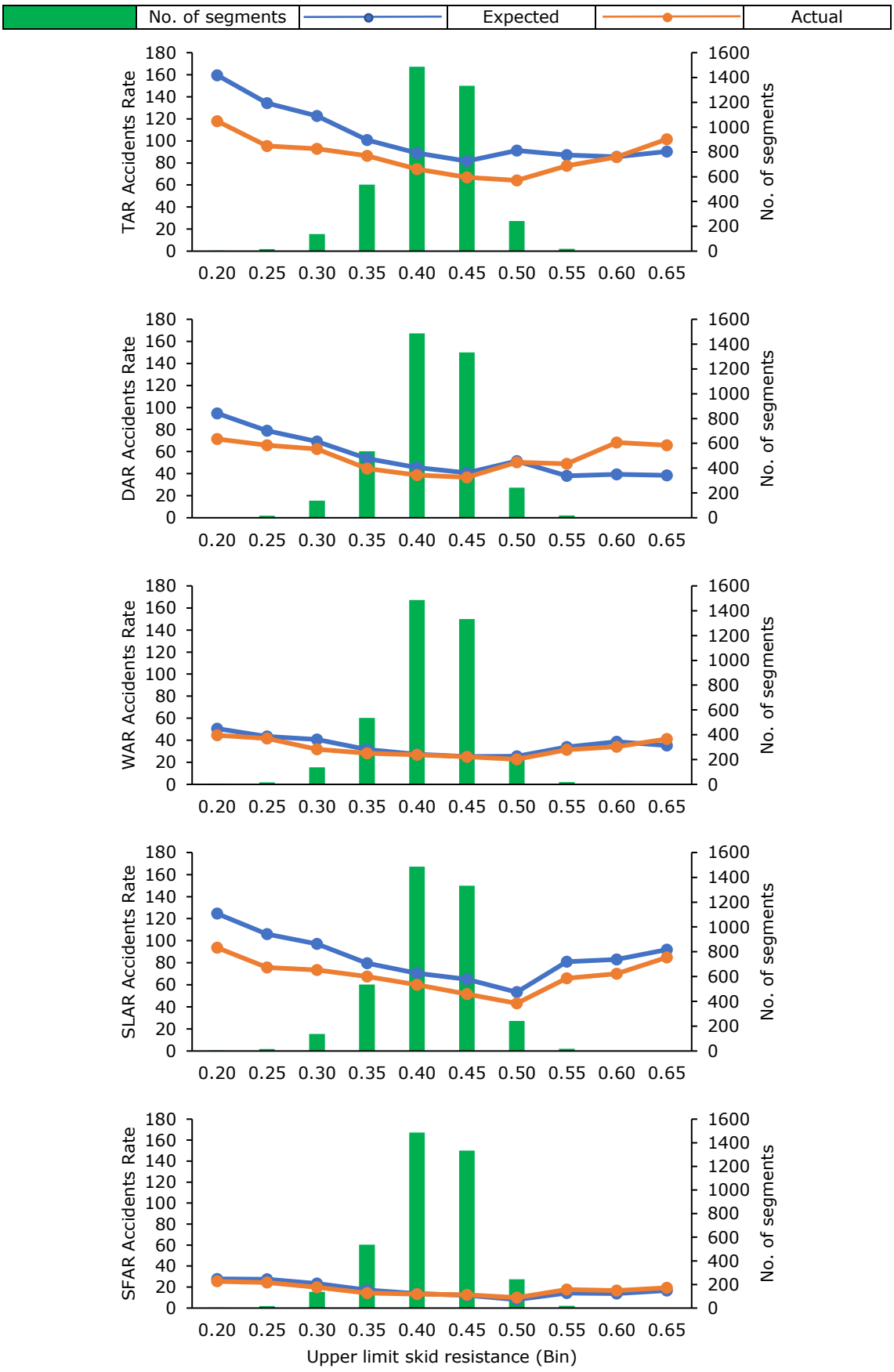


Figure 8-2: Actual and expected total, dry, wet, slight and serious and fatal accidents rates as a function of skid resistance for NT roadway segments for 3C network

8.2.2 Non- event roadway segments (NE)

As mentioned in Section 3.5, a non-event roadway segment is defined as any dual or single carriageway roadway segment with no roundabouts, junctions, or notable bends (radius of curvature ≤500 m) or gradients ≥5%, located at an A–road of 3C network.

8.2.2.1 Frequency models

Table 8-4 summarises the estimated coefficients that are associated with the variable skid resistance of the expected total, dry, wet, slight and serious and fatal accident frequencies using RPNB models for NE roadway segments. The RPNB model results reveal that skid resistance is negatively related to total, dry, wet, slight and serious and fatal accident frequencies. Regarding data in Table 8-4, skid resistance is found to influence accident frequencies as random parameter for total, dry, wet and slight models, while it resulted as fixed for serious and fatal models. The results in Table 8-4 shows that there is a lower positive effect in all accident frequency models. This implies that the majority of NE roadway segments experience a decrease in total, dry, wet and slight accident frequencies as the skid resistance increase, while all NE roadway segments experience a decrease in serious and fatal accident frequencies as the skid resistance increase. Table 8-4 suggests that for NE roadway segments, a 10% increase in skid resistance is most effective at wet accident frequencies (11.40% reduction).

Table 8-4: Statistical details of skid resistance coefficient for NE roadway segment frequency models

Model	SR effect	Fixed (F) or Random (R)	Positive effect %	Elasticity %	Note
T	⬇	R	1	-8.48	T, D, W, SL and SF accidents frequencies decrease with increasing SR for the majority of NE roadway segments
D	⬇	R	1	-9.93	
W	⬇	R	1	-11.40	
SL	⬇	R	2	-2.36	
SF	⬇	F	0	-10.53	

Figure 8-3 shows the actual and expected total, dry, wet, slight and serious and fatal accident frequencies for the NE roadway segments of 3C network as a function of the skid resistance. With regard to Figure 8-5, the following points can be obtained:

- There is an increase in the total, dry and slight accident frequencies when the skid resistance decreases below 0.45. On the other hand, wet and serious and fatal accident frequencies decline when the skid resistance increase is below 0.5.
- For the NE roadway segments the expected total, dry and slight accident frequencies reduce by 67, 74, and 67%, respectively when the skid resistance increases from 0.2 to 0.45; the expected wet and serious and fatal accident frequencies reduce by 59 and 49% respectively, when the skid resistance increases from 0.2 to 0.5.

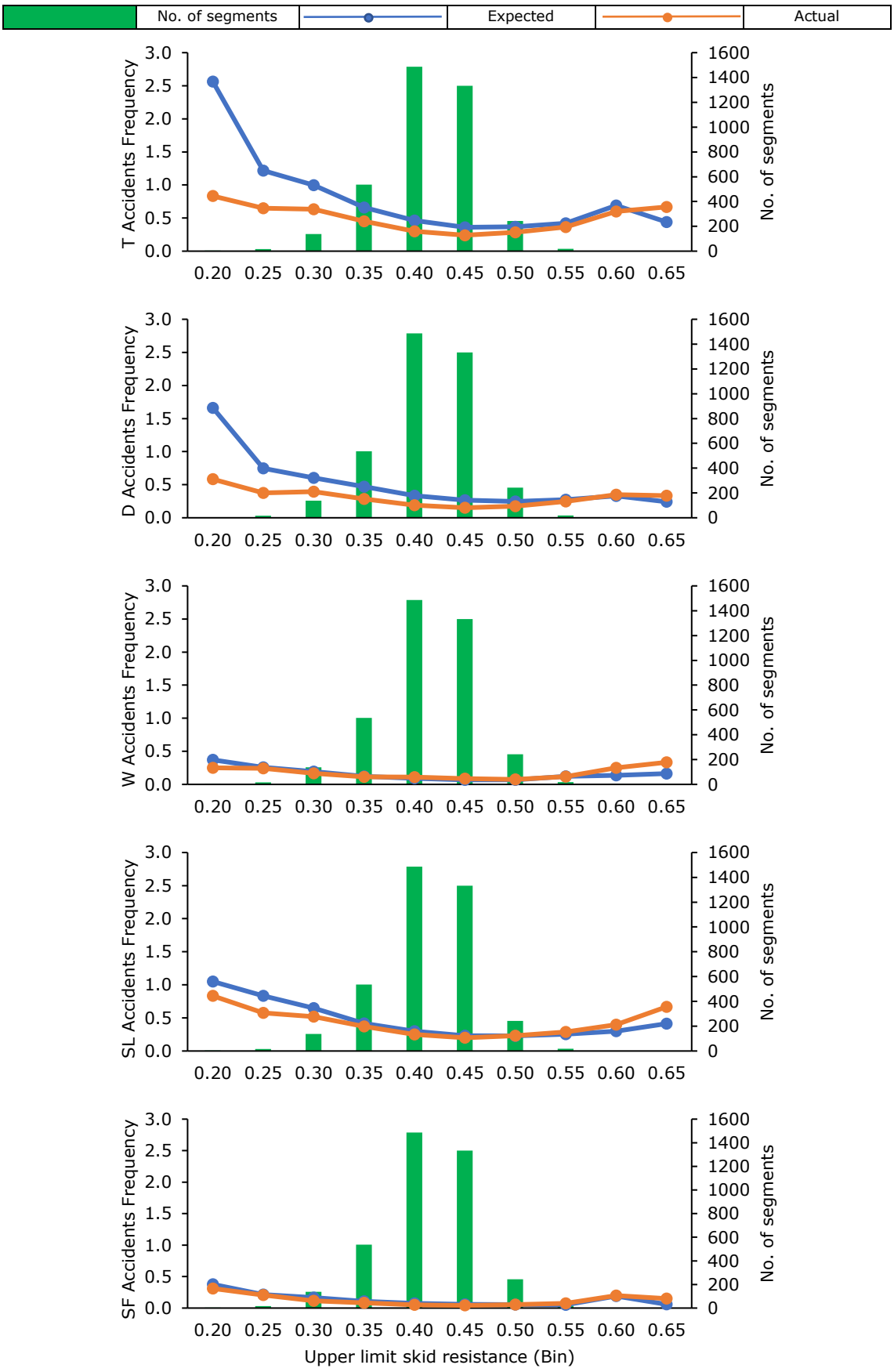


Figure 8-3: Actual and expected wet and serious and fatal accidents frequencies as a function of skid resistance for NE roadway segments for 3C network

8.2.2.2 Rate models

Table 8-5 summarises the estimated coefficients that are associated with the variable skid resistance for the expected wet and serious and fatal accident rates using RPT models for NE roadway segments. The RPT model results reveal that the skid resistance is negatively associated with the wet and serious and fatal accident rates. Skid resistance was found to have fixed effect on wet and serious and fatal accident rates, this implies that for all NE roadway segments experience an increase in accident rates as skid resistance decrease. A 10% increase in the skid resistance would decrease wet and serious and fatal accident rates by 15.29, 10.00, 14.51, 3.37, and 2.04%, respectively.

Table 8-5: Statistical details of skid resistance coefficient for NE roadway segment frequency models

Model	SR effect	Fixed (F) or Random (R)	Positive effect %	Elasticity %	Note
TAR	⬇	F	0	-15.29	TAR, DAR, WAR, SLAR and SFAR accidents rates decrease with increasing SR for the majority of NE roadway segments
DAR	⬇	F	0	-10.00	
WAR	⬇	F	0	-14.51	
SLAR	⬇	F	0	-3.37	
SFAR	⬇	F	0	-2.04	

Figure 8-4 shows the actual and expected wet and serious and fatal accident rates for NE roadway segments of 3C network as a function of the skid resistance. From Figure 8-6, the following points can be obtained:

- The relationship between total, dry and slight the skid resistance bins is considerably similar among the three cases, although the total accident rate is slightly higher, whereas the relationship between wet and serious and fatal and the skid resistance bins is substantially similar.
- There is an increase in total, dry and slight accident rates when the skid resistance decreases to values below 0.45. On the other hand, wet and serious and fatal accident rates reduce when the skid resistance increase is below 0.5.

- For NT roadway segments, the expected total, dry and slight accident rates reduce by 67, 74, and 67%, respectively when the skid resistance is between 0.2 and 0.45; the expected wet and serious and fatal accident rates reduce by 59 and 49%, respectively, when the skid resistance increases from 0.2 to 0.5.

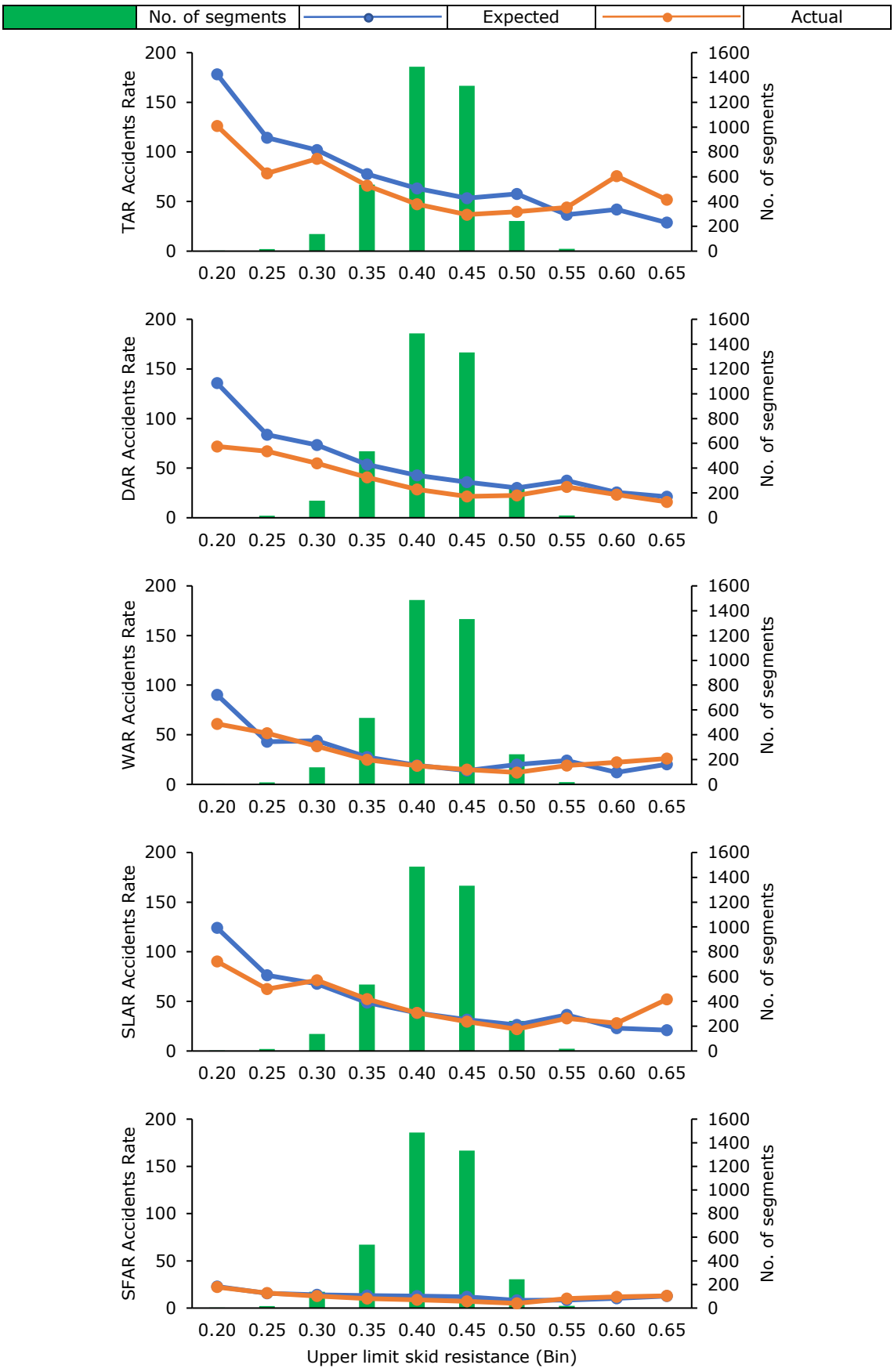


Figure 8-4: Actual and expected wet and serious and fatal accidents rates as a function of skid resistance for NE roadway segments for 3C network

8.2.3 Bends roadway segments (B1)

As mentioned in section 3.5, B1 site category is refers to any roadway segment with RC less than 250 m.

8.2.3.1 Frequency models

Table 8-6 summarises the effect of skid resistance on the expected accident frequencies of B1 roadway segments. The results of RPNB models show that the skid resistance is negatively correlated with all accident frequencies. As indicated by positive effect percentage 79, 85, 76, 79 and 100% of B1 roadway segments had a lower total, dry, wet, slight and serious and fatal accident frequencies with higher skid resistance values. On the other hand, only 21, 15, 24, 21 and 0% of B1 roadway segments skid resistance a higher total, dry, wet, slight and serious and fatal accident frequencies are expected with higher skid resistance values. This implies that increasing skid resistance is significantly related to reduce all accident frequencies at the majority of B1 roadway segments. A 10% increase in the skid resistance would decrease total, dry, wet, slight and serious and fatal accidents by 23.92, 18.43, 26.95, 22.02, and 17.13%, respectively.

Table 8-6: The effect of skid resistance coefficient for B2 roadway segment on total, dry, wet, slight and serious and fatal accident frequency models

Model	SR effect	Fixed (F) or Random (R)	Positive effect %	Elasticity %	Note
T	⬇	R	21	-23.92	T, D, W, SL and SF accidents frequencies decrease with increasing SR for the majority of B1 roadway segments
D	⬇	R	15	-18.43	
W	⬇	R	24	-26.95	
SL	⬇	R	21	-22.02	
SF	⬇	F	0	-17.13	

Figure 8-5 presents the relationship between the skid resistance bins, and the actual and expected total, dry, wet, slight and serious and fatal accident frequencies for B1 roadway segments. The RPNB model results for the expected total, dry, wet, slight and serious and fatal accident frequencies, show a significant effect of the skid

resistance on accident frequencies. The most interesting points that can be drawn from Figure 8-7 are the following:

- The relationship between total, dry and slight accident frequencies and skid resistance bins is considerably similar among the three cases, although the total accident frequency is slightly higher, whereas the relationship between wet and serious and fatal accident frequencies with the skid resistance bins is substantially similar.
- For B1 roadway segments, when the skid resistance falls below 0.45, there is a significant increase in the expected total, dry, wet, slight and serious and fatal accident frequencies.
- Reductions of 68, 60, 79, 55, and 59% in the expected total, dry, wet, slight and serious and fatal accident frequencies, respectively, are observed when the skid resistance is increased from 0.2 to 0.45.

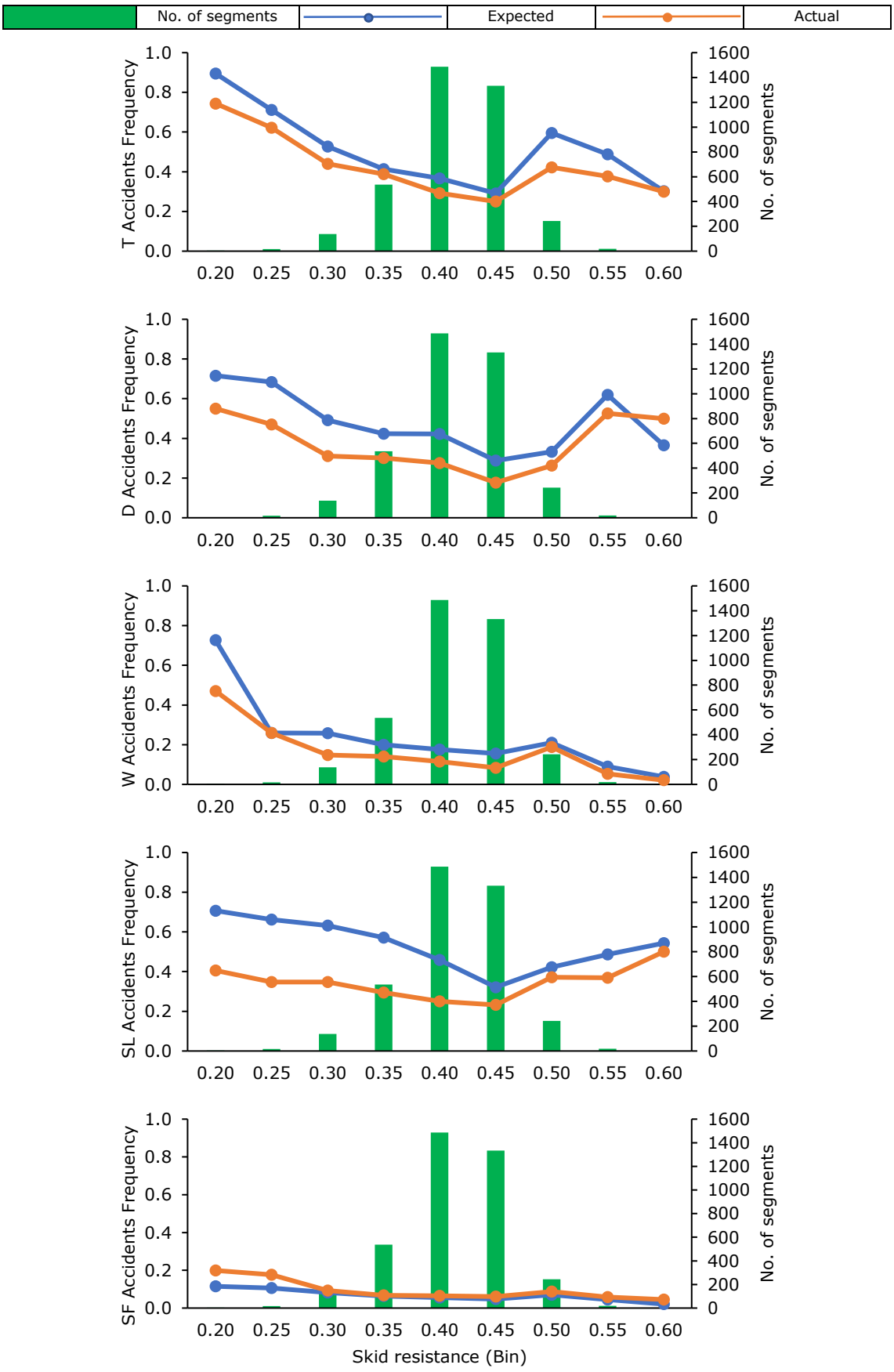


Figure 8-5: Actual and expected total, dry, wet, slight and serious and fatal accidents frequencies as a function of skid resistance for B1 roadway segments for 3C network

8.2.3.2 Rate models

Table 8-7 summarises the effect of skid resistance on the expected accident rates of B1 roadway segments. The results obtained from the RPT models show that there is a negative correlation between the skid resistance and all accident rates. According to Table 8-7, the positive effects of skid resistance indicate that only 11, 0, 0, 1 and 0 % of B1 roadway segments had higher total, dry, wet, slight and serious and fatal accident rates with higher skid resistance values. This implies that increasing skid resistance values for the majority of B1 roadway segments leads to decrease total and slight accidents, while increasing skid resistance values for all B1 roadway segments leads to decrease dry, wet and serious and fatal accident rates. A 10% increase in the skid resistance would decrease total, dry, wet, slight and serious and fatal accident rates by 15.29, 19.10, 21.89, 6.78, and 5.14%, respectively. These findings suggest that increasing skid resistance values can be improved road safety by relatively decreasing total, dry and wet compared to slight and serious and fatal accident rates.

Table 8-7: The effect of skid resistance coefficient for B1 roadway segment on total, dry, wet, slight and serious and fatal accident rate models

Model	SR effect	Fixed (F) or Random (R)	Positive effect %	Elasticity %	Note
TAR	⬇	R	11	-15.29	TAR, DAR, WAR, SLAR and SFAR accidents rates decrease with increasing SR for the majority of B1 roadway segments
DAR	⬇	F	0	-19.10	
WAR	⬇	F	0	-21.89	
SLAR	⬇	R	1	-6.78	
SFAR	⬇	F	0	-5.14	

Figure 8-6 represents the variation between the actual and expected values of total, dry, wet, slight and serious and fatal accident rates in terms of skid resistance bins. Both actual and expected accident rates show a negative trend as skid resistance values increase. Some interesting point can be deduced from Figure 8-8, as follows:

- For the majority of B1 roadway segments, when the skid resistance falls below 0.5, there is clearly an increase in the expected total, dry, wet, slight and serious and fatal accident rates.
- As shown in Figure 8-8, for the same skid resistance values, the rates of wet accident are generally lower than those of dry accidents. Similarly, the rates of serious and fatal accidents are generally lower than those of slight accidents.
- The average estimated safety effect of increasing the skid resistance below 0.5 resulted in the reduction of total, dry, wet, slight and serious and fatal accident rates by 73, 59, 80, 43, and 82%, respectively.

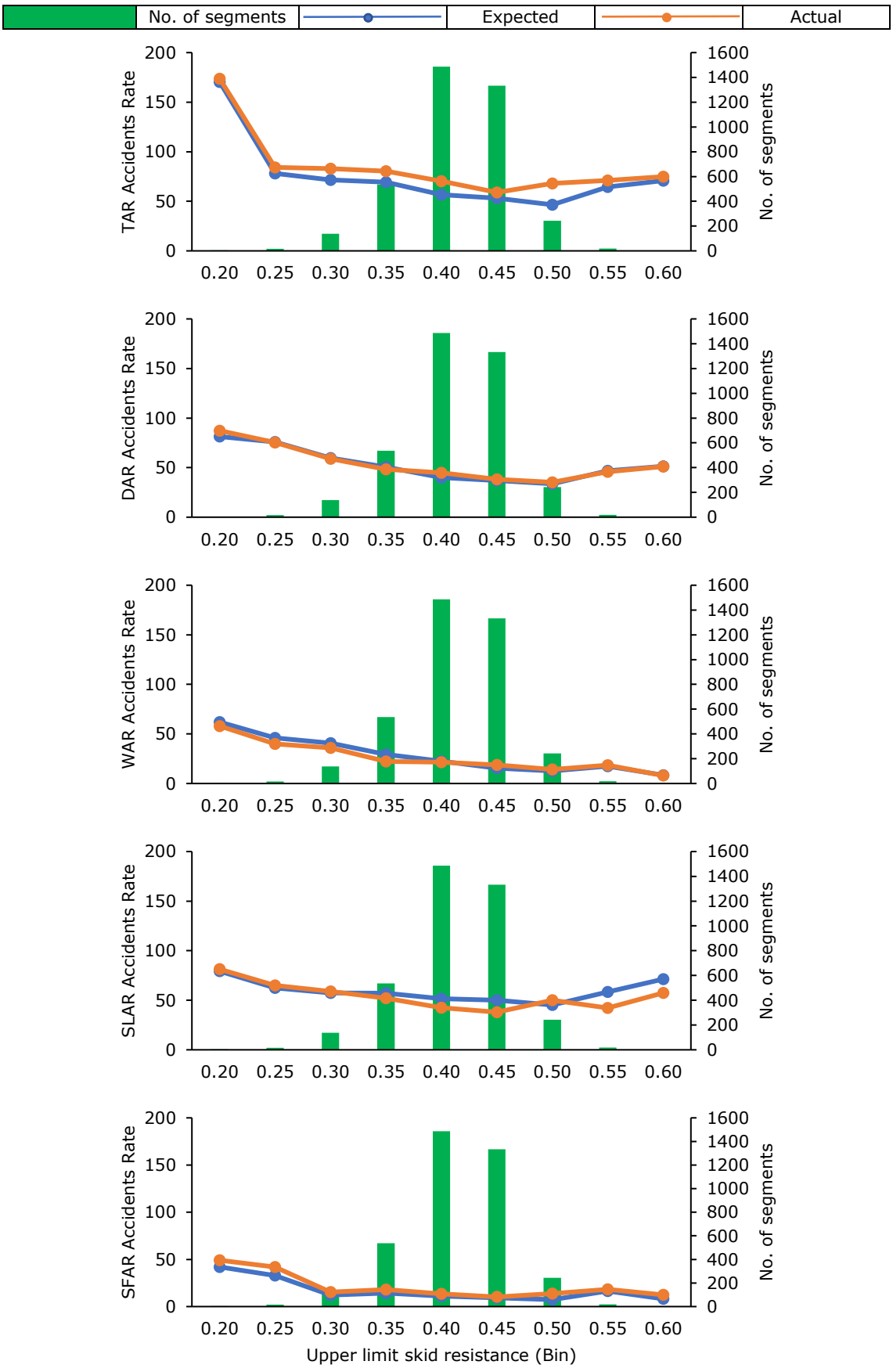


Figure 8-6: Actual and expected total, dry, wet, slight and serious and fatal accidents rates as a function of skid resistance for B1 roadway segments for 3C network

8.2.4 Bends roadway segments (B2)

As mentioned in Section 3.5, the site category B2 refers to any roadway segment with RC greater than 250 m but less than or equal to 500 m.

8.2.4.1 Frequency models

Statistically, the skid resistance significantly influences the expected total, dry, wet, slight and serious and fatal accident frequencies in B2 roadway segments. Table 8-8 summarises the effect of skid resistance on the expected accident frequencies using RPNB models for B2 roadway segments. The results of RPNB models reveal that the skid resistance is negatively associated with all accident frequencies. The influence of skid resistance on total, dry, wet and slight accidents was varied across the B2 roadway segments, while skid resistance resulted as a fixed parameter for serious and fatal accidents. This implies that for 97, 99, 99, 97 and 100% of roadway segments increasing skid resistance leads to decrease total, dry, wet, slight and serious and fatal accident frequencies; respectively. A 10% increase in the skid resistance would decrease total, dry, wet, slight and serious and fatal accidents by 11.50, 12.72, 23.8, 12.58, and 5.09%, respectively. Table 8-8 suggests that at B2 roadway segments a 10% increase in skid resistance is most effective for wet accident frequencies (23.80% reduction) but least effective for serious and fatal accident frequencies (5.09% reduction).

Table 8-8: The effect of skid resistance coefficient for B2 roadway segment on total, dry, wet, slight and serious and fatal accident frequency models

Model	SR effect	Fixed (F) or Random (R)	Positive effect %	Elasticity %	Note
T	⬇	R	3	-11.50	T, D, W, SL and SF accidents frequencies decrease with increasing SR for the majority of B2 roadway segments
D	⬇	R	1	-12.72	
W	⬇	R	1	-23.80	
SL	⬇	R	3	-12.58	
SF	⬇	F	0	-5.09	

Figure 8-7 represents the actual and expected total, dry, wet, slight and serious and fatal accident frequencies as a function of the skid resistance. In this figure it is

apparent that all accident frequencies decrease as skid resistance values increase. A number of interesting points can be concluded from Figure 8-9:

- The expected total, dry, wet, slight and serious and fatal accident frequencies decrease as the skid resistance values increase, following a negative trend. This trend is valid for total and slight accident frequencies when skid resistance values are greater than 0.3 and less than 0.45; this trend is valid for dry, wet and serious and fatal accident frequencies when the skid resistance values are greater than 0.25 and less than 0.45.
- The expected total, dry, wet, slight and serious and fatal accident frequencies reduce by 55, 56, 41, 58, and 89%, respectively, when the skid resistance increases from 0.20 to 0.5.

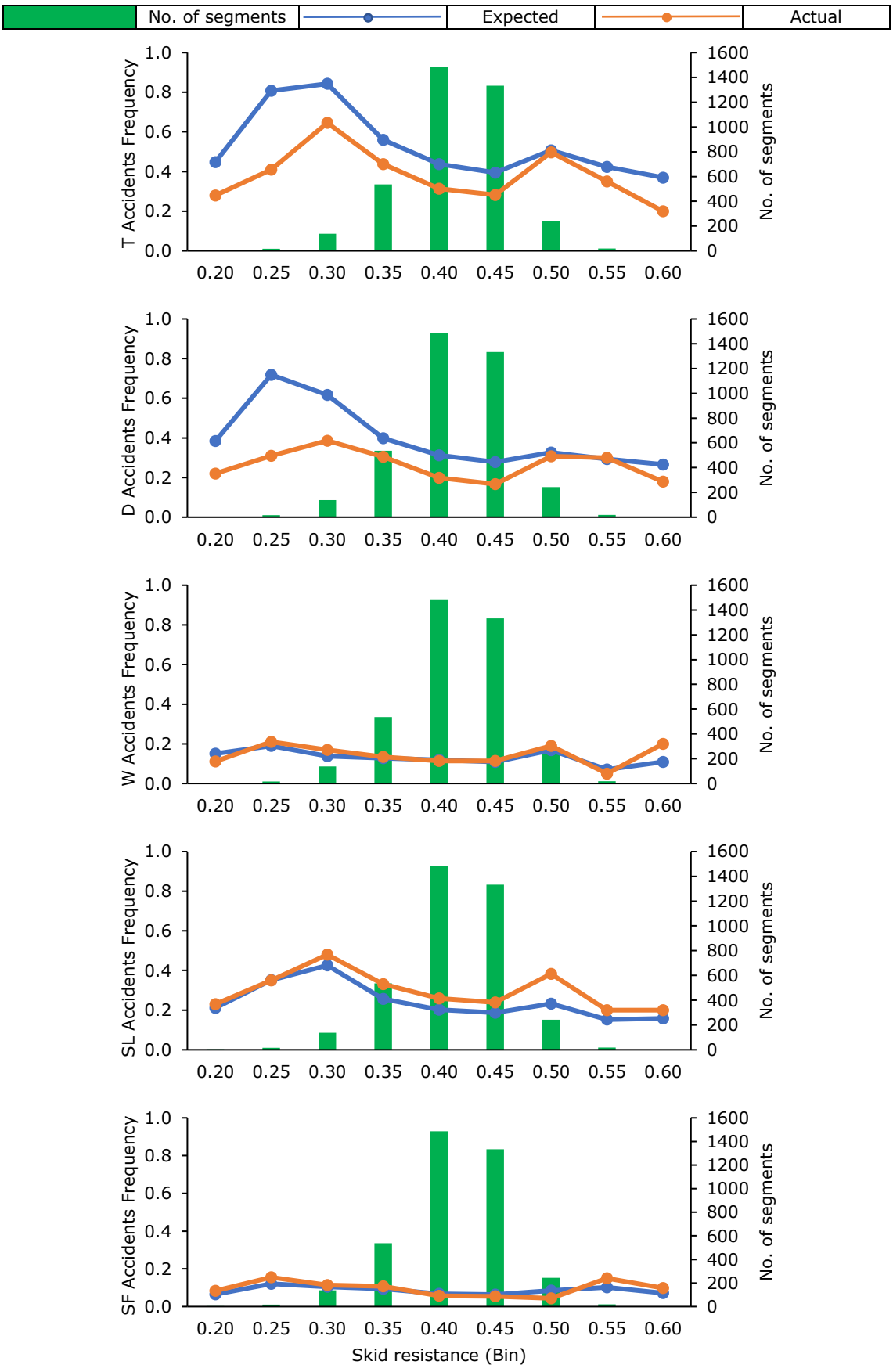


Figure 8-7: Actual and expected total, dry, wet, slight and serious and fatal accidents frequencies as a function of skid resistance for B2 roadway segments for 3C network

8.2.4.2 Rate models

Table 8-9 summarises the effect of skid resistance on the expected accident rates for B2 roadway segments. The results obtained from the RPT models show that there is a negative correlation between the skid resistance and all accident rates. The influence of skid resistance on total and slight accident rates was fixed across the B2 roadway segments. This indicates that increasing skid resistance always decreases both total and slight accident rates. On the other hand, the influence of skid resistance on dry, wet and serious and fatal accident rates was varied across B2 roadway segments. The positive effect of skid resistance for dry, wet and serious and fatal models are 1, 12 and 46%, respectively. This implies that increasing skid resistance nearly always decrease both dry and wet accident rates, while increasing skid resistance for half of B2 roadway segments leads to decrease serious and fatal accident rates. A 10% increase in the skid resistance would decrease dry, wet and serious and fatal accident rates by 10.51, 12.65, 17.05, 4.49, and 4.13%, respectively. Table 8-9 suggests that at B2 roadway segments a 10% increase in skid resistance is most effective for wet accident rates (17.05% reduction) but least effective for serious and fatal accident rates (4.13% reduction).

Table 8-9: The effect of skid resistance coefficient for B2 roadway segment on dry, wet and serious and fatal accident rate models

Model	SR effect	Fixed (F) or Random (R)	Positive effect %	Elasticity %	Note
TAR	⬇	F	0	-10.51	TAR, DAR, WAR, SLAR and SFAR accidents rates decrease with increasing SR for the majority of B2 roadway segments
DAR	⬇	R	1	-12.65	
WAR	⬇	R	12	-17.05	
SLAR	⬇	F	0	-4.49	
SFAR	⬇	R	46	-4.13	

Figure 8-8 shows the actual and expected dry, wet and serious and fatal accident rates of B2 roadway segments as a function skid resistance bins. A number of interesting points can be obtained from Figure 8-10:

- The five plots are similar and show a significant decrease in the expected dry, wet and serious and fatal accident rates when the skid resistance increase is below 0.45.
- As shown in Figure 8-10, for the same skid resistance values, the rates of wet accident are generally lower than those of dry accidents. Similarly, the rates of slight accident rates are generally lower than those of serious and fatal accident rates.
- The expected total, dry, wet, slight and serious and fatal accident rates reduce by 52, 69, 41, 43, and 65%, respectively, when the skid resistance values increase from 0.2 to 0.45.

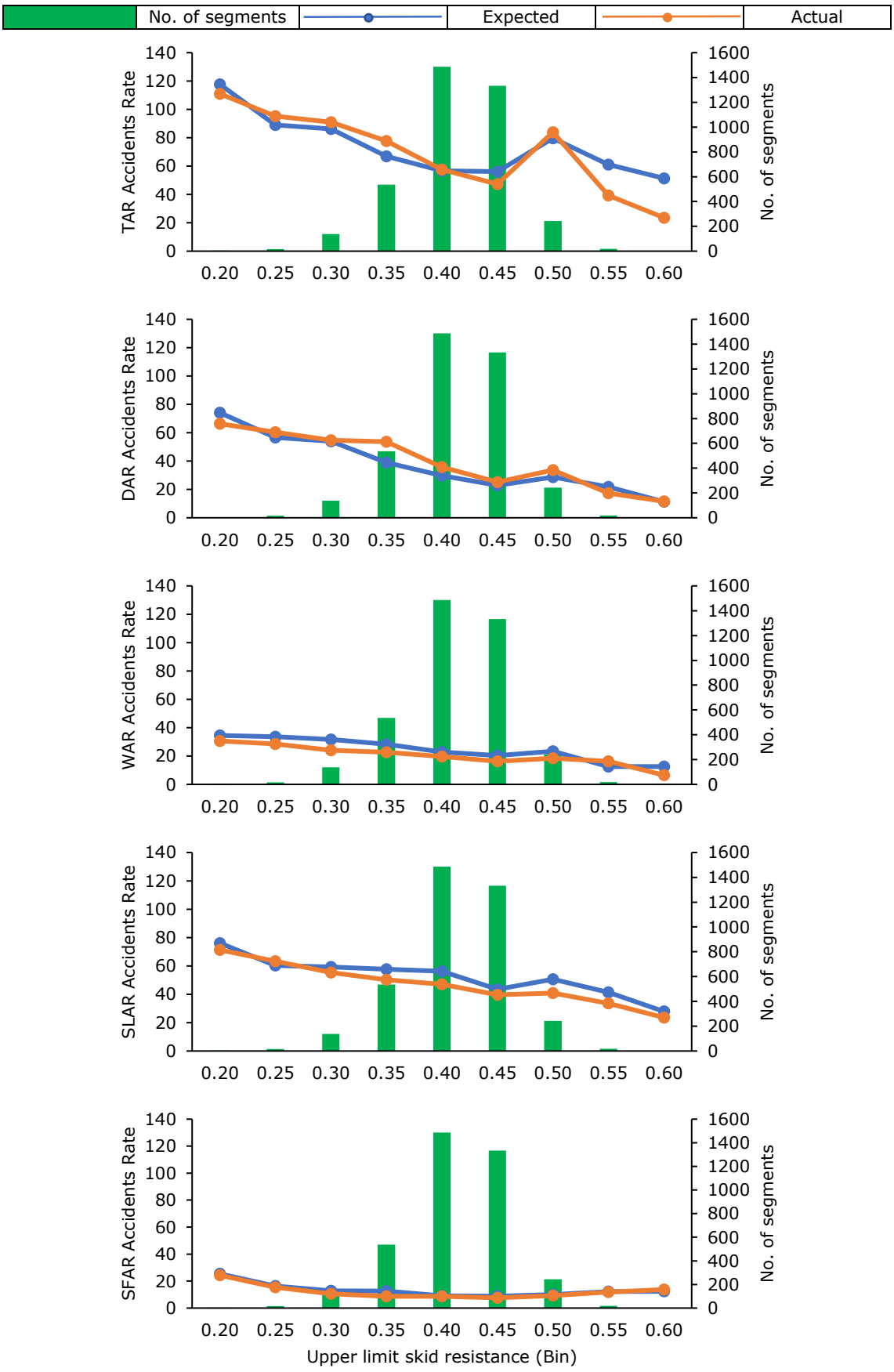


Figure 8-8: Actual and expected total, dry, wet, slight and serious and fatal accidents rates as a function of skid resistance for B2 roadway segments for 3C network

8.2.5 Roundabout roadway segments (RA)

As mentioned in section 3.5, the RA site category can be defined as any roadway segments across roundabout and any roadway segments that located within 50m from the outer edge of the roundabout in all directions.

8.2.5.1 Frequency models

Table 8-10 summarises the effect of skid resistance on the expected accident frequencies using RPNB models for RA roadway segments. The results obtained from the RPNB models show that there is a negative correlation between the skid resistance and all accident frequencies.

The skid resistance had varied effect on total, wet and slight models at RA roadway segments. Table 8-10 shows that a 10% increase in skid resistance leads to decrease total, wet and slight accident frequencies by 9.36, 12.20 and 7.24% respectively for 84, 79 and 87% of RA roadway segments. However, 16, 21 and 13% of RA roadway segments expected higher total, wet and slight accidents with higher skid resistance values. On the other hand, the effect of skid resistance on dry and serious and fatal models was fixed across the RA roadway segments, a 10 % increase in skid resistance leads to decrease dry and serious and fatal accident frequencies by 10.21 and 0.34%, respectively for all RA roadway segments. This result suggests that, skid resistance is significantly related to decrease total, dry, wet and slight accident frequencies, while it is hardly related to reduce serious and fatal accident frequencies.

Table 8-10: The effect of skid resistance coefficient for RA roadway segment on total, dry, wet, slight and serious and fatal accident frequency models

Model	SR effect	Fixed (F) or Random (R)	Positive effect %	Elasticity %	Note
T	⇩	R	16	-9.36	T, D, W, SL and SF accidents frequencies decrease with increasing SR for the majority of RA roadway segments
D	⇩	F	0	-10.21	
W	⇩	R	21	-12.20	
SL	⇩	R	13	-7.24	
SF	⇩	F	0	-0.34	

Figure 8-9 shows the actual and expected total, dry, wet, slight and serious and fatal accident frequencies for RA roadway segments as a function of skid resistance bins. A number of interesting points can be concluded from Figure 8-11:

- Based on the relationship between the skid resistance and all expected accident frequencies, total, dry, wet, slight and serious and fatal accident frequencies decrease as the skid resistance value increases following an exponential trend. Such a trend is valid for total and dry accident frequencies when the skid resistance is greater than 0.2 and less than 0.45. On the other hand, this trend is valid for wet, slight and serious and fatal accident frequencies when skid resistance is greater than 0.2 and less than 0.5.
- The expected total, dry, wet, slight and serious and fatal accident frequencies reduce by 55, 73, 67, 83, 75, and 58%, respectively, when the skid resistance increases from 0.2 to 0.45.

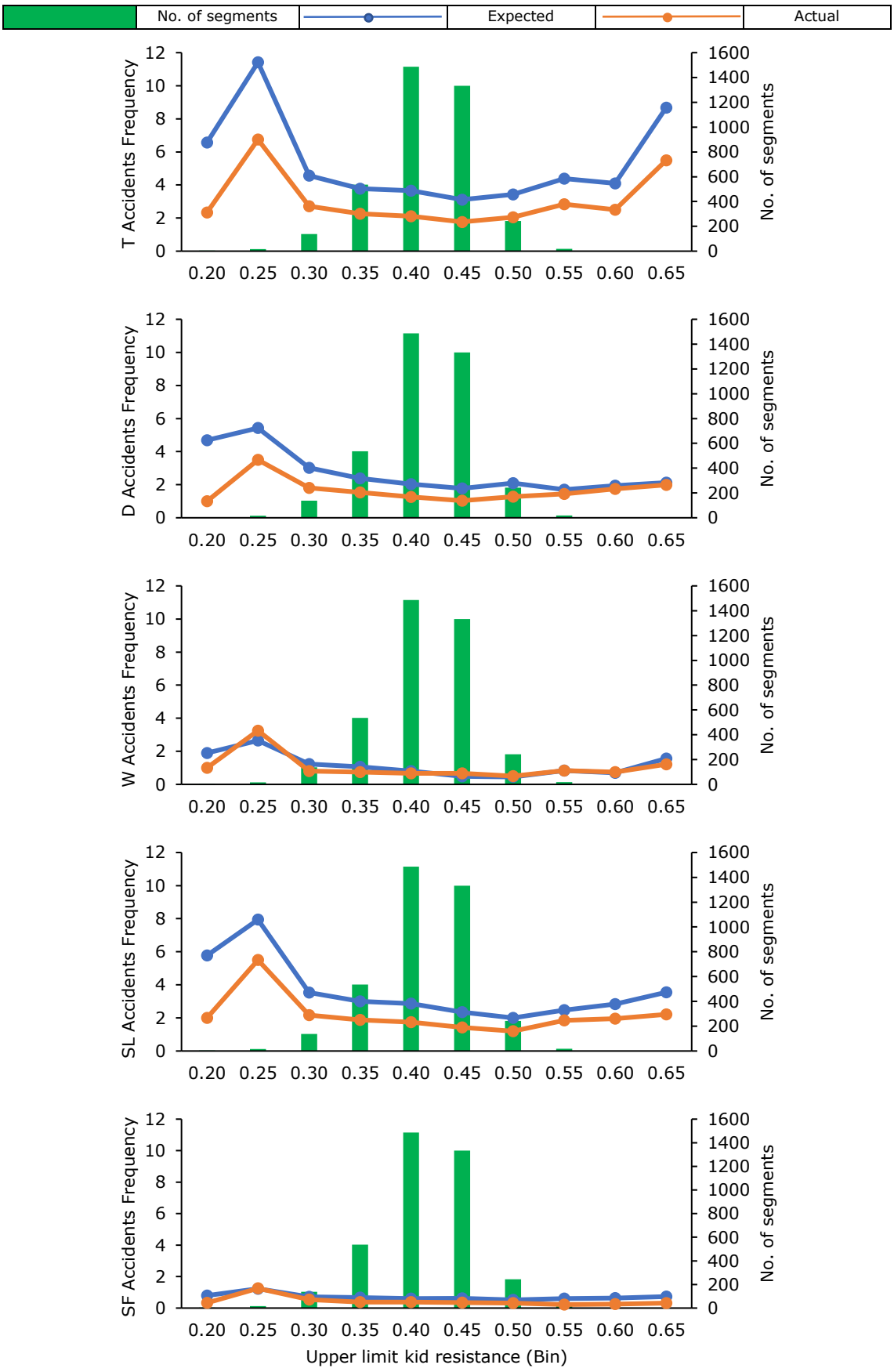


Figure 8-9: Actual and expected total, dry, wet, slight and serious and fatal accidents frequencies as a function of skid resistance for RA roadway segments for 3C network

8.2.5.2 Rate models

Table 8-11 summarises the effect of skid resistance on the expected accident rates for RA roadway segments. The results obtained from the RPT models show that there is a negative correlation between the skid resistance and all accident rates. The skid resistance had varied effect on total, slight and serious and fatal accident rates at RA roadway segments. The result in Table 8-11 shows that 92, 96 and 99% of RA roadway segments had lower total, slight and serious and fatal accident rates with higher skid resistance values. However, only 8, 4 and 1% of RA roadway segments had higher total, slight and serious and fatal accident rates with higher skid resistance values. For dry and wet accident rates the effect of skid resistance was found to be fixed across RA segments. This implies that increasing skid resistance values leads to decrease both dry and wet accident rates across all RA segments. A 10% increase in the skid resistance would decrease total, dry, wet, slight and serious and fatal accident rates by 7.77, 8.25, 13.61, 5.66, and 1.88%, respectively. It can therefore be seen that as skid resistance increases, WAR accident rates are significantly reduced in comparison with other accident rates.

Table 8-11: The effect of skid resistance coefficient for RA roadway segment on total, dry, wet, slight and serious and fatal accident rate models

Model	SR effect	Fixed (F) or Random (R)	Positive effect %	Elasticity %	Note
TAR	⬇	R	8	-7.77%	TAR, DAR, WAR, SLAR and SFAR accidents rates decrease with increasing SR for the majority of RA roadway segments
DAR	⬇	F	0	-8.25%	
WAR	⬇	F	0	-13.61%	
SLAR	⬇	R	4	-5.66%	
SFAR	⬇	R	1	-1.88%	

Figure 8-10 shows the actual and expected total, dry, wet, slight and serious and fatal accident rates for RA roadway segments as a function of skid resistance bins. A few interesting points can be concluded from Figure 8-10:

- The five plots are similar and show a significant negative trend for all actual accident rates when the skid resistance increase is below 0.5. These findings

are also supported by the relationship between skid resistance and all expected accident rate results, which reveal that when the skid resistance value is below 0.5, it has a significant effect on the expected total, dry, wet, slight and serious and fatal accident rates.

- For the same skid resistance values, the rates of wet accidents are generally lower than those of dry accidents. Similarly, the rates of serious and fatal accidents are generally lower than those of slight accidents.
- The expected total, dry, wet, slight and serious and fatal accident rates reduce by 40, 62, 58, 32, and 63%, respectively, when the skid resistance increases from 0.2 to 0.5.

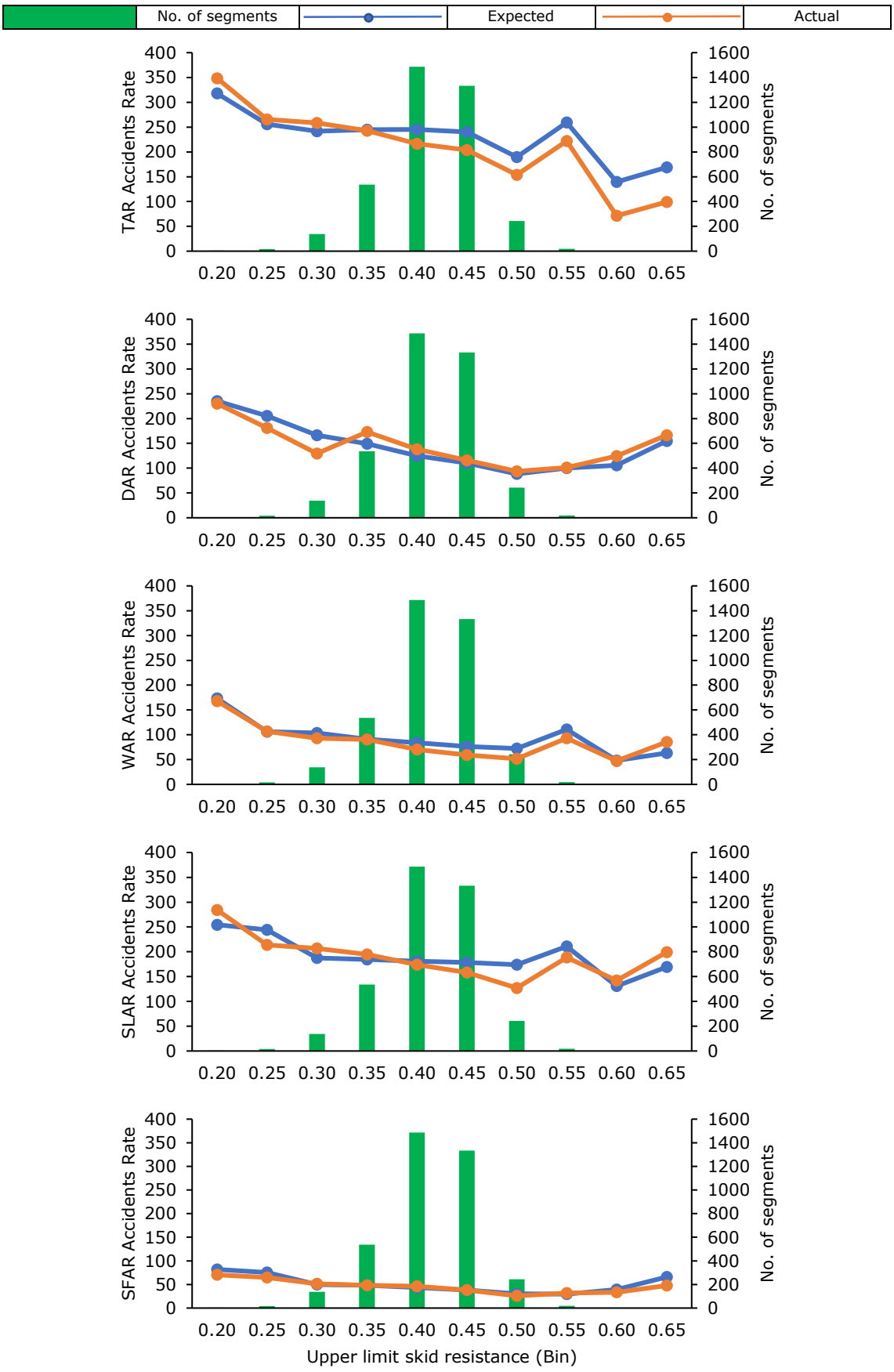


Figure 8-10: Actual and expected total, dry, wet, slight and serious and fatal accidents rates as a function of skid resistance for RA roadway segments for 3C network

8.2.6 Junctions roadway segments (JN)

As mentioned in Section 3.5, the JN site category can be defined as any roadway segment across minor roads and any road segment located within 50 m from the junction boundary in all direction.

8.2.6.1 Frequency models

Table 8-12 summarises the effect of skid resistance on the expected accident frequencies using RPNB models for the JN roadway segments. The results of RPNB models reveal that the skid resistance is negatively associated with all accident frequencies. As shown in Table 8-12, increases in skid resistance decrease total, dry, wet, slight and serious and fatal accident frequencies in 74, 83, 96, 78 and 100%, respectively. On the other hand, increases in skid resistance increase total, dry, wet, slight and serious and fatal accident frequencies in 26, 17, 4, 22 and 0% of the JN roadway segments, respectively. This implies that increasing skid resistance at the majority of JN roadway segments leads to decrease all accidents frequencies. A 10% increase in the skid resistance would decrease total, dry, wet, slight and serious and fatal accidents by 2.23, 2.21, 4.21, 3.08, and 0.63%, respectively. This finding suggests relatively related to reduce total, dry, wet and slight accident frequencies, while skid resistance is hardly related to reduce serious and fatal accident frequencies.

Table 8-12: The effect of skid resistance coefficient for JN roadway segment on and serious and fatal accident frequency models

Model	SR effect	Fixed (F) or Random (R)	Positive effect %	Elasticity %	Note
T	⬇	R	26	-2.23%	T, D, W, SL and SF accidents frequencies decrease with increasing SR for the majority of JN roadway segments
D	⬇	R	17	-2.21%	
W	⬇	R	4	-4.21%	
SL	⬇	R	22	-3.08%	
SF	⬇	F	0	-0.63%	

Figure 8-11 represents the actual and expected and serious and fatal accident frequencies as a function of the skid resistance. In the figure, there is a distinct

reduction in all accident frequencies with increasing skid resistance values. A few interesting points can be obtained from Figure 8-13:

- For all accident frequencies, there is a negative exponential trend. This trend can be observed for all expected accident frequencies when skid resistance decreases to values below 0.45. This is practically true for all accident frequencies; however, its value is higher for the expected total than dry, wet, slight and serious and fatal accident frequencies.
- The expected total, dry, wet, slight and serious and fatal accident frequencies reduce by 55, 56, 41, 58, and 89%, respectively, when skid resistance increases from 0.20 to 0.5.

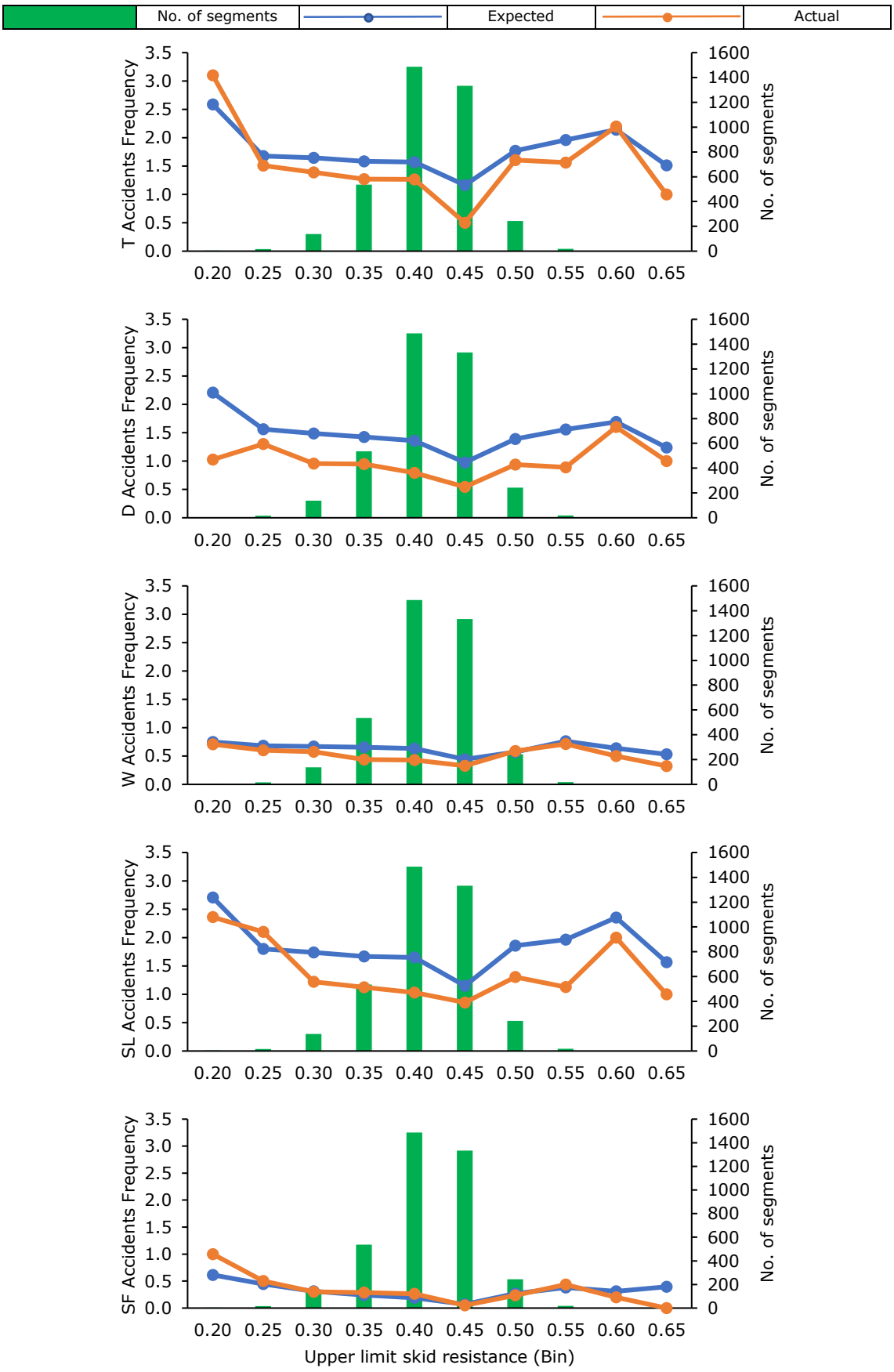


Figure 8-11: Actual and expected total, dry, wet, slight and serious and fatal accidents frequencies as a function of skid resistance for JN roadway segments for 3C network

8.2.6.2 Rate models

Roadway segments with higher skid resistance values have fewer total, dry, wet, slight and serious and fatal accident rates. Table 8-13 summarises the effect of skid resistance on the expected accident rates for JN roadway segments. The results of RPT model show that there is a significant negative correlation between the skid resistance and expected total, dry, wet, slight and serious and fatal accident rates. As shown in Table 8-13, increases in skid resistance decrease total, dry, wet, slight and serious and fatal accident rates in 74, 83, 96, 78 and 100%, respectively. On the other hand, increases in skid resistance increase total, dry, wet, slight and serious and fatal accident rates in 26, 17, 4, 22 and 0% of the JN roadway segments, respectively. A 10% increase in the skid resistance would decrease total, dry, wet, slight and serious and fatal accident rates by 2.23, 2.21, 4.21, 3.08, and 0.63%, respectively. This finding suggests relatively related to reduce total, dry, wet and slight accident rates, while skid resistance is hardly related to reduce serious and fatal accident rates.

Table 8-13: The effect of skid resistance coefficient for JN roadway segment on total, dry, wet, slight and serious and fatal accident rate models

Model	SR effect	Fixed (F) or Random (R)	Positive effect %	Elasticity %	Note
TAR	⬇	F	0	-3.39%	TAR, DAR, WAR, SLAR and SFAR accidents rates decrease with increasing SR for the majority of JN roadway segments
DAR	⬇	F	0	-2.66%	
WAR	⬇	R	2	-6.42%	
SLAR	⬇	R	40	-3.58%	
SFAR	⬇	R	1	-1.32%	

The variation in total, dry, wet, slight and serious and fatal accidents rates with skid resistance bins for both actual and expected is presented in Figure 8-12. This figure produced numerous findings:

- For the majority of JN roadway segments skid resistance is statistically negative significant factor in explaining the variation in the actual accident rates. In the RPT accident rate models this trend is found to be very

significant, the expected total, dry, wet, slight and serious and fatal accidents rates increase with decreasing skid resistance.

- There is an obvious trend of decreasing in the expected total, dry, wet, slight and serious and fatal accidents rates, when skid resistance falls below 0.5.
- For the majority of JN roadway segments evaluated, the expected reduction in total, dry, wet, slight and serious and fatal accidents rates by 47%, 38%, 50%, 34% and 49%, respectively, due to increasing skid resistance from 0.2 to 0.5.
- Regardless of skid resistance values dry accident rates is significantly higher than wet accident rates. Similarly, slight accident rates is significantly higher than serious and fatal accident rates.

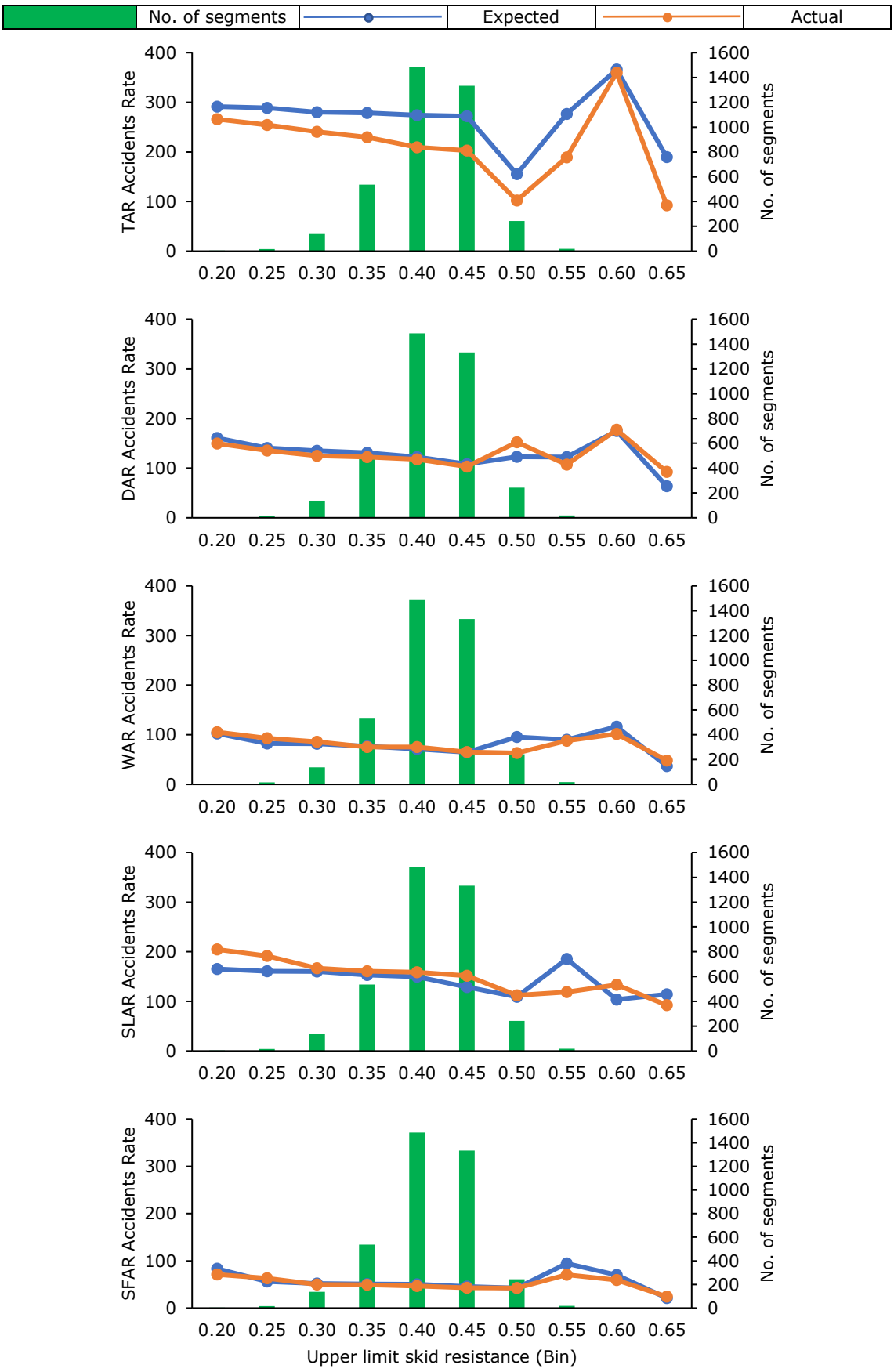


Figure 8-12: Actual and expected total, dry, wet, slight and serious and fatal accidents rates as a function of skid resistance for JN roadway segments for 3C network

8.2.7 Gradients roadway segments (GR)

As mentioned in Section 3.5 GR site category is defined as any roadway segments with %G ≥5%.

8.2.7.1 Frequency models

Table 8-14 summarises the effect of estimated coefficients associated with the variable skid resistance for the expected total, dry, wet, slight and serious and fatal accident frequencies of GR roadway segments. The results of RPNB models reveal that the skid resistance is negatively associated with the total, dry, wet, slight and serious and fatal accident frequencies. For total, dry, wet, slight and serious and fatal accident frequency models the effect of skid resistance was found to be fixed across GR roadway segments. This implies that increases skid resistance decreases total, dry, wet, slight and serious and fatal accident frequencies at all GR roadway segments. As seen in Table 8-13 at GR site category a 10% increase in skid resistance is most effective for slight accident frequencies (18.43% reduction) and least effective for dry accident frequencies (9.60% reduction).

Table 8-14: The effect of skid resistance coefficient for GR roadway segment on total, dry, wet, slight and serious and fatal accident frequency models

Model	SR effect	Fixed (F) or Random (R)	Positive effect %	Elasticity %	Note
T	⬇	F	0	-11.41%	T, D, W, SL and SF accidents frequencies decrease with increasing SR for all GR roadway segments
D	⬇	F	0	-5.36%	
W	⬇	F	0	-10.11%	
SL	⬇	F	0	-12.19%	
SF	⬇	F	0	-11.85%	

The variations in the actual and expected total, dry, wet, slight and serious and fatal accident frequencies with skid resistance for the GR site category are presented in Figure 8-13. The following points can be summarised from this figure:

- For all accident frequencies, there is a negative exponential trend for all expected accident frequencies when the skid resistance decreases to values below 0.5.

- The expected total, dry, wet, slight and serious and fatal accident frequencies reduce by 70, 78, 82, 78, and 91%, respectively, due to the increase of skid resistance from 0.2 to 0.5.

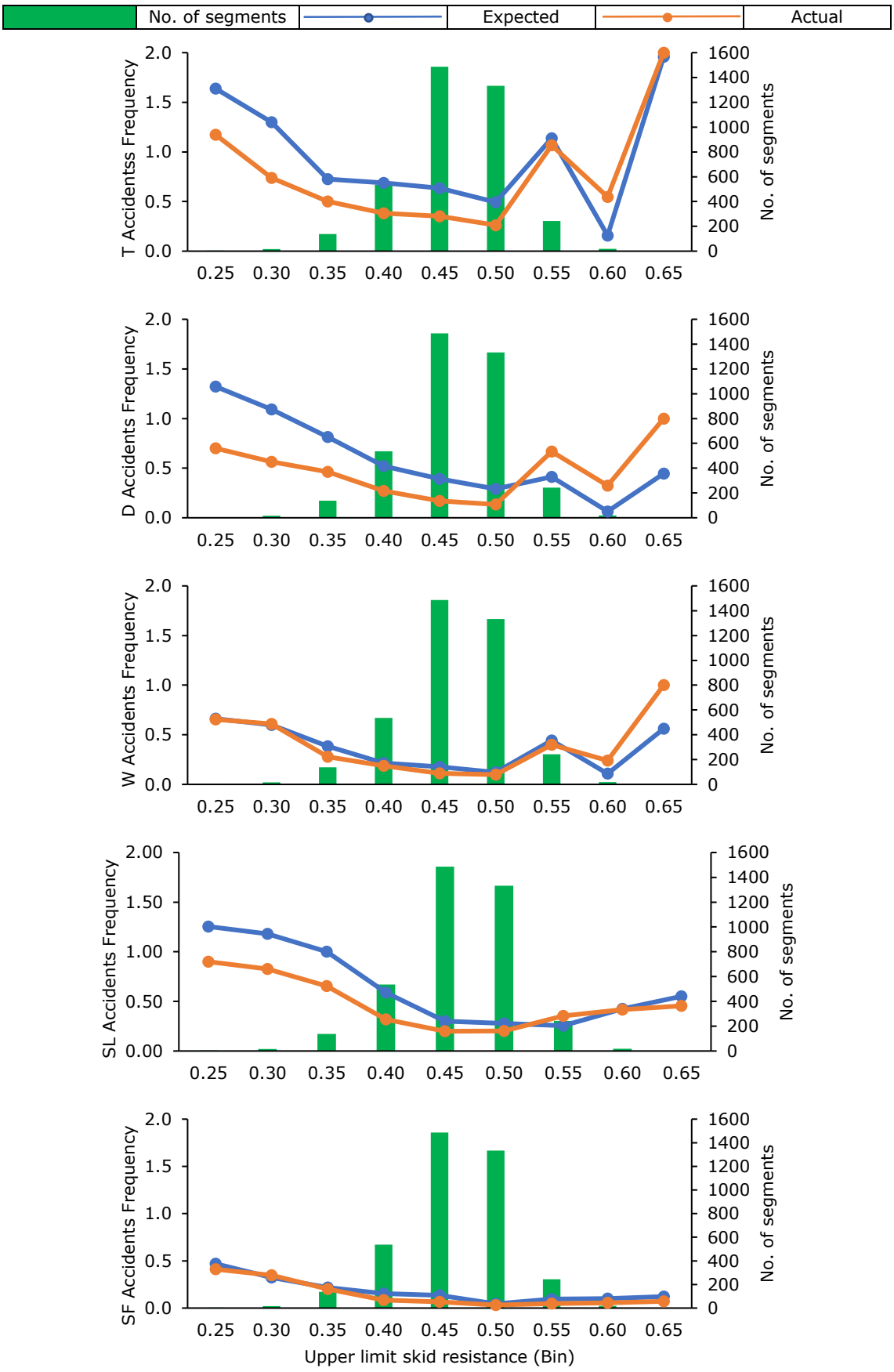


Figure 8-13: Actual and expected total, dry, wet, slight and serious and fatal accidents frequencies as a function of skid resistance for GR roadway segments for 3C network

8.2.7.2 Rate models

Table 8-15 summarises the effect of estimated coefficients associated with the variable skid resistance for the expected total, dry, wet, slight and serious and fatal accident rates of GR roadway segments. The results of RPT models reveal that skid resistance is negatively associated with all accident rates. For total, dry, wet, slight and serious and fatal accident rate models the effect of skid resistance was found to be fixed across GR roadway segments. This implies that increases skid resistance decreases total, dry, wet, slight and serious and fatal accident rates at all GR roadway segments. A 10% increase in the skid resistance would decrease accident rates by 12.34, 5.06, 15.85, 8.79, and 8.61%, for total, dry, wet, slight and serious and fatal accident rates, respectively. A 10% increase in skid resistance values is most effective for wet accident rates and least effective for dry accident rates.

Table 8-15: The effect of skid resistance coefficient for GR roadway segment on total, dry, wet, slight and serious and fatal accident rate models

Model	SR effect	Fixed (F) or Random (R)	Positive effect %	Elasticity %	Note
TAR	⬇	F	0	-12.34%	TAR, DAR, WAR, SALR and SFAR accidents rates decrease with increasing SR for all GR roadway segments
DAR	⬇	F	0	-5.06%	
WAR	⬇	F	0	-15.85%	
SLAR	⬇	F	0	-8.79%	
SFAR	⬇	F	0	-8.61%	

The variations in the actual and expected total, dry, wet, slight and serious and fatal accident rates with skid resistance for the GR site category are presented in Figure 8-14. The following points can be summarised from the figure:

- For all accident rate datasets, the total, dry and slight accident rates are significantly higher than the wet and serious and fatal accident rates, regardless of the skid resistance values.
- The expected total, dry, wet, slight and serious and fatal accident rates decrease as the skid resistance increases, following a negative exponential trend; this trend is valid for skid resistance values less than 0.55. However,

this finding must be treated with some caution, especially for skid resistance less than 0.3 because of the limited number of roadway segments.

- For GR roadway segments, the expected total, dry, wet, slight and serious and fatal accident rates reduce by 70, 78, 82, 78, and 91%, respectively, when the skid resistance value is between 0.2 and 0.55.

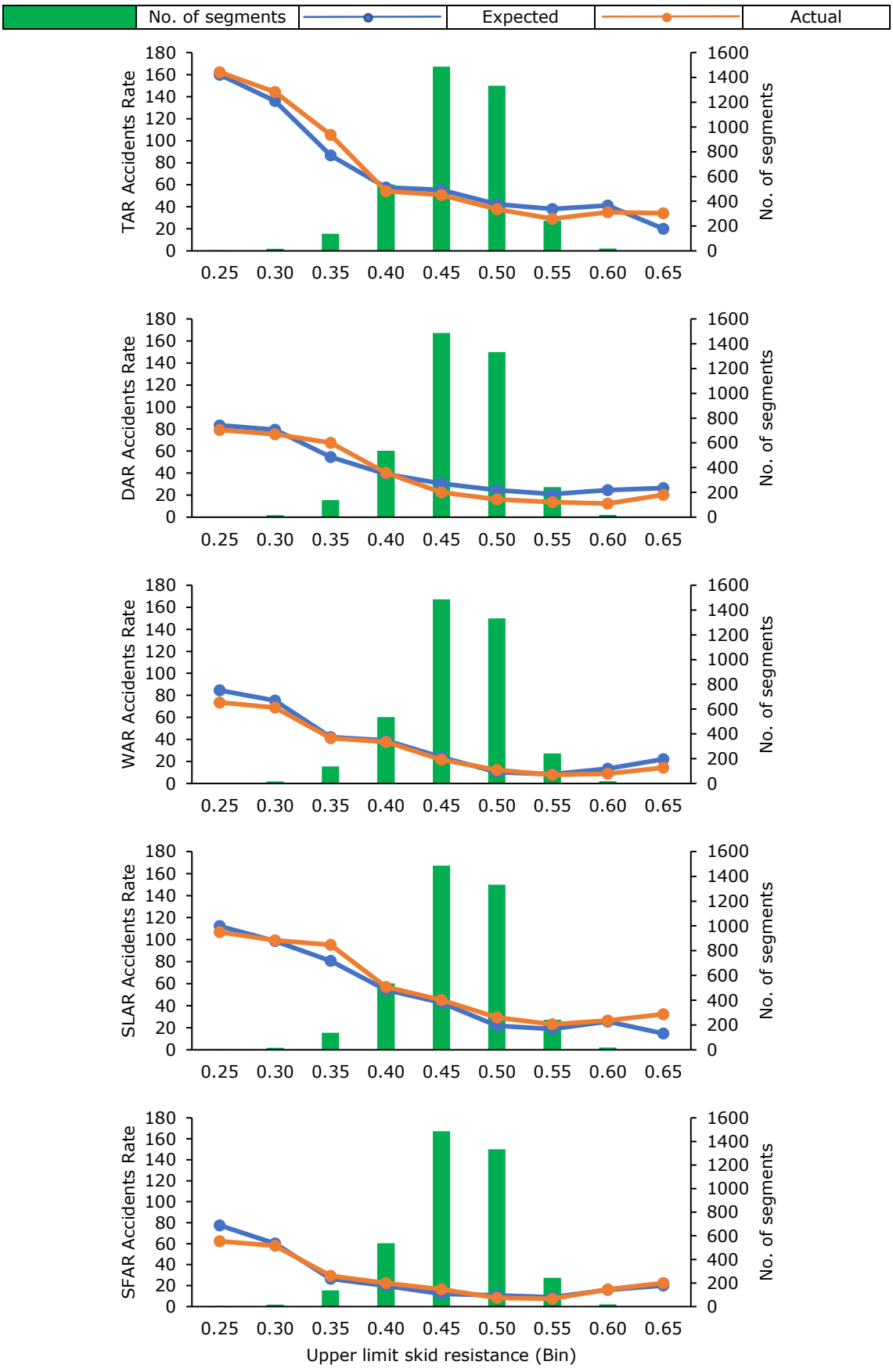


Figure 8-14: Actual and expected total, dry, wet, slight and serious and fatal accidents rates as a function of skid resistance for GR roadway segments for 3C network

8.3 Skid resistance threshold determination

The skid resistance threshold values for different site categories and different accident types can be identified by evaluating the curve characteristics of the relationship between the expected accident frequency (total, dry, wet, slight and serious and fatal accident frequencies) and accident rate (total, dry, wet, slight and serious and fatal accident rates) with skid resistance bins. The inflection point method is proposed to identify the required skid resistance threshold, below which the expected accident frequencies or rates would increase at relatively rate with the decrease in the selected skid resistance threshold.

8.4 Recommended skid resistance thresholds

Based on the relationship between the expected total, dry, wet, slight and serious and fatal accident frequencies and skid resistance bins and the relationship of the expected total, dry, wet, slight and serious and fatal accident rates and skid resistance bins, which were all reviewed above, new site category definitions and new skid resistance thresholds are recommended for the different types of accident frequencies and rates.

- NE

This site category, which defined as any single carriageway roadway segment with no roundabouts or junctions, or notable bends (radius of curvature, RC≤500 m) or gradients ≥5%, located in an A–road in the 3C network. This site category is matched to the non-event single carriageway site category in HD 28/15.

As shown in Figures 8-3 and 8-4, the skid resistance thresholds for all accident frequencies above (0.45 to 0.50), is the same as that for all accident rates, thus (0.45 – 0.50) has been adopted as the recommended skid resistance threshold for NE site category.

Table 8-16 summarises the recommended skid resistance thresholds for the different types of accident frequencies and rates for NE roadway segments.

Table 8-16: Skid resistance threshold values for NE roadway segments

Accident frequency	SR threshold	Accident rate	SR threshold
T	0.45 – 0.50	TAR	0.45 – 0.50
D	0.45 – 0.50	DAR	0.45 – 0.50
W	0.45 – 0.50	WAR	0.45 – 0.50
SL	0.45 – 0.50	SLAR	0.45 – 0.50
SF	0.45 – 0.50	SFAR	0.45 – 0.50

Referring to section 7.3.4 both the RPNB and PRT models show that number of minor access to be a significant variable in all site categories models, especially for NE site category models (see Figures 7-13 and 7-14). The RPNB and RPT models show that number of minor access is positively correlated with both accident frequencies and rates. This indicates that the high number of minor access in all NE roadway segments is associated with increasing both total, dry, wet, slight and serious and fatal accident frequencies and rates. This finding may be explained by the fact that roadway segments with high number of minor access attract more traffic volume, which leads to the increase in the number of vehicles travelling in opposite directions—major and minor. Thus, a higher skid resistance is required for emergency braking.

- B1 and B2

Site category B1 refers to any roadway segment with radius of curvature less than or equal to 250 m, whereas site category B2 pertains to any roadway segment with radius of curvature greater than 250 m but less than or equal 500 m. These two site categories are matched to bends site category (radius of curvature<500 m) at single carriageway in HD 28/15.

As shown in Figures 8-5 and 8-6, it is recommended that the skid resistance threshold for roadway segments with radius of curvature below 250m should be 0.45 to 0.50 for both all accident frequency and rate types.

Similarly, it is recommended that the skid resistance threshold for roadway segments with radius of curvature more than 250m and below 500m should be 0.45 to 0.50 for both all accident frequency and rate types (see Figures 8-7 and 8-8).

Table 8-17 summarises the recommended skid resistance thresholds for the different types of accident frequencies and rates for B1 and B2 roadway segments.

Table 8-17: Skid resistance threshold values for B1 and B2 roadway segments

B1			
Accident frequency	SR threshold	Accident rate	SR threshold
T	0.45 -0.50	TAR	0.45 -0.50
D	0.45 -0.50	DAR	0.45 -0.50
W	0.45 -0.50	WAR	0.45 -0.50
SL	0.45 -0.50	SLAR	0.45 -0.50
SF	0.45 -0.50	SFAR	0.45 -0.50
B2			
Accident frequency	SR threshold	Accident rate	SR threshold
T	0.45 -0.50	TAR	0.45 -0.50
D	0.45 -0.50	DAR	0.45 -0.50
W	0.45 -0.50	WAR	0.45 -0.50
SL	0.45 -0.50	SLAR	0.45 -0.50
SF	0.45 -0.50	SFAR	0.45 -0.50

As expected, both RPNB and PRT models show that radius of curvatures to be a significant variable in all site categories models, especially for B1 and B2 site category models (as discussed in section 7.3.1). The RPNB and RPT models show that the radius of curvature is negatively correlated to both accident frequencies and rates. This indicates that the lower radius of curvature in the majority of B1 and B2 roadway segments is associated with the increasing both total, dry, wet, slight and serious and fatal accident frequencies and rates comparable to those of roadway segments with the higher radius of curvature. Roadway segments with a small radius of curvature require high skid resistance levels to help drivers manoeuvre their vehicles around sharp curves safely by overcoming the centrifugal force developed as vehicles move along the curve.

- RA

The RA site category can be defined as any roadway segment in a roundabout and any road segment located within 50 m from the outer edge of the roundabout in any direction. This site category matches the roundabout site category in HD 28/15.

As shown in Figures 8-9 and 8-10, for RA site category the level of accident frequencies and rates is higher than other site categories, for this reason a higher skid resistance threshold are recommended for RA site category. Thus, it is

recommended that skid resistance threshold range from 0.50 to 0.55 in order to allow for a large reduction in all accident frequency and rate types.

Table 8-18 summarises the recommended skid resistance thresholds for the different types of accident frequencies and rates for the RA roadway segments.

Table 8-18: Skid resistance threshold values for RA roadway segments

Accident frequency	SR threshold	Accident rate	SR threshold
T	0.45 – 0.50	TAR	0.50 – 0.55
D	0.45 – 0.50	DAR	0.50 – 0.55
W	0.50 – 0.55	WAR	0.50 – 0.55
SL	0.50 – 0.55	SLAR	0.50 – 0.55
SF	0.50 – 0.55	SFAR	0.50 – 0.55

- JN

The JN site category can be defined as any roadway segment across minor and major junctions and any road segment located within 50 m from the junction boundary in each direction. This site category is matched to approaches, and across minor and major junction site category in HD 28/15.

In spite of, the higher level of all accident frequencies for JN site category in comparison with NE site category, same skid resistance threshold for all accident frequency types (0.45 -0.50) has been adopted for JN site category (see Figure 8-11).

As shown in Figure 8-12, for JN site category all accident rates are generally higher than for NE site category roadway segments, thus a higher skid resistance threshold than NE site category is recommended, that is above 0.50 to 0.55.

Table 8-19 summarises the recommended skid resistance thresholds for the different types of accident frequencies and rates for the JN roadway segments.

Table 8-19: Skid resistance threshold values for JN roadway segments

Accident frequency	SR threshold	Accident rate	SR threshold
T	0.45 – 0.50	TAR	0.50 – 0.55
D	0.45 – 0.50	DAR	0.50 – 0.55
W	0.45 – 0.50	WAR	0.50 – 0.55
SL	0.45 – 0.50	SLAR	0.50 – 0.55
SF	0.45 – 0.50	SFAR	0.50 – 0.55

The RPNB and RPT models show that texture depth is negatively correlated with both accident frequencies and rates in all models. Referring to section 7.4.3 both RPNB and PRT models show that texture depth to be a significant variable in all site categories models, especially for both RA and JN site categories (see Figures 7-19 and 7-20). For the majority of JN and RA roadway segment increasing texture depth is associated with decreasing both total, dry, wet, slight and serious and fatal accident frequencies and rates. Therefore, it is suggested that the texture depth be considered as one of the important factors that contribute to the reduction of accidents, especially for roadway segments where braking manoeuvres (RA and JN) are more common.

- GR

The GR site category refers to any roadway segment with gradient more than or equal to 5%. This site category matches the 5–10% gradient and gradient>10% site categories in HD 28/015. For GR site category, there is a clear trend to increase all accident frequencies at lower skid resistance values. As shown in Figure 8-13, the level of all accident frequencies on NE site category, at the recommended skid resistance thresholds, have the same trend for this site category at a skid resistance of approximately 0.45 to 0.50 and this range is recommended, therefore, as the skid resistance threshold for GR site category. Referring to Figure 8-14, higher accident rates are observed for GR site category, thus, skid resistance threshold range of 0.5 – 0.55 is recommended for all accident rate types for this site category.

Table 8-19 summarises the recommended skid resistance thresholds for different accident frequencies and rate types for the GR roadway segments.

Table 8-19: Skid resistance threshold values for GR roadway segments

Accident frequency	SR threshold	Accident rate	SR threshold
T	0.45 – 0.50	TAR	0.50 – 0.55
D	0.45 – 0.50	DAR	0.50 – 0.55
W	0.45 – 0.50	WAR	0.50 – 0.55
SL	0.45 – 0.50	SLAR	0.50 – 0.55
SF	0.45 – 0.50	SFAR	0.50 – 0.55

Referring to section 7.3.2 both RPNB and PRT models show the gradient to be a significant variable in all site categories models especially for the GR site category models. Increasing gradient in the majority of the GR roadway segment is associated with increases in both total, dry, wet, slight and serious and fatal accident frequencies and rates. In the GR site category, the main safety concern is the braking distance of roadway segments. Hence, high skid resistance values are required to reduce the braking distance.

8.4.1 Recommended action for highway agencies

The relationship between the total, dry, wet, slight and serious and fatal accident frequencies and rates and skid resistance bin can be defied into four zones as shown in Figure 8-15, according to these four zones it can be recommended three thresholds for skid resistance values, therefore, due to theses threshold it can be recommended the actions that should be carried out by the local highway agency to maintain the pavement surface or not due to the values of skid resistance thresholds.

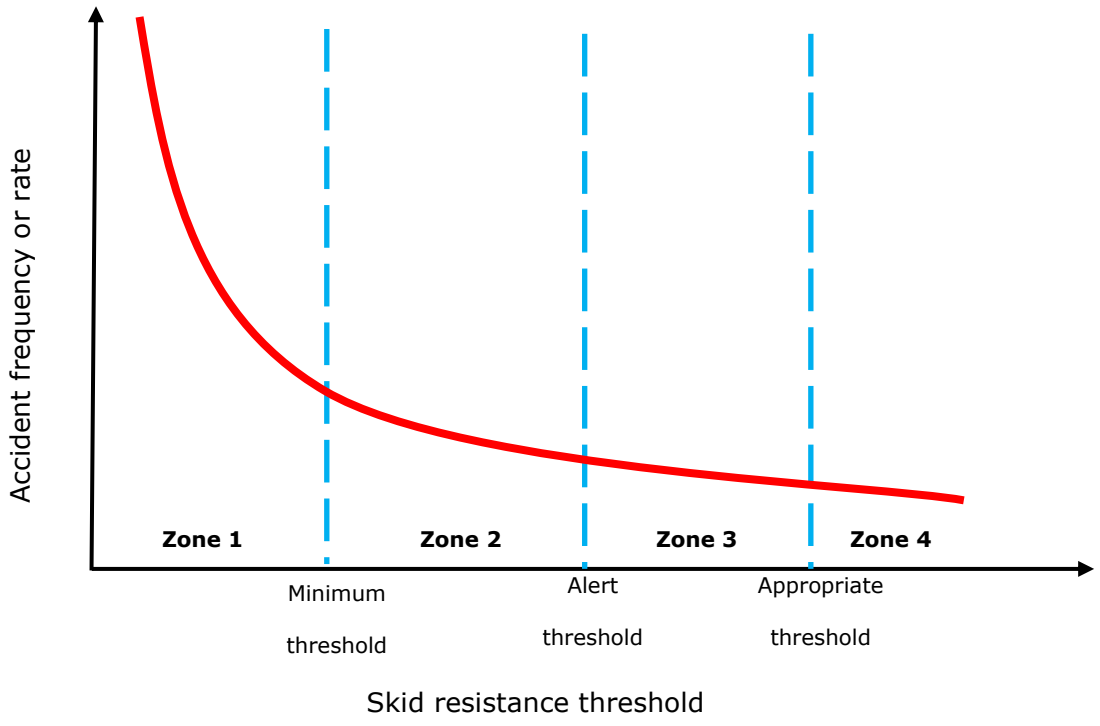


Figure 8-15: Typical skid resistance thresholds

After determining the skid resistance threshold for different site categories, it is recommended to make an action for each threshold obtained from Figure 8-15. Table 8- 20 shows the recommended action that should be carried out by local highway agency based on different skid resistance thresholds.

Table 8-20: Suggested actions for highway agency

Zone	Skid resistance value	Recommended Action
1	Skid resistance < Minimum threshold (SR1)	Urgent action needs to increase the value of skid resistance
2	Minimum threshold (SR1) <Skid resistance < Alert threshold (SR2)	Critical action needs more studying to prove that skid resistance is the significant factor on accident frequencies or rates
3	Alert threshold (SR2) <Skid resistance < Appropriate threshold (SR3)	Recommended for safety requirements
4	Skid resistance > Appropriate threshold (SR3)	Increasing in skid resistance could be has minor effect on accident frequencies or rates

- Zone 1

If the skid resistance level is below the minimum skid resistance threshold (SR1), the accident frequencies or rates increases significantly as skid resistance decrease, thus urgent pavement maintenance should be carried out by the local highway agency to solve this case.

- Zone 2

The roadway segments with skid resistance values between the minimum skid resistance threshold and the alert skid resistance threshold are suggested as critical action need more studying to prove that skid resistance is the significant factor on accident frequencies or rates.

- Zone 3

The roadway segments with skid resistance values between the alert skid resistance threshold and the appropriate skid resistance threshold are recommended for local highway agencies as an appropriate skid resistance value for safety perspective.

- Zone 4

The appropriate skid resistance threshold (SR3) can be defied as the yielded value of skid resistance where once it is reached, more increase in skid resistance could have a minor effect on decreasing the accident frequencies and rates. Therefore; and from safety perspective any roadway segments with skid resistance value more than SR3 would be consider as well well-maintained in terms of skid resistance and no further action is need.

8.4.2 Maintenance priority for different site categories

The objective of this section is to find the maintenance priority for different skid resistance bins for NE, B1, B2, RA, JN and GR site categories for total, dry, wet, slight and serious and fatal accidents different based on the reduction in accident frequencies due to 10% increase in skid resistance.

The reduction in accident frequencies for each skid resistance bins is calculated based on Equation (8 – 1):

$$RD\ (\%) = \frac{N_{AC} * E_{SR}}{N_{SG}} \qquad (8 - 1)$$

Where:

RD (%): Reduction in accident frequency; $N_{AC:}$ Number of accident frequency; E_{SR}: Elasticity effect of skid resistance; and N_{SG}: Number of segments.

Tables 8-21 to 8-24 show the reduction in total, dry, wet, slight and serious and fatal accident frequencies and rates for different skid resistance bins. For example, based on Equation (8 – 1) the reduction in total accident frequency for NE site category at skid resistance bin (0.2 – 0.3) is 5%.

Table 8- 21: Reduction in accident frequencies for different site categories for skid resistance (0.2 – 0.3)

Accident	Site category	Elasticity (E_{SR})	N_{AC}	N_{SG}	RD (%)
Total	NE	-8.48	329	530	5%
	B1	-18.92	73	155	9%
	B2	-11.41	103	176	7%
	RA	-9.36	122	39	29%
	JN	-2.23	230	142	4%
	GR	-10.85	28	25	12%
Dry	NE	-11.40	208	530	4%
	B1	-9.78	51	155	3%
	B2	-8.43	61	176	3%
	RA	-10.21	77	39	20%
	JN	-4.21	139	142	4%
	GR	-5.36	14	25	3%
Wet	NE	-15.60	122	530	4%
	B1	-23.31	22	155	3%
	B2	-15.95	42	176	4%
	RA	-12.20	41	39	13%
	JN	-9.21	76	142	5%
	GR	-14.85	14	25	8%
Slight	NE	-2.36	269	530	1%
	B1	-17.68	61	155	7%
	B2	-12.19	94	176	7%
	RA	-10.70	98	39	27%
	JN	-3.08	182	142	4%
	GR	-8.99	20	25	7%
Serious and fatal	NE	-11.20	60	530	1%
	B1	-15.72	12	155	1%
	B2	-11.85	9	176	1%
	RA	-5.34	24	39	3%
	JN	-3.63	48	142	1%
	GR	-7.14	8	25	2%

Table 8-22: Reduction in accident frequencies for different site categories for skid resistance (0.3 – 0.4)

Accident	Site category	Elasticity (E_{SR})	N_{AC}	N_{SG}	RD (%)
Total	NE	-8.48	3528	10537	3%
	B1	-18.92	671	2022	6%
	B2	-11.41	888	2590	4%
	RA	-9.36	1599	743	20%
	JN	-2.23	2536	1950	3%
	GR	-10.85	281	623	5%
Dry	NE	-11.40	2219	10537	2%
	B1	-9.78	424	2022	2%
	B2	-8.43	580	2590	2%
	RA	-10.21	989	743	14%
	JN	-4.21	1618	1950	3%
	GR	-5.36	191	623	2%
Wet	NE	-15.60	1307	10537	2%
	B1	-23.31	247	2022	3%
	B2	-15.95	306	2590	2%
	RA	-12.20	543	743	9%
	JN	-9.21	836	1950	4%
	GR	-14.85	89	623	2%
Slight	NE	-2.36	2913	10537	1%
	B1	-17.68	531	2022	5%
	B2	-12.19	715	2590	3%
	RA	-10.70	1320	743	19%
	JN	-3.08	2058	1950	3%
	GR	-8.99	238	623	3%
Serious and fatal	NE	-11.20	615	10537	1%
	B1	-15.72	140	2022	1%
	B2	-11.85	173	2590	1%
	RA	-5.34	279	743	2%
	JN	-3.63	478	1950	1%
	GR	-7.14	43	623	0%

Table 8-23: Reduction in accident frequencies for different site categories for skid resistance (0.4 – 0.5)

Accident	Site category	Elasticity (E_{SR})	N_{AC}	N_{SG}	RD (%)
Total	NE	-8.48	3163	12711	2%
	B1	-18.92	707	1576	8%
	B2	-11.41	759	2393	4%
	RA	-9.36	1452	794	17%
	JN	-2.23	2695	2022	3%
	GR	-10.85	282	843	4%
Dry	NE	-11.40	1980	12711	2%
	B1	-9.78	432	1576	3%
	B2	-8.43	453	2393	2%
	RA	-10.21	824	794	11%
	JN	-4.21	1648	2022	3%
	GR	-5.36	138	843	1%
Wet	NE	-15.60	1161	12711	1%
	B1	-23.31	288	1576	4%
	B2	-15.95	301	2393	2%
	RA	-12.20	554	794	9%
	JN	-9.21	950	2022	4%
	GR	-14.85	144	843	3%
Slight	NE	-2.36	2608	12711	1%
	B1	-17.68	602	1576	7%
	B2	-12.19	627	2393	3%
	RA	-10.70	1158	794	16%
	JN	-3.08	2168	2022	3%
	GR	-8.99	239	843	3%
Serious and fatal	NE	-11.20	555	12711	1%
	B1	-15.72	105	1576	1%
	B2	-11.85	132	2393	1%
	RA	-5.34	294	794	2%
	JN	-3.63	527	2022	1%
	GR	-7.14	43	843	1%

Table 8-24: Reduction in accident frequencies for different site categories for skid resistance (0.5 – 0.6)

Accident	Site category	Elasticity (E_{SR})	N_{AC}	N_{SG}	RD (%)
Total	NE	-8.48	109	287	3%
	B1	-18.92	12	21	11%
	B2	-11.41	8	25	4%
	RA	-9.36	61	22	26%
	JN	-2.23	97	60	4%
	GR	-10.85	16	20	9%
Dry	NE	-11.40	73	287	3%
	B1	-9.78	11	21	5%
	B2	-8.43	6	25	2%
	RA	-10.21	33	22	15%
	JN	-4.21	57	60	4%
	GR	-5.36	10	20	3%
Wet	NE	-15.60	36	287	2%
	B1	-23.31	1	21	1%
	B2	-15.95	2	25	1%
	RA	-12.20	27	22	15%
	JN	-9.21	36	60	6%
	GR	-14.85	6	20	4%
Slight	NE	-2.36	85	287	1%
	B1	-17.68	8	21	7%
	B2	-12.19	5	25	2%
	RA	-10.70	56	22	27%
	JN	-3.08	72	60	4%
	GR	-8.99	13	20	6%
Serious and fatal	NE	-11.20	24	287	1%
	B1	-15.72	4	21	3%
	B2	-11.85	3	25	1%
	RA	-5.34	5	22	1%
	JN	-3.63	25	60	2%
	GR	-7.14	3	20	1%

In addition Tables 8-25 to 8-29 show the priority of maintenance for total, dry, wet, slight and serious and fatal accident frequencies for different site categories and different skid resistance bins.

Very high priority		High priority		Medium priority		Low priority	

Table 8- 25: Priority of maintenance for total accident frequencies

Site category	Skid resistance			
	(0.2 – 0.3)	(0.3 – 0.4)	(0.4 – 0.5)	(0.5 -0.6)
NE	5%	3%	2%	3%
B1	9%	6%	8%	11%
B2	7%	4%	4%	4%
RA	29%	20%	17%	26%
JN	4%	3%	3%	4%
GR	12%	5%	4%	9%

Table 8- 26: Priority of maintenance for dry accident frequencies

Site category	Skid resistance			
	(0.2 – 0.3)	(0.3 – 0.4)	(0.4 – 0.5)	(0.5 -0.6)
NE	4%	2%	2%	3%
B1	3%	2%	3%	5%
B2	3%	2%	2%	2%
RA	20%	14%	11%	15%
JN	4%	3%	3%	4%
GR	3%	2%	1%	3%

Table 8- 27: Priority of maintenance for wet accident frequencies

Site category	Skid resistance			
	(0.2 – 0.3)	(0.3 – 0.4)	(0.4 – 0.5)	(0.5 -0.6)
NE	4%	2%	1%	2%
B1	3%	3%	4%	1%
B2	4%	2%	2%	1%
RA	13%	9%	9%	15%
JN	5%	4%	4%	6%
GR	8%	2%	3%	4%

Table 8- 28: Priority of maintenance for slight accident frequencies

Site category	Skid resistance			
	(0.2 – 0.3)	(0.3 – 0.4)	(0.4 – 0.5)	(0.5 -0.6)
NE	1%	1%	1%	1%
B1	7%	5%	7%	7%
B2	7%	3%	3%	2%
RA	27%	19%	16%	27%
JN	4%	3%	3%	4%
GR	7%	3%	3%	6%

Table 8- 29: Priority of maintenance for serious and fatal accident frequencies

Site category	Skid resistance			
	(0.2 – 0.3)	(0.3 – 0.4)	(0.4 – 0.5)	(0.5 -0.6)
NE	1%	1%	1%	1%
B1	1%	1%	1%	3%
B2	1%	1%	1%	1%
RA	3%	2%	2%	1%
JN	1%	1%	1%	2%
GR	2%	1%	1%	1%

8.4.3 Increasing skid resistance

There are many approaches to increase skid resistance for roadway segments, one of the sufficient approaches is high friction surface. High friction surfaces are used primarily for restoring or enhancing the skid resistance of a pavement surface. There are many benefits for using high friction surface:

- Provides a solution for restoration of skid resistance on existing pavements or enhancement of skid resistance on new pavements.
- Provides a solution for "spot treatment" of a pavement where friction demand is highest.
- Low Cost Treatment (when compared to removal and replacement existing pavement).
- Can be installed during short (4-6 hour) closures of the pavement and only one lane at a time.

Areas where high friction or anti-skidding properties are desired, include:

- Roundabouts/ Roundabouts approaches.
- Junctions/Junctions approaches
- Bends roadway segments.
- Steep gradients.
- Pedestrian Walkways.

8.5 Summary

With the aim of recommending changes to the skid resistance standard for England's strategic roads (HD 28/15) in terms of the definitions of skid resistance threshold and site categories, a network level analysis of the A-roads of three counties (Norfolk, Oxfordshire, and Nottinghamshire) in England was conducted to evaluate the effect of skid resistance on both accident frequency and rate.

- The effect of skid resistance on the expected total, dry, wet, slight and serious and fatal accident frequencies on NT level and NE, B1, B2, RA, JN, and GR site categories (RPNB model results, chapter 5) was evaluated.

- The effect of skid resistance on the expected total, dry, wet, slight and serious and fatal accident rates on NT level and NE, B1, B2, RA, JN, and GR site categories (RPT model results, chapter 6).
- The skid resistance thresholds for NE, B1, B2, RA, JN, and GR site categories were established by analysing the expected total, dry, wet, slight and serious and fatal accident frequencies, and total, dry, wet, slight and serious and fatal accident rates as functions of skid resistance.

The first part of the chapter involves the comparison of elasticity effects of skid resistance on both the expected total, dry, wet, slight and serious and fatal accident frequencies and rates for different site categories.

It is expected that roads managed by other highway authorities or those located in other parts of the UK, may not necessarily exhibit similar characteristics. Hence, the recommendations of this chapter for the definitions of new site categories and skid resistance thresholds should be interpreted with discretion when applied to other roads. Therefore, a network level analysis of the influence of skidding resistance on accident risk has been made in order to recommend any changes required to the skidding resistance standard for the English strategic road network. The bases for the findings in this chapter are the A-road networks of Norfolk, Oxfordshire, and Nottinghamshire counties in England. The accident analysis was then repeated for different site categories that defined in section 3.5. New skid resistance thresholds for different site categories and have been recommended as a result of these analyses. The second part involves the analysis of both the expected total, dry, wet, slight and serious and fatal accident frequencies and rates as functions of the skid resistance for different site categories. Based on the results obtained from this analysis, new skid resistance thresholds for both total, dry, wet, slight and serious and fatal accident frequencies and rates.

However, the relationship between both expected total, dry, wet, slight and serious and fatal accident frequencies and rates with skid resistance must be treated with caution particularly when the skid resistance is below 0.3 or above 0.55 because of the small number of segments in these two bins this finding was also reported by

Parry *et al*. (2005). It showed that there is a significant increase in both accident frequencies and rates when the skid resistance is below 0.3. A possible explanation for this might be that the majority of roadway segments with skid resistance value less than 0.3 are located at high interaction locations (e. g. bus stopping, parking, petrol stations, etc.), thus, vehicle travelling along these roadway segments with high roadside activities are more expected to use brake to avoid the unexpected events that involved in these roadside activities. On the other hand, higher accident frequencies and rates are observed for roadway segments when skid resistance is above 0.55. This finding could be related to driver behaviour. Mannering (2007) observed that drivers, tend to drive at higher speed on roadway segment with high pavement condition. Thus, it increases the likelihood of accidents.

The recommended skid resistance thresholds for accident frequencies and rates for different site categories for local authority roads are summarised in Tables 8-30.

Table 8-30: Recommended skid resistance thresholds for accident frequencies and rates for different site categories for 3C network

Site category	Accidents frequencies	SR thresholds	Accidents rates	SR thresholds	HD 28/15 SR thresholds
NE	T	0.45 – 0.50	TAR	0.45 – 0.50	0.40 – 0.45
	D	0.45 – 0.50	DAR	0.45 – 0.50	
	W	0.45 – 0.50	WAR	0.45 – 0.50	
	SL	0.45 – 0.50	SLAR	0.45 – 0.50	
	SF	0.45 – 0.50	SFAR	0.45 – 0.50	
B1	T	0.45 -0.50	TAR	0.45 -0.50	0.50 -0.55
	D	0.45 -0.50	DAR	0.45 -0.50	
	W	0.45 -0.50	WAR	0.45 -0.50	
	SL	0.45 -0.50	SLAR	0.45 -0.50	
	SF	0.45 -0.50	SFAR	0.45 -0.50	
B2	T	0.45 -0.50	TAR	0.45 -0.50	0.50 – 0.55
	D	0.45 -0.50	DAR	0.45 -0.50	
	W	0.45 -0.50	WAR	0.45 -0.50	
	SL	0.45 -0.50	SLAR	0.45 -0.50	
	SF	0.45 -0.50	SFAR	0.45 -0.50	
RA	T	0.45 – 0.50	TAR	0.50 – 0.55	0.45 – 0.50
	D	0.45 – 0.50	DAR	0.50 – 0.55	
	W	0.50 – 0.55	WAR	0.50 – 0.55	
	SL	0.50 – 0.55	SLAR	0.50 – 0.55	
	SF	0.50 – 0.55	SFAR	0.50 – 0.55	
JN	T	0.45 – 0.50	TAR	0.50 – 0.55	0.45 – 0.55
	D	0.45 – 0.50	DAR	0.50 – 0.55	
	W	0.45 – 0.50	WAR	0.50 – 0.55	
	SL	0.45 – 0.50	SLAR	0.50 – 0.55	
	SF	0.45 – 0.50	SFAR	0.50 – 0.55	
GR	T	0.50 – 0.55	TAR	0.50 – 0.55	0.45 – 0.50 (for G1) 0.50 – 0.55 (for G2)
	D	0.50 – 0.55	DAR	0.50 – 0.55	
	W	0.50 – 0.55	WAR	0.50 – 0.55	
	SL	0.50 – 0.55	SLAR	0.50 – 0.55	
	SF	0.50 – 0.55	SFAR	0.50 – 0.55	

CHAPTER NINE

CONCLUSIONS AND

RECOMMENDATIONS

CHAPTER NINE: CONCLUSIONS AND RECOMMENDATIONS

9.1 Overview

For decades, traffic accidents in many countries are one of the high priority problems that needs to be solved. A traffic accident is a complex event, this event occurs on the roads as a result of many contributing factors. It is widely recognised that pavement characteristics including skid resistance have an important role in traffic safety. For maintenance purposes, it is very important to establish reference values for skid resistance. In 1988 the UK Department of Transport introduced a standard for skid resistance of the UK strategic roads, in HD28/88 of the Design Manual for Roads and Bridges. The Highways Agency decided to review the skid resistance standard for the conditions that prevail today. The Design Manual for Roads and Bridges was then updated in 2015 with the latest version of the skid resistance standard for strategic roads called HD 28/15. Local highway authorities in the UK employ the skid resistance standard, HD 28/15, in its definition of site categories and uses it to set the skid resistance thresholds for these site categories on A-road networks. Notwithstanding this, there are still some challenges in arriving at the appropriate skid resistance thresholds for local A-roads, owing to the fact that there is variation between local authority roads and strategic roads with regard to the traffic and geometric characteristics of the roads. For this reason, the skid resistance thresholds established for strategic roads are not necessarily suitable for A-roads managed by local authorities. Thus, this study aimed to established SR thresholds for different site categories for local authority roads (A-roads) in the context of accident frequencies and rates. This has been achieved by evaluating the effect of skid resistance on both accident frequency (using RPNB models) and rate (using RPT models) at different site categories based on accident data obtained from A-road networks in Norfolk, Oxfordshire and Nottinghamshire from 2005-2010.

9.2 Summary of thesis chapters

9.2.1 Literature Review

In Chapter 2, the thesis started with a review of the studies undertaken previously by researchers in the area of factors that affect skid resistance. The factors affecting skid resistance were related to pavement texture, aggregate properties and environmental factors. In terms of skid resistance measurement there are several equipment's for skid resistance measurement. In UK, skid resistance is usually measured using the sideway-force coefficient routine investigation machine (SCRIM). In terms of skid resistance policy, many highway agencies around the world have different standards for the management of skid resistance; these agencies use different approaches to set the adequate threshold for the highway based on the relationship between skid resistance and the traffic accident. Chapter 2 highlighted UK, Australia and New Zealand approach to manage skid resistance on their major roads.

Chapter 2 has offered a broad review of current literature on various factors affecting road safety, including traffic characteristics (Ln AADF, heavy vehicles percentage and speed limit), geometric characteristics (radius of curvature, gradient, number of lanes and number of minor access), pavement characteristics (skid resistance, rut depth and texture depth).

In terms of statistical models, there are a number of statistical methods available to predict the frequency and rate of traffic accidents on road segments. The literatures had emphasized that random parameters approach has been proved to be the most appropriate statistical model for modelling accident counts.

9.2.2 Methodology

Different data were collected to conduct this research. This thesis was based on road segment level analysis, and the study area chosen was the A-road networks for Norfolk, Oxfordshire and Nottinghamshire counties in England, UK. Four types of data are used in this thesis:

- Accidents characteristics data

- Traffic characteristics data
- Geometric characteristics data
- pavement characteristics data

As mentioned in section 3.5, A-road networks in Norfolk, Oxfordshire and Nottinghamshire were divided into different site categories (NE, B1, B2, RA, JN AND GR) depending on accident layouts at different network features (e.g. junctions, roundabouts) and the relationships between accidents and geometric characteristics (radius of curvature and gradient).

In terms of statistical models fixed and random parameters Negative Binomial models were used to evaluate the effect of traffic, geometric and pavement characteristics on accident frequency. On the other hand, fixed and random parameters Tobit models were used to evaluate the effect of traffic, geometric and pavement characteristics on accident rate.

9.2.3 Model development and selection

Chapter 4 describes the main steps required to build and select the best total, dry, wet, slight, serious and fatal accident frequency models presented in chapters 5 (frequency models) and total, dry, wet, slight, serious and fatal accident rate models in chapter 6 (rate models) for NT level, NE, B1, B2, RA, JN and GR site categories for 3C, Norfolk, Oxfordshire and Nottinghamshire A–road networks, by using different statistical tools:

- According to the collinearity test, all VIF values between the independent variables for all site categories are all less than 5. Therefore, no evidence was established for the existence of collinearity.
- With respect to the result of log likelihood ratio test, it can be concluded that random parameters models were statistically better to predict total, dry, wet, slight and serious and fatal accident frequencies and rates in all site categories for 3C, Norfolk, Oxfordshire and Nottinghamshire A – roads network than fixed parameters models at a level of confidence interval of 99%.

- Regarding the log likelihood ratio test for parameter transferability, for all RPNB and RPT models the null hypothesis which assumed that there was no significant difference in the parameter values for the independent variables between the full data model (3C) and separate models (Norfolk, Oxfordshire and Nottinghamshire) was accepted with over 99.99% level of confidence, suggesting that the estimation of separate models for the three individuals counties was statistically not necessary.

9.2.4 Frequency and rate models

This thesis employed RPNB modelling to develop accident frequency models; and RPT modelling to develop accident rate models for various accident aggregations. The aggregations are based on: 1. Total accident frequencies and rates, 2. Dry and wet accident frequencies and rates; and 3. Slight and serious and fatal accident frequencies and rates. Traffic characteristics (Ln AADF, heavy vehicles percentage and speed limit), Geometric characteristics (radius of curvature, gradient, number of lanes and number of minor access), and pavement characteristics (skid resistance, rut depth and texture depth) were used as independent variables in all accident types and in all site categories. Regarding the parameter estimation results of the RPNB and RPT models, our findings suggest that:

- Ln AADF

The coefficient estimates of RPNB and RPT models demonstrate that Ln AADF was an important independent variable in accident frequencies and rates models. Ln AADF had significant fixed positive effects on both accident frequencies and rates in all site categories. This indicated that for all roadway segments in all site categories the increased Ln AADF leads to higher total, dry, wet, slight and serious and fatal accident frequencies and rates. This study supports evidence from previous observations (Poch and Mannering, 1996; Abdel-Aty and Radwan, 2000; Chin and Quddus, 2003; Abdel-Aty and Haleem, 2011; Das and Abdel-Aty, 2011).

- Heavy vehicles percentage

Heavy vehicles percentage has a negative effect on road safety in terms of increased total, dry, wet, slight and serious and fatal accident frequencies at all site categories. This finding was also reported by Dong *et al*. (2015) who found that heavy vehicles percentage was positive and statistically significant with accident frequencies. On the other hand, RPT models showed that heavy vehicles percentage has a mixed effect on road safety, increased heavy vehicles percentage has a positive effect on road safety in terms of decreased all accident rates at NT and NE site categories. These results reflect those of Miaou, (1994); Milton and Mannering (1998) and Anastasopoulos *et al.,* (2008, 2012) who supported the idea that the number of other vehicle types (passenger vehicles) that will change lane and overtake is reduced in traffic streams with higher numbers of heavy vehicles, leading to lower accident rates.

However, heavy vehicles percentage had a negative effect on road safety in terms of increased all accident rates at B1, B2, RA, JN and GR site categories. This result may be explained by the fact that increasing heavy vehicles percentage, effects other driver behaviour, increasing lane changing and overtaking (Dong *et al.*, 2015).

The effect of heavy vehicles percentage was found to have a high effect on both accident frequencies and rates particularly at GR site category. Queuing is increased with increasing of heavy vehicles percentage, particularly along roadway segment with gradient≥5%, this situation may encourage drivers of other type of vehicles to make unsafe overtaking manoeuvres (Rusli, 2017).

- Speed limit

Roadway segment with lower speed limit was associated with higher total, dry, wet, slight and serious ad fatal accident frequencies and rates for the majority of observations at all site categories. This finding was highlighted by several previous studies (Milton and Mannering, 1998; Donnell *et al.* , 2010; Lao *et al.*, 2014; Li *et al.*, 2015). There are several possible explanations for this result. Firstly, highway

agencies fix a lower speed limit to roadway segments with high accident rates as a safety policy to reduce the likelihood of accidents. Secondly, some researchers have claimed that road segments with higher speed limit are usually well-planned, constructed, and managed (Milton and Mannering, 1998; Zeng *et al.*, 2016) and these features could be improved highway safety. However, these results would not encourage highway agencies to increase speed limit, to reduce accident rates on A road networks in the UK.

- Radius of curvature

In terms of geometric characteristics, the radius of curvature plays a significant effect in road safety. As expected roadway segment with higher radius of curvature results in lower total, dry, wet, slight and serious ad fatal accident frequencies and rates for the majority roadway segments at all site categories. These results are in line with those of previous studies (Glennon, 1987; Zegeer *et al.*, 1990, 1991;Aram, 2010; Vayalamkuzhi and Amirthalingam, 2016).

- Gradient

Roadway segment with higher gradient results in higher total, dry, wet, slight and serious ad fatal accident frequencies and rates. Finding from this thesis identify that the roadway segments with gradient ≥5% had a significant positive effect on both accident frequencies and rates. This particularly true for all accident frequencies and rates at GR roadway segments. This finding was supported by other studies, for example, Ahmed *et al.* (2012) reported a roadway segment with a gradient of 6–8% was more hazardous, when compared to 4–6% and 2–4% gradients. Similarly, Yu et al., (2015) concluded that the presence of a steep grade slope, increased accident frequencies. In addition, these results were consistent with the finding of Fu *et al.*, (2011), who concluded that accident rates increased exponentially, with the gradient of roadway segments.

- Number of lanes

For the majority of roadway segments at all site categories increasing number of lanes was found to has a positive effect on road safety. The RPNB and RPT model results revealed that roadway segments with fewer lanes expected more total, dry, wet, slight and serious ad fatal accidents frequencies and rates in comparison with roadway segments with higher number of lanes. These results were consistent with a previous study by Ma and Kockelman (2006). These authors found that increasing the number of lanes led to decreased accident frequencies. In addition, Park *et al.* (2010) found that four-lane freeways experienced higher accident occurrences, when compared with six lane freeways. This relationship may be explained by the fact that wider roads allow drivers to make more manoeuvres, avoiding contact between vehicles.

- Number of minor access

Number of minor access has statistically significant influence on both accident frequencies and rates at all site categories. The results of RPNB and RPT models show that increasing number of minor access at all roadway segments lead to increase total, dry, wet, slight and serious ad fatal accident frequencies rates for all site categories. This finding broadly supports the work of other studies in this area linking accident frequencies and rates with number of minor access (Gattis *et al.*, 2005; Baek and Hummer, 2008; Schultz *et al.*, 2010; Ackaah and Salifu, 2011). This result further supports the idea that at access point the conflict between vehicles increase due to the variation in traffic speed hence increase the likelihood of accidents. Graves *et al.* (1993) observed that accident rates were significantly related to traffic speed variation.

- Skid resistance

The effect of skid resistance was observed to have a negative effect on accident frequencies and rates at all site categories. For the majority of roadway segments

increasing the skid resistance leads to a significant decrease in total, dry, wet, slight and serious and fatal accident frequencies and rates for all site categories. These results appeared to be consistent with other studies, that found that skid resistance was a significant parameter that could include in the accident models (Abdel-Aty *et al.*, 2009; Anastasopoulos and Mannering, 2009; Hou *et al.*, 2018).

- Rut depth

In terms of accident frequency models, relatively roadway segments with high rut depth was observed to higher total, dry, wet, slight and serious ad fatal accident frequencies. From Figure 7-17, it was interesting to note that in all site categories, the most obvious effects of rut depth were observed for wet accident frequencies. This result was in agreement with Anastasopoulos, and Mannering, (2009) who argued that roadway segments with high rut depth increased the chances of hydroplaning when the road surface is wet and may be thus contribute to vehicle tracking and loss of control, during lane changes and manoeuvring.

In terms of accident rate models, rut depth has a mixed effect, increased rut depth was associated with increase total, wet, slight and serious ad fatal accident rates at all site categories. On the other hand, increased rut depth was associated with decrease dry accident rates at all site categories. A possible explanation for this could be that rut depth is more obvious during normal weather. Thus, drivers can control their vehicles to safely manoeuvre through the rutted zones (Chan *et al.*, 2009).

- Texture depth

For the majority of roadway segments increasing texture depth leads to a significant decrease in total, dry, wet, slight and serious ad fatal accident frequencies and rates; at all site categories. This finding is consistent with that of Pulugurtha *et al.*, (2010) who demonstrated a significant relationship between different types of accident and texture depth.

9.2.5 Skid resistance threshold

Based on both RPNB and RPT models skid resistance was found to be a significant factor affecting accident frequencies and rates at all site categories. The elasticity effect provides new insight on the relationship between skid resistance with total, dry, wet, slight and serious ad fatal accident frequencies and rates at different site categories which can lead to proposed accident prevention policies in the future. Regarding, the elasticity effects of skid resistance on both accident frequencies and rates the following points can be concluded:

- In all RPNB and RPT models for all site categories, the effect of skid resistance is found to be a significant variable in all accident frequencies and rates. This is particularly true for wet accident frequencies and rates in all site categories rather than for other types of accident frequencies and rates.
- In spite of the statistically significant effect of skid resistance coefficient in all RPNB and RPT models for the NE site category, the elasticity effect of skid resistance (reductions in the expected accident frequencies and rates due to a 10% increase in skid resistance values) on accident frequencies and rates is found to be less than those in bend site categories B1 and B2. Therefore, it is reasonable that the effect of skid resistance on the NE site category (mostly straight roadway segments) is less than those in B1 and B2 site categories (bend roadway segments).
- Significant reductions in all accident frequencies and rates are more evident in B1 and B2 site categories, which are characterised as bend segments. In each site category, a 10% increase in the skid resistance shows a significant reduction in all accident frequencies and rates, with a slight difference. This is practically true for the wet accident frequencies and rates rather than for other types of accident frequencies and rates.
- For RA and JN site categories, the skid resistance is introduced as an independent variable with a statistical significance in all RPNB accident frequency models and all RPT accident rate models. However, the introduction

of other independent variables, especially Ln AADF, reduced the importance of skid resistance coefficient, as reflected in the reduction of the elasticity effect of skid resistance on accident frequencies and rates.

- Despite the limited number of roadway segments for the GR site category, which is characterised by roadway segments with gradient≥5%, the RPNB and RPT models exhibited significant skid resistance effects on all accident frequencies and rates.

9.3 Contribution to knowledge

This thesis has offered a number of contributions to knowledge. These consist of the following areas:

- In terms of accident prediction approach, applied random parameters model as a new approach in the UK to estimate accident frequency and rate on A – road networks in Norfolk, Oxfordshire and Nottinghamshire counties. This approach is considered as an appropriate approach for the researcher due to its ability to account and correct for heterogeneity, which can be raised as a result of several factors relating to the characteristics of traffic, geometric and pavement characteristics. In addition, the random parameters approach provides a reasonable understanding of the main factors that affect accident frequency and rate. Therefore, this approach allows the research to identify and control for confounding factors that may bias estimation.
- New site categories definitions and new skid resistance thresholds for are established based on the analysis of expected accident frequencies (outputs of RPNB models); and the analysis of expected accident rates (outputs of RPT models) as function of skid resistance.

9.4 Extensions and recommendation for further research

The following section presents recommendation for further work that can be done in future:

- The main aim of this thesis is to establish new skid resistance thresholds for local authority roads (A-roads) at Norfolk, Oxfordshire and Nottinghamshire. Therefore, further research is required to establish new skid resistance thresholds for B-roads network.
- In spite of the limited number of observations for GR site category, heavy vehicles percentage was found to have an obvious significant effect on accident frequencies (sections 5.2.1.2, 5.2.2.2 and 5.2.3.2); and on accident rates (sections 6.2.1.2, 6.2.2.2 and 6.2.3.2) at GR site category rather than other site categories. Thus, further investigation is required including higher number of roadway segments of GR site category to evaluate the effect heavy vehicles percentage on all accident frequencies and rates.
- As shown in Figures 7-9 and 7-10, it is interesting to observe that the risk of accident tends to be more serious when there is a combination of radius of curvature <250m and gradient>5% in the roadway segments. Further research is required to evaluate the combination of sharp curves and steep gradients on accident severity due to the limited observations of this combination.

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APPENDICES

APPENDIX A

Table A-1: RPNB models estimation results for T accident frequencies for Norfolk site categories

Variables	NT		NE		B1		B2		RA		JN		GR	
	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t
Constant	-8.911	-28.01	-7.319	-12.99	-7.098	-7.35	-8.307	-8.21	-4.556	-3.84	-8.562	-11.60	-3.398	-3.55
Ln AADF	1.114	31.64	0.457	12.05	0.969	9.75	1.242	11.41	0.677	5.67	0.942	11.87	0.386	2.19
Std.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
%HV	0.008	1.32	0.047	5.11	0.007	0.32	0.033	1.84	0.034	1.86	0.005	0.41	0.078	3.42
Std.	0.024	8.57	0.072	17.68	0.095	8.94	0.044	5.13	-	-	0.056	8.41	-	-
SPL	-0.018	-18.32	-0.019	-12.53	-0.009	-3.02	-0.009	-3.33	-0.005	-1.74	-0.015	-4.71	-0.028	-2.07
Std.	0.017	43.94	0.008	23.55	-	-	-	-	-	-	0.009	15.65	0.0027	3.25
RC	$-0.800*10^{-3}$	-27.32	$-0.330*10^{-3}$	-6.54	-0.003	-4.22	$-0.268*10^{-2}$	-4.16	$-0.430*10^{-3}$	-1.84	$-0.400*10^{-3}$	-5.88	$-0.200*10^{-3}$	-3.58
Std.	$0.500*10^{-3}$	32.08	$0.330*10^{-3}$	18.14	-	-	$0.213*10^{-2}$	16.17	-	-	$0.360*10^{-3}$	8.87	-	-
%G	0.026	2.06	0.022	0.87	0.029	0.93	0.058	1.95	0.037	1.13	0.064	2.35	0.162	1.73
Std.	0.093	12.49	0.062	4.18	0.091	4.93	-	-	0.073	4.59	0.141	8.78	-	-
NL	-0.145	-5.18	-0.125	-1.73	-0.215	-2.13	-0.356	-2.33	-0.233	-3.23	-0.229	-4.53	-0.015	-1.72
Std.	-	-	0.075	5.65	0.187	7.92	-	-	-	-	-	-	-	-
NMA	0.219	7.37	0.278	5.57	0.139	1.72	0.247	2.95	0.278	1.72	0.132	2.23	0.179	1.67
Std.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SR	-1.546	-5.12	-4.014	-8.35	-1.833	-1.95	-3.063	-3.59	-2.339	-6.28	-0.398	-2.59	-0.876	-4.81
Std.	0.987	22.5	-	-	1.379	10.22	-	-	2.328	45.78	-	-	0.248	1.99
RD	0.004	0.68	0.003	0.19	0.011	1.65	0.035	1.42	0.02	2.05	0.009	0.37	0.017	3.25
Std.	0.002	2.98	0.084	19.42	-	-	0.066	8.64	-	-	0.028	4.63	-	-
TX	-0.046	-0.51	-0.478	-3.59	-0.475	-1.55	-0.814	-3.07	-0.061	-0.25	-0.189	-0.97	-0.475	-2.72
Std.	0.412	14.41	-	-	0.349	4.00	0.522	6.33	-	-	0.176	2.84	-	-

Table A-2: RPNB models estimation results for D accident frequencies for Norfolk site categories

Variables	NT		NE		B1		B2		RA		JN		GR	
	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t
Constant	-8.747	-21.79	-7.855	-11.70	-6.916	-6.54	-9.224	-7.00	-7.029	-3.86	-7.314	-7.88	-8.357	-3.88
Ln AADF	1.055	23.84	0.622	5.57	0.885	8.04	1.29	9.02	0.893	4.79	0.836	8.34	0.414	1.83
Std.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
%HV	0.024	3.54	0.046	4.19	0.048	1.92	0.033	1.99	0.025	2.69	0.148	5.07	0.089	1.67
Std.	0.049	13.15	0.064	13.06	0.026	1.77	-	-	-	-	0.087	7.92	-	-
SPL	-0.021	-16.12	-0.037	-12.26	-0.019	-5.43	-0.015	-4.07	-0.012	-3.01	-0.014	-2.95	-0.017	-2.13
Std.	0.016	33.09	0.016	23.77	0.012	13.32	0.012	12.11	-	-	-	-	0.018	2.77
RC	$-0.730*10^{-3}$	-19.12	$-0.240*10^{-3}$	-4.00	$-0.274*10^{-2}$	-3.21	$-0.154*10^{-2}$	-1.93	$-0.186*10^{-2}$	-2.56	$-0.500*10^{-3}$	-5.16	$-0.100*10^{-3}$	-2.93
Std.	$0.420*10^{-3}$	33.09	-	-	-	-	-	-	$0.148*10^{-2}$	2.93	$0.420*10^{-3}$	7.08	-	-
%G	0.039	2.38	$0.700*10^{-3}$	1.02	0.006	3.61	0.065	2.35	0.104	2.19	0.089	2.37	0.124	2..05
Std.	0.041	4.39	0.037	1.71	-	-	-	-	0.158	6.29	0.068	3.21	-	-
NL	-0.125	-3.44	-0.202	-2.39	-0.047	-0.48	-0.457	-2.38	-0.162	-1.47	-0.278	-4.41	-0.108	-1.66
Std.	0.115	11.95	0.205	13.64	-	-	-	-	0.097	3.61	-	-	-	-
NMA	0.252	6.66	0.265	4.45	0.159	1.78	0.307	3.04	0.236	3.15	0.182	2.17	0.143	1.81
Std.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SR	-1.386	-3.66	-3.521	-6.13	-1.365	-1.83	-2.813	-2.66	-0.91	-1.94	-0.276	-2.32	-0.813	-1.68
Std.	-	-	-	-	-	-	-	-	-	-	0.689	5.2	-	-
RD	0.008	3.11	0.008	2.04	0.016	1.96	0.007	4.25	0.017	3.34	0.042	1.16	0.013	7.14
Std.	0.015	4.63	0.088	17.09	-	-	-	-	0.016	1.66	0.067	7.55	-	-
TX	-0.056	-0.47	-0.314	-1.91	-0.627	-1.85	-0.51	-1.55	-0.028	-9.06	-0.213	-3.17	-0.391	-2.89
Std.	0.036	2.99	-	-	0.432	4.35	0.42	3.92	-	-	-	-	-	-

Table A-3: RPNB models estimation results for W accident frequencies for Norfolk site categories

Variables	NT		NE		B1		B2		RA		JN		GR	
	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t
Constant	-8.828	-15.68	-7.645	-7.76	-7.984	-4.16	-9.253	-6.01	-10.333	-3.56	-8.231	-6.69	-7.254	-5.22
Ln AADF	0.995	16.4	0.832	37.02	1.029	5.12	1.204	7.51	1.149	3.82	0.844	6.02	0.108	2.05
Std.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
%HV	0.009	0.87	0.036	2.47	0.023	0.52	0.014	0.33	0.028	3.04	0.046	1.69	0.061	2.39
Std.	0.037	6.25	0.052	7.79	0.114	5.88	0.075	5.46	-	-	0.028	1.84	-	-
SPL	-0.017	-10.04	-0.022	-5.47	-0.017	-1.68	-0.011	-2.37	-0.005	-4.78	-0.019	-3.22	-0.021	-6.12
Std.	0.009	23.53	-	-	0.008	5.75	-	-	-	-	0.017	10.69	-	-
RC	$-0.670*10^{-3}$	-13.39	$-0.240*10^{-3}$	-2.98	$-0.299*10^{-2}$	-2.32	$-0.154*10^{-2}$	-1.54	$-0.610*10^{-3}$	-3.00	$-0.760*10^{-3}$	-5.73	$-0.930*10^{-3}$	-1.89
Std.	$0.470*10^{-3}$	16.16	$0.300*10^{-3}$	9.89	-	-	$0.200*10^{-2}$	10.26	-	-	$0.590*10^{-3}$	7.63	-	-
%G	0.021	0.97	0.051	1.25	0.068	1.08	0.053	2.91	0.025	4.33	0.09	1.95	0.041	1.92
Std.	0.053	4.19	0.034	3.37	0.133	3.79	-	-	-	-	-	-	-	-
NL	-0.119	-2.41	-0.113	-1.85	-0.391	-1.99	-0.308	-4.22	-0.239	-1.75	-0.226	-5.88	-0.286	-1.87
Std.	0.043	3.45	-	-	-	-	-	-	-	-	-	-	-	-
NMA	0.147	2.77	0.251	2.83	0.058	2.34	0.128	2.99	0.049	3.25	0.126	2.64	0.362	2.66
Std.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SR	-2.053	-3.99	-5.182	-6.32	-1.626	-2.91	-4.076	-3.03	-1.594	-1.18	-3.802	-2.61	-2.951	-1.72
Std.	-	-	1.631	14.34	-	-	1.736	8.59	1.367	5.78	-	-	1.051	2.41
RD	0.005	0.34	0.015	0.56	0.072	2.43	0.031	1.74	0.018	4.12	0.059	1.34	0.109	1.71
Std.	0.019	4.04	0.107	14.85	0.044	3.17	-	-	-	-	0.023	1.91	-	-
TX	-0.176	-1.17	-0.612	-2.84	-0.075	-2.13	-0.563	-1.65	-0.796	-1.78	-0.513	-3.09	-0.328	-4.17
Std.	0.889	18.08	-	-	-	-	-	-	-	-	-	-	-	-

Table A-4: RPNB models estimation results for SL accident frequencies for Norfolk site categories

Variables	NT		NE		B1		B2		RA		JN		GR	
	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t
Constant	-8.904	-25.88	-7.519	-12.14	-7.302	-6.92	-8.892	-7.06	-8.234	-5.51	-8.494	-10.37	-8.552	-4.52
Ln AADF	1.113	29.83	0.844	23.77	0.945	8.84	1.303	9.68	1.112	6.63	0.963	10.89	0.337	2.01
Std.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
%HV	0.006	0.84	0.031	3.14	0.038	1.43	0.039	1.83	0.039	1.73	0.002	0.17	0.089	1.86
Std.	0.025	6.43	0.033	7.28	0.125	9.96	-	-	-	-	0.021	2.82	-	-
SPL	-0.022	-20.17	-0.048	-14.43	-0.011	-3.44	-0.028	-5.58	-0.007	-1.97	-0.015	-4.02	-0.011	-2.34
Std.	0.011	42.39	0.017	28.89	-	-	0.016	12.39	-	-	-	-	-	-
RC	$-0.760*10^{-3}$	-23.02	$-0.270*10^{-3}$	-4.96	$-0.389*10^{-2}$	-4.78	$-0.820*10^{-3}$	-7.09	$-0.690*10^{-3}$	-4.52	$-0.580*10^{-3}$	-7.09	$-0.100*10^{-3}$	-2.88
Std.	$0.500*10^{-3}$	26.86	$0.220*10^{-3}$	10.8	$0.241*10^{-2}$	6.39	-	-	-	-	$0.500*10^{-3}$	10.15	-	-
%G	0.014	1.03	0.025	0.91	0.047	1.15	0.054	3.13	0.011	0.29	0.073	2.42	0.149	3.12
Std.	0.103	13.28	0.031	1.97	0.115	5.45	-	-	0.097	5.19	0.105	5.93	-	-
NL	-0.157	-5.53	-0.335	-2.49	-0.084	-3.88	-0.345	-1.84	-0.274	-2.94	-0.272	-4.97	-0.121	-2.13
Std.	-	-	-	-	-	-	-	-	0.173	8.14	-	-	-	-
NMA	0.236	7.72	0.298	5.76	0.143	1.75	0.242	2.43	0.024	4.14	0.151	2.33	0.144	2.31
Std.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SR	-1.887	-6.02	-3.519	-6.74	-0.907	-0.91	-3.665	-3.51	-0.812	-1.96	-0.565	-0.75	-0.502	-6.12
Std.	1.278	26.89	-	-	0.999	6.86	-	-	-	-	1.334	12.6	-	-
RD	$0.710*10^{-3}$	7.12	0.002	1.09	0.006	2.58	0.014	3.14	0.039	0.93	0.038	1.02	0.033	2.34
Std.	0.012	4.49	0.081	17.42	-	-	-	-	0.018	1.91	0.098	13.42	-	-
TX	-0.08	-0.83	-0.218	-1.43	-0.298	-1.89	-0.599	-1.88	-0.178	-2.59	-0.443	-4.25	-0.216	-3.84
Std.	0.455	14.85	0.597	12.61	-	-	0.355	3.69	-	-	-	-	0.092	1.87

Table A-5: RPNB models estimation results for SF accident frequencies for Norfolk site categories

Variables	NT		NE		B1		B2		RA		JN		GR	
	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t
Constant	-10.297	-15.11	-8.382	-6.94	-6.914	-3.00	-9.834	-5.08	-6.113	-2.35	-8.585	-5.48	-5.225	-3.54
Ln AADF	0.956	12.55	0.759	12.15	0.938	3.64	1.038	4.91	0.079	3.49	0.594	3.32	0.095	3.22
Std.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
%HV	0.043	4.12	0.015	0.81	0.116	2.38	0.037	2.99	0.017	3.84	0.069	3.43	0.055	1.75
Std.	0.023	4.52	0.064	7.94	-	-	-	-	-	-	-	-	-	-
SPL	$-0.790*10^{-3}$	-0.41	-0.007	-1.98	-0.075	-2.67	-0.002	-0.39	$-0.500*10^{-3}$	-2.12	-0.002	-4.36	-0.025	-3.02
Std.	0.003	6.39	0.004	6.46	-	-	0.017	8.21	-	-	0.007	3.51	-	-
RC	$-0.125*10^{-2}$	-17.82	$-0.300*10^{-3}$	-2.73	$-0.296*10^{-2}$	-1.83	$-0.234*10^{-2}$	-1.65	$-0.110*10^{-3}$	-4.25	$-0.422*10^{-4}$	-3.35	$-0.714*10^{-3}$	-1.74
Std.	$0.770*10^{-3}$	19.09	$0.300*10^{-3}$	7.79	0.007	2.87	-	-	-	-	-	-	-	-
%G	0.031	1.12	0.009	2.16	0.103	3.13	0.037	2.47	0.107	1.75	0.091	3.62	0.055	1.66
Std.	0.057	3.67	-	-	-	-	-	-	-	-	-	-	-	-
NL	-0.107	-1.67	-0.277	-1.82	-0.521	-1.92	-0.712	-1.84	-0.273	-1.73	-0.184	-1.91	-0.114	-2.66
Std.	0.038	2.45	-	-	-	-	-	-	-	-	-	-	-	-
NMA	0.153	2.22	0.135	3.06	0.088	2.38	0.321	1.91	0.939	2.02	0.065	2.52	0.107	3.44
Std.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SR	-0.738	-1.93	-4.03	-3.81	-5.426	-2.39	-0.129	-0.07	-1.139	-1.89	-1.713	-1.81	-2.029	-1.65
Std.	-	-	-	-	-	-	1.314	5.24	-	-	-	-	2.147	2.41
RD	0.011	1.01	0.068	1.98	0.015	2.25	0.016	3.17	0.063	2.98	0.004	2.08	0.036	1.65
Std.	0.025	4.47	0.112	11.85	-	-	-	-	-	-	-	-	-	-
TX	-0.011	-1.01	-0.703	-2.55	-1.385	-1.73	-0.654	-4.16	-0.401	-1.77	-0.473	-1.73	-0.198	-2.44
Std.	0.073	1.66	-	-	-	-	-	-	0.088	3.41	-	-	-	-

Table A-6: RPNB models estimation results for T accident frequencies for Oxfordshire site categories

Variables	NT		NE		B1		B2		RA		JN		GR	
	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t
Constant	-3.514	-9.89	-2.637	-4.75	-5.503	-3.91	-4.614	-3.77	-1.015	-1.88	-0.631	-2.11	-2.769	-1.92
Ln AADF	0.278	9.03	0.437	7.97	0.196	1.81	0.469	4.66	0.202	3.66	0.341	2.55	0.622	3.03
Std.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
%HV	0.057	6.35	0.079	5.57	0.021	0.56	0.054	2.13	0.011	0.62	0.068	3.87	0.178	2.25
Std.	0.029	5.08	0.063	9.81	0.031	2.11	-	-	0.018	2.62	-	-	-	-
SPL	-0.014	-14.99	-0.016	-10.42	-0.013	-3.74	-0.017	-6.13	-0.004	-1.94	-0.004	-2.58	-0.006	-3.96
Std.	0.013	49	0.013	31.32	0.011	11.8	0.012	15.88	-	-	0.007	17.51	-	-
RC	$-0.153*10^{-4}$	-1.14	$-0.946*10^{-5}$	-0.45	$-0.820*10^{-3}$	-0.74	$-0.140*10^{-3}$	-2.17	$-0.793*10^{-4}$	-2.46	$-0.284*10^{-4}$	-1.12	$-0.130*10^{-3}$	-1.72
Std.	$0.445*10^{-4}$	4.72	$0.504*10^{-4}$	4.06	0.003	6.17	-	-	-	-	$0.140*10^{-3}$	8.42	-	-
%G	0.002	0.17	0.021	0.75	0.016	0.46	0.034	1.16	0.012	0.58	0.009	2.51	0.109	1.79
Std.	0.001	3.15	0.133	9.09	0.096	5.09	0.028	1.65	0.038	2.79	-	-	-	-
NL	-0.471	-16.58	-0.168	-2.67	-0.511	-3.95	-0.192	-1.78	-0.309	-7.44	-0.524	-14.17	-0.521	-2.42
Std.	-	-	0.057	4.18	0.302	9.7	-	-	-	-	-	-	-	-
NMA	0.949	34.95	0.868	16.66	0.913	6.93	1.041	11.67	0.284	7.22	0.524	14.11	0.572	2.41
Std.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SR	-0.956	-1.69	-2.286	-2.49	-1.348	-3.55	-0.671	-3.38	-3.33	-2.29	-1.881	-1.94	-0.88	-1.02
Std.	-	-	-	-	-	-	-	-	-	-	1.174	14.47	1.336	4.81
RD	0.014	1.41	0.008	0.53	0.071	1.71	0.041	1.22	0.051	2.15	0.011	2.63	0.018	2.25
Std.	0.017	8.35	0.018	2.83	-	-	0.06	9.26	0.086	18.93	-	-	-	-
TX	-0.349	-3.29	-0.99	-5.65	-1.156	-3.00	-0.168	-0.51	-0.965	-4.13	-0.644	-3.71	-0.749	-1.07
Std.	1.202	31.6	1.618	26.29	-	-	1.342	11.69	0.491	6.63	-	-	1.436	5.58

Table A-7: RPNB models estimation results for D accident frequencies for Oxfordshire site categories

Variables	NT		NE		B1		B2		RA		JN		GR	
	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t
Constant	-5.263	-9.89	-4.472	-6.00	-11.006	-5.35	-5.883	-3.12	-2.279	-1.66	-0.204	-2.24	-2.474	-1.76
Ln AADF	0.581	14.04	0.586	8.28	0.755	4.97	0.647	4.47	0.524	4.93	0.239	3.06	0.531	1.81
Std.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
%HV	0.067	5.89	0.034	1.98	0.163	2.98	0.058	1.39	0.016	2.31	0.082	3.73	0.228	1.99
Std.	0.058	11.19	0.046	5.58	0.186	8.57	0.072	4.17	-	-	-	-	-	-
SPL	-0.013	-10.45	-0.031	-9.18	-0.019	-3.98	-0.013	-2.75	-0.006	-1.65	-0.009	-2.76	-0.006	-2.72
Std.	0.014	30.45	0.021	22.66	-	-	-	-	-	-	0.014	15.46	-	-
RC	$-0.217*10^{-5}$	-0.12	$-0.615*10^{-4}$	-1.93	-0.001	-0.63	$-0.877*10^{-4}$	-0.07	$-0.959*10^{-3}$	-1.65	$-0.120*10^{-3}$	-3.33	$-0.180*10^{-3}$	-1.86
Std.	$0.676*10^{-4}$	5.48	$0.220*10^{-3}$	12.82	0.005	8.27	$0.340*10^{-3}$	1.65	-	-	$0.280*10^{-3}$	12.77	-	-
%G	0.001	0.07	0.025	0.68	0.004	0.09	0.032	1.71	0.019	2.43	0.058	2.42	0.032	2.32
Std.	0.003	3.38	0.185	9.29	0.144	5.54	-	-	-	-	0.143	9.37	-	-
NL	-0.12	-3.04	-0.247	-2.77	-0.172	-0.63	-0.236	-1.88	-0.49	-6.04	-0.738	-16.56	-0.173	-2.44
Std.	0.286	26.72	0.177	9.55	-	-	-	-	-	-	-	-	-	-
NMA	1.123	34.01	1.156	17.15	0.923	6.02	1.158	7.82	0.526	6.13	0.738	16.56	0.697	2.82
Std.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SR	-2.444	-3.25	-2.897	-2.28	-6.967	-2.06	-0.734	-2.27	-4.397	-2.12	-4.971	-3.93	-1.912	-1.99
Std.	-	-	-	-	-	-	-	-	-	-	-	-	0.814	2.27
RD	0.004	0.25	0.007	0.31	0.035	2.61	0.023	0.48	0.001	0.02	0.053	2.09	0.075	1.85
Std.	0.048	17.38	0.016	2.11	-	-	0.054	5.66	0.048	6.13	-	-	-	-
TX	-0.788	-5.71	-0.34	-1.58	-2.18	-4.55	-0.798	-1.75	-0.147	-0.32	-0.094	-0.41	-0.122	-2.14
Std.	1.319	26.45	0.326	4.16	-	-	1.223	7.06	1.271	8.03	1.062	13.58	-	-

Table A-8: RPNB models estimation results for W accident frequencies for Oxfordshire site categories

Variables	NT		NE		B1		B2		RA		JN		GR	
	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t
Constant	-3.093	-6.84	-2.297	-2.93	-1.726	-2.63	-5.331	-2.43	-1.468	-1.94	-1.092	-2.8	-5.051	-2.24
Ln AADF	0.017	2.43	0.325	4.15	0.355	1.71	0.294	1.79	0.133	2.16	0.109	1.74	0.366	1.72
Std.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
%HV	0.038	3.05	0.069	3.09	0.051	1.74	0.092	1.71	0.016	0.67	0.038	2.34	0.248	2.36
Std.	0.025	4.91	-	-	-	-	-	-	0.078	8.85	-	-	-	-
SPL	-0.016	-7.66	-0.022	-5.65	-0.002	-3.34	-0.017	-3.16	-0.005	-1.85	-0.002	-0.95	-0.011	-1.17
Std.	0.011	33.92	0.022	22.61	-	-	0.016	10.05	0.005	9.21	-	-	0.024	8.84
RC	$-0.645*10^{-4}$	-3.44	$-0.692*10^{-4}$	-2.08	-0.002	-1.88	$-0.360*10^{-3}$	-2.27	$-0.568*10^{-4}$	-4.35	$-0.902*10^{-5}$	-2.15	$-0.110*10^{-3}$	-3.18
Std.	$0.140*10^{-3}$	10.99	$0.180*10^{-3}$	9.55	-	-	-	-	-	-	-	-	-	-
%G	0.006	0.42	0.013	1.79	0.033	2.59	0.048	3.73	0.002	2.06	0.056	3.68	0.218	1.71
Std.	0.03	3.81	-	-	-	-	-	-	-	-	-	-	-	-
NL	-0.651	-19.19	-0.183	-2.01	-0.861	-3.22	-0.603	-3.49	-0.164	-2.59	-0.242	-3.83	-0.811	-3.24
Std.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
NMA	0.696	20.81	0.745	9.22	1.119	3.18	0.833	4.17	0.095	1.89	0.242	3.83	0.137	2.05
Std.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SR	-1.742	-2.42	-3.664	-2.83	-3.795	-1.88	-0.549	-3.18	-2.347	-1.79	-0.635	-2.44	-1.315	-2.21
Std.	-	-	-	-	-	-	-	-	-	-	1.251	10.5	-	-
RD	0.041	3.18	0.007	0.366	0.001	2.01	0.019	3..28	0.021	0.71	0.023	1.93	0.109	2.21
Std.	-	-	0.032	6.51	-	-	-	-	0.025	4.63	-	-	-	-
TX	-0.016	-0.12	-1.416	-5.1	-0.803	-1.13	-1.183	-2.14	-1.063	-3.43	-0.441	-1.63	-1.472	-1.68
Std.	0.987	21.12	2.315	24.56	1.061	4.48	-	-	-	-	0.663	7.44	-	-

Table A-9: RPNB models estimation results for SL accident frequencies for Oxfordshire site categories

Variables	NT		NE		B1		B2		RA		JN		GR	
	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t
Constant	-3.765	-10.08	-3.212	-5.28	-5.714	-3.65	-5.121	-4.31	-0.272	-2.25	-0.414	-2.52	-1.206	-2.30
Ln AADF	0.325	10.1	0.435	7.45	0.154	1.82	0.486	5.22	0.167	2.08	0.129	1.78	0.236	1.93
Std.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
%HV	0.088	8.57	0.101	6.14	0.032	0.78	0.065	2.15	0.001	2.03	0.099	4.63	0.174	1.66
Std.	0.051	12.31	0.102	13.98	0.103	6.24	0.047	3.41	-	-	-	-	-	-
SPL	-0.017	-10.26	-0.016	-5.61	-0.011	-2.89	-0.027	-3.97	-0.005	-1.57	-0.004	-1.84	-0.013	-2.22
Std.	0.011	40.17	0.015	21.21	0.012	12.05	0.017	12.23	0.006	8.59	0.007	14.14	-	-
RC	$-0.243*10^{-4}$	-1.73	$-0.316*10^{-5}$	-0.13	$-0.940*10^{-3}$	-0.76	$-0.620*10^{-3}$	-1.83	$-0.110*10^{-3}$	-2.26	$-0.656*10^{-4}$	-2.14	$-0.650*10^{-4}$	-2.59
Std.	$0.688*10^{-4}$	7.06	$0.910*10^{-4}$	6.45	0.002	4.28	-	-	-	-	$0.190*10^{-3}$	9.44	-	-
%G	0.001	0.05	0.05	1.58	0.089	2.02	0.045	1.63	0.007	0.2	$0.330*10^{-3}$	0.02	0.163	1.43
Std.	0.007	1.11	0.186	11.13	0.221	9.39	-	-	-	-	0.072	5.43	-	-
NL	-0.363	-12.39	-0.213	-3.07	-0.696	-5.05	-0.18	-1.82	-0.402	-6.14	-0.573	-12.69	-0.509	-1.82
Std.	0.239	28.7	-	-	-	-	-	-	-	-	-	-	-	-
NMA	0.998	37.29	1.047	17.94	0.926	6.64	1.031	13.31	0.337	4.73	0.573	12.69	0.439	0.99
Std.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SR	-1.38	-2.33	-2.377	-2.33	-1.569	-2.57	-0.054	-2.03	-1.016	-1.65	-3.284	-2.87	-0.502	-0.1
Std.	-	-	1.066	12.73	-	-	-	-	-	-	1.275	13.25	-	-
RD	0.002	0.15	0.002	0.11	0.058	1.89	0.034	0.89	0.016	0.45	0.021	1.95	0.033	2.34
Std.	0.039	17.62	0.01	2.73	-	-	0.048	6.62	0.044	6.93	-	-	0.025	1.87
TX	-0.838	-7.27	-1.158	-5.84	-1.303	-3.27	-0.601	-1.57	-0.957	-2.75	-0.621	-3.05	-1.747	-1.93
Std.	1.783	43.02	1.948	28.11	-	-	1.708	12.53	-	-	-	-	-	-

Table A-10: RPNB models estimation results for SF accident frequencies for Oxfordshire site categories

Variables	NT		NE		B1		B2		RA		JN		GR	
	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t
Constant	-4.915	-7.14	-2.506	-2.01	-10.402	-3.29	-5.347	-1.78	-6.427	-4.04	-1.103	-1.81	-11.347	-2.34
Ln AADF	0.238	3.67	0.379	3.24	0.665	2.37	0.707	2.43	0.438	3.29	0.162	1.87	0.614	2.88
Std.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
%HV	0.002	2.09	0.087	2.71	0.058	1.77	0.013	2.19	0.024	2.61	0.027	1.72	0.265	1.77
Std.	-	-	0.116	8.61	-	-	-	-	-	-	-	-	-	-
SPL	-0.013	-6.77	-0.017	-5.51	-0.014	-1.65	-0.013	-2.24	-0.004	-1.74	-0.001	-2.28	-0.005	-2.28
Std.	0.009	17.87	0.016	12.66	-	-	-	-	-	-	-	-	-	-
RC	$-0.258*10^{-4}$	-0.94	$-0.200*10^{-3}$	-3.61	-0.003	-1.96	-0.002	-2.04	$-0.199*10^{-4}$	-2.33	$-0.125*10^{-3}$	-2.23	$-0.230*10^{-3}$	-4.33
Std.	$0.110*10^{-3}$	5.82	$0.300*10^{-3}$	10.66	-	-	-	-	-	-	-	-	-	-
%G	0.064	2.91	0.012	1.22	0.054	0.76	0.042	2.47	0.045	1.88	0.046	1.19	0.13	1.67
Std.	0.115	8.82	0.139	4.58	0.149	4.12	-	-	-	-	0.041	1.77	-	-
NL	-0.467	-8.41	-0.266	-1.74	-0.221	-2.33	-0.489	-1.81	$-0.301*10^{-3}$	-2.06	-0.458	-5.47	-0.435	-2.63
Std.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
NMA	0.773	15.17	0.668	6.73	0.873	3.49	0.745	2.81	0.209	2.13	0.452	5.47	0.497	2.18
Std.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SR	-0.869	-1.79	-4.497	-2.31	-1.008	-0.82	-6.927	-1.87	-1.073	-2.38	-1.181	-2.62	-3.365	-2.47
Std.	-	-	-	-	0.657	1.85	-	-	0.415	2.88	-	-	0.705	3.81
RD	0.012	0.62	0.011	2.32	0.123	1.67	0.071	0.75	0.003	3.06	0.031	0.95	0.041	2.19
Std.	0.047	11.34	-	-	-	-	0.027	1.82	-	-	0.044	5.23	-	-
TX	-0.037	-0.18	-0.285	-1.83	-2.052	-2.31	-1.275	-1.87	-1.439	-2.85	-0.768	-1.99	-0.274	-2.13
Std.	0.498	7.13	-	-	-	-	-	-	-	-	-	-	-	-

Table A-11: RPNB models estimation results for T accident frequencies for Nottinghamshire site categories

Variables	NT		NE		B1		B2		RA		JN		GR	
	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t
Constant	-2.625	-8.56	-3.241	-7.52	-4.732	-4.11	-3.233	-2.59	-0.806	-2.66	-2.184	-2.98	-4.745	-2.96
Ln AADF	0.626	21.53	0.626	14.95	0.697	6.55	0.625	5.71	0.283	2.51	0.393	6.01	0.725	2.03
Std.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
%HV	0.109	23.32	0.081	15.39	0.247	7.09	0.085	3.22	0.065	3.53	0.077	4.44	0.163	4.99
Std.	0.036	14.79	0.032	11.08	0.101	7.52	-	-	0.03	3.56	-	-	-	-
SPL	-0.012	-13.89	-0.013	-8.37	-0.014	-4.16	-0.017	-4.86	-0.012	-4.15	-0.007	-3.48	-0.002	-3.37
Std.	-	-	-	-	-	-	0.009	10.62	0.008	11.75	-	-	0.007	7.17
RC	$-0.154*10^{-3}$	-8.06	$-0.470*10^{-3}$	-14.32	$-0.220*10^{-3}$	-2.21	$-0.190*10^{-3}$	-0.23	$-0.180*10^{-3}$	-2.83	$-0.746*10^{-3}$	-1.85	$-0.100*10^{-3}$	-1.95
Std.	-	-	-	-	-	-	$0.320*10^{-3}$	1.99	$0.747*10^{-4}$	2.07	$0.469*10^{-4}$	2.07	-	-
%G	0.017	1.77	0.089	3.17	0.055	1.51	0.009	3.02	0.059	1.79	0.013	2.44	0.068	1.68
Std.	0.044	7.25	0.105	8.66	0.064	2.78	-	-	-	-	-	-	-	-
NL	-0.367	-3.71	-0.235	-1.77	-0.325	-4.66	-0.074	-1.65	-0.132	-1.97	-0.082	-2.11	-0.142	-2.16
Std.	-	-	0.131	17.84	0.27	10.64	-	-	-	-	0.135	10.28	0.333	11.12
NMA	0.651	10.22	0.664	7.01	0.249	2.55	0.067	2.64	0.172	1.86	0.048	1.93	0.033	2.19
Std.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SR	-4.312	-21.64	-5.463	-19.21	-1.261	-1.22	-2.868	-2.15	-2.308	-4.86	-1.159	-1.47	-1.813	-4.09
Std.	3.148	64.56	3.315	54.08	3.172	17.35	-	-	-	-	0.847	8.87	-	-
RD	0.003	0.38	0.025	2.14	0.045	1.72	0.036	1.24	0.021	0.77	0.029	1.45	0.023	0.72
Std.	0.015	5.91	0.064	19.91	-	-	0.056	5.43	0.094	10.82	0.083	12.88	0.017	1.97
TX	-0.497	-5.08	-0.797	-6.14	-0.87	-2.26	-0.702	-2.85	-0.047	-0.14	-0.435	-1.73	-1.73	-3.12
Std.	0.233	7.33	0.576	14.17	0.356	2.84	0.359	2.9	0.145	1.83	-	-	1.594	9.03

Table A-12: RPNB models estimation results for D accident frequencies for Nottinghamshire site categories

Variables	NT		NE		B1		B2		RA		JN		GR	
	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t
Constant	-3.478	-8.912	-4.226	-7.73	-5.339	-3.43	-4.053	-2.96	-1.642	-1.85	-3.187	-3.79	-4.537	-1.83
Ln AADF	0.671	18.23	0.652	12.37	0.762	5.58	0.748	6.06	0.236	1.8	0.471	6.33	0.531	1.81
Std.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
%HV	0.132	21.41	0.104	15.04	0.306	5.84	0.109	3.56	0.085	3.84	0.096	5.16	0.214	4.06
Std.	0.063	19.72	0.056	16.09	0.154	7.9	-	-	0.086	7.73	0.033	3.41	-	-
SPL	-0.014	-12.16	-0.011	-7.73	-0.015	-3.12	-0.014	-3.59	-0.013	-3.89	-0.008	-3.13	-0.006	-0.91
Std.	-	-	0.004	12.18	-	-	-	-	0.006	7.81	-	-	0.009	5.73
RC	$-0.132*10^{-3}$	-5.33	$-0.453*10^{-3}$	-11.02	$-0.890*10^{-3}$	-2.58	-0.002	-1.63	$-0.160*10^{-3}$	-2.12	$-0.824*10^{-4}$	-1.76	$-0.160*10^{-3}$	-1.89
Std.	-	-	-	-	-	-	0.002	9.68	-	-	$0.643*10^{-3}$	2.44	-	-
%G	0.0139	2.06	0.055	2.56	0.042	1.92	0.054	1.99	0.051	1.21	0.008	2.35	0.114	1.98
Std.	-	-	-	-	-	-	-	-	0.049	2.07	-	-	0.074	4.27
NL	-0.288	-3.88	-0.222	-0.75	-0.267	-3.12	-0.091	-1.88	-0.127	-1.83	-0.081	-1.77	-0.307	-3.08
Std.	-	-	0.209	22.99	-	-	-	-	-	-	0.136	8.86	-	-
NMA	0.443	8.31	0.502	5.31	0.182	1.89	0.073	3.62	0.159	1.97	0.032	2.54	0.026	3.11
Std.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SR	-4.156	-14.57	-4.389	-11.7	-2.594	-1.45	-2.547	-2.31	-2.41	-4.81	-1.149	-1.24	-0.992	-3.07
Std.	2.605	43.86	2.655	36.27	1.304	6.07	-	-	-	-	0.495	4.53	-	-
RD	$-0.400*10^{-3}$	-0.04	-0.039	-2.72	-0.086	-1.66	-0.051	1.55	-0.019	-0.32	-0.027	-1.13	-0.017	-2.35
Std.	0.006	1.91	0.085	20.69	0.159	9.67	0.031	2.72	0.022	2.32	0.067	9.21	-	-
TX	-0.477	-3.89	-0.934	-5.68	-1.316	-2.49	-1.005	-2.78	-0.503	-1.26	-0.355	-1.85	-0.214	-2.36
Std.	0.279	6.98	0.903	17.71	-	-	1.044	6.88	0.975	7.58	-	-	-	-

Table A-13: RPNB models estimation results for W accident frequencies for Nottinghamshire site categories

Variables	NT		NE		B1		B2		RA		JN		GR	
	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t
Constant	-3.578	-7.92	-7.059	-6.48	-5.772	-2.89	-2.421	-1.82	-2.342	-1.98	-1.818	-1.76	-6.991	-2.48
Ln AADF	0.591	13.99	0.889	7.65	0.536	2.64	0.406	2.96	0.462	2.41	0.237	2.74	0.366	3.22
Std.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
%HV	0.102	14.34	0.022	2.34	0.263	4.71	0.068	1.69	0.071	2.23	0.058	2.42	0.144	2.75
Std.	0.041	4.77	0.031	4.38	0.134	5.79	0.049	3.27	-	-	-	-	-	-
SPL	-0.015	-10.82	-0.014	-4.81	-0.017	-3.01	-0.019	-4.11	-0.007	-2.37	-0.007	-2.39	-0.003	-2.31
Std.	0.008	24.48	-	-	-	-	0.011	9.7	-	-	-	-	0.005	4.25
RC	$-0.133*10^{-3}$	-4.53	$-0.140*10^{-3}$	-1.72	$-0.102*10^{-3}$	-3.51	$-0.473*10^{-3}$	-2.41	$0.200*10^{-3}$	-1.82	$-0.692*10^{-4}$	-2.09	$-0.620*10^{-4}$	-2.54
Std.	-	-	-	-	-	-	-	-	0.002	2.47	-	-	-	-
%G	0.033	2.28	0.059	1.77	0.033	3.51	0.061	3.12	0.056	1.93	$0.300*10^{-3}$	2.01	0.021	0.23
Std.	-	-	-	-	-	-	-	-	-	-	-	-	0.05	2.72
NL	-0.268	-2.52	-0.258	-1.73	-0.039	-3.33	-0.037	-2.18	-0.037	-2.28	-0.104	-1.88	-0.213	-1.85
Std.	-	-	0.134	5.82	-	-	-	-	-	-	-	-	-	-
NMA	0.306	6.52	0.662	4.52	0.156	1.83	0.074	1.69	0.283	1.83	0.087	1.88	0.024	2.09
Std.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SR	-2.645	-11.37	-2.303	-5.57	-3.355	-1.94	-2.07	-1.69	-3.83	-2.22	-1.041	-1.97	-1.08	-2.18
Std.	2.278	32.78	1.604	12.8	-	-	-	-	-	-	0.749	4.44	-	-
RD	0.001	0.07	0.023	0.74	0.654	1.96	0.044	1.08	0.004	0.08	0.008	2.27	0.014	1.88
Std.	0.008	2.25	0.048	6.03	-	-	0.054	3.96	-	-	-	-	-	-
TX	-0.091	-3.32	-0.283	-1.12	-0.06	-2.07	-0.966	-3.37	-0.603	-2.12	-0.063	-3.17	-1.171	-1.73
Std.	-	-	0.844	10.45	0.091	5.18	0.534	3.02	-	-	-	-	-	-

Table A-14: RPNB models estimation results for SL accident frequencies for Nottinghamshire site categories

Variables	NT		NE		B1		B2		RA		JN		GR	
	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t
Constant	-3.261	-9.78	-4.196	-8.50	-5.721	-3.91	-2.715	-2.03	-0.757	-2.73	-3.017	-3.96	-5.188	-2.45
Ln AADF	0.692	21.77	0.712	14.95	0.767	5.75	0.585	5.15	0.324	3.42	0.458	6.66	0.236	1.78
Std.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
%HV	0.102	20.25	0.075	12.66	0.319	6.81	0.076	2.75	0.076	4.68	0.072	4.45	0.161	3.76
Std.	0.04	15.49	0.042	14.51	0.182	9.35	0.024	2.11	0.07	9.15	-	-	-	-
SPL	-0.015	-15.35	-0.013	-9.55	-0.017	-3.97	-0.014	-3.79	-0.012	-4.95	-0.009	-4.19	-0.007	-1.25
Std.	-	-	-	-	-	-	-	-	0.005	9.13	-	-	0.008	6.07
RC	$-0.130*10^{-3}$	-6.4	$-0.453*10^{-3}$	-11.45	$-0.500*10^{-3}$	-2.37	$-0.760*10^{-3}$	-0.84	$-0.160*10^{-3}$	-2.92	$-0.110*10^{-3}$	-2.61	$-0.110*10^{-3}$	-3.81
Std.	-	-	$0.160*10^{-3}$	11.12	-	-	0.002	8.34	0.140 E -03	4.43	$0.814*10^{-4}$	3.42	-	-
%G	0.019	1.85	0.097	3.07	0.021	0.46	0.019	0.43	0.076	2.68	0.013	2.69	0.056	1.86
Std.	0.046	6.97	-	-	0.045	1.84	0.063	2.37	0.041	2.55	-	-	-	-
NL	-0.465	-3.28	-0.169	-2.63	-0.153	-1.89	-0.045	-1.68	-0.184	-1.62	-0.07	-1.74	-0.233	-2.56
Std.	-	-	0.064	7.89	-	-	-	-	0.396	22.04	0.148	10.93	-	-
NMA	0.719	10.66	0.702	11.66	0.204	1.96	0.167	1.85	0.153	1.95	0.076	1.93	0.069	3.33
Std.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SR	-4.174	-19.73	-5.855	-15.48	-2.555	-1.71	-3.405	-2.41	-1.842	-6.48	-0.822	-1.01	-1.153	-3.37
Std.	3.144	60.22	3.112	45.89	-	-	-	-	-	-	1.146	11.44	-	-
RD	0.005	0.53	0.045	3.36	0.043	0.93	0.021	0.71	0.009	0.43	0.027	1.28	0.003	2.06
Std.	0.01	3.59	0.087	22.93	0.144	9.81	0.043	4.01	0.019	2.84	0.071	10.9	-	-
TX	-0.42	-4.00	-0.644	-4.38	-1.075	-2.16	-0.633	-3.13	-0.234	-0.83	-0.544	-2.11	-1.505	-2.23
Std.	0.26	7.68	0.651	14.1	-	-	0.707	5.29	0.382	4.39	-	-	1.308	5.75

Table A-15: RPNB models estimation results for SF accident frequencies for Nottinghamshire site categories

Variables	NT		NE		B1		B2		RA		JN		GR	
	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t
Constant	-3.071	-5.33	-2.908	-3.34	-5.684	-2.59	-4.769	-2.06	-1.561	-2.91	-1.359	-2.07	-4.866	-1.68
Ln AADF	0.364	6.96	0.319	3.77	0.42	2.06	0.687	3.24	0.162	2.06	0.155	1.94	0.614	1.88
Std.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
%HV	0.184	15.27	0.131	9.87	0.204	3.25	0.091	1.72	0.081	2.69	0.067	2.63	0.307	4.15
Std.	0.071	13.13	-	-	-	-	-	-	-	-	-	-	-	-
SPL	-0.005	-2.81	-0.003	-1.25	-0.002	-2.24	-0.023	-3.42	-0.003	-0.81	$-0.170*10^{-3}$	-2.05	-0.015	-1.66
Std.	0.005	12.65	0.004	7.51	-	-	0.013	8.03	0.004	4.16	-	-	-	-
RC	$-0.120*10^{-4}$	-3.54	$-0.402*10^{-4}$	-5.59	-0.004	-1.92	-0.001	-3.72	$-0.180*10^{-3}$	-1.77	$-0.188*10^{-4}$	-3.31	$-0.840*10^{-4}$	-2.65
Std.	-	-	-	-	-	-	-	-	-	-	0.002	3.05	-	-
%G	0.014	0.72	0.125	1.69	0.261	2.64	0.177	1.68	0.046	0.87	0.012	3.34	0.119	1.92
Std.	0.006	2.56	0.042	1.66	0.287	5.53	0.266	5.09	0.195	6.84	-	-	-	-
NL	-0.169	-2.02	-0.152	-1.96	-0.018	-3.14	-0.276	-2.04	-0.318	-2.49	-0.124	-1.99	-0.31	-2.22
Std.	0.086	7.91	0.208	12.34	-	-	-	-	-	-	-	-	-	-
NMA	0.377	6.55	0.377	6.55	0.116	2.61	0.202	3.26	0.252	2.06	0.009	2.09	0.237	3.67
Std.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SR	-2.665	-6.21	-3.696	-6.38	-1.408	-0.51	-2.334	-1.81	-4.179	-2.81	-3.66	-2.98	-3.823	-1.99
Std.	0.932	11.81	2.466	19.97	2.735	8.05	-	-	2.007	10.51	-	-	1.071	2.42
RD	0.016	1.02	0.008	0.35	0.085	1.32	0.121	2.06	0.024	2.61	0.018	3.51	0.021	3.33
Std.	0.029	6.07	0.027	3.84	0.052	2.64	-	-	-	-	-	-	-	-
TX	-0.184	-3.46	-1.147	-3.98	-0.708	-1.97	-0.882	-1.72	-0.488	-2.02	-0.067	-3.16	-1.255	-2.00
Std.	0.193	3.16	-	-	-	-	-	-	-	-	-	-	-	-

APPENDIX B

Table B-1: RPT models estimation results for TAR accident rates for Norfolk site categories

Variables	NT		NE		B1		B2		RA		JN		GR	
	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t
Constant	-10.433	-25.92	-6.127	-12.39	-13.693	-9.44	-6.997	-7.56	-5.828	-2.36	-8.726	-9.45	-0.241	-3.59
Ln AADF	1.339	28.97	0.875	16.10	1.979	11.35	0.984	9.63	1.207	4.45	0.909	8.67	0.619	2.66
Std.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
%HV	0.021	2.79	0.068	7.45	0.095	2.91	0.028	1.67	0.007	0.22	0.024	1.33	2.727	3.66
Std.	0.149	25.47	0.139	21.86	-	-	0.108	8.18	0.025	1.88	0.230	13.21	6.489	5.77
SPL	-0.014	-11.84	-0.014	-9.79	-0.035	-7.07	-0.013	-4.99	-0.008	-1.99	-0.007	-2.40	-0.005	-1.78
Std.	0.005	12.40	0.005	11.13	0.038	13.38	0.014	12.85	-	-	-	-	-	-
RC	-0.002	-33.11	-0.001	-6.97	-0.007	-5.69	-0.001	-1.80	$-0.254*10^{-4}$	-2.44	-0.001	-5.59	-0.005	-3.14
Std.	0.002	41.54	0.001	22.17	0.008	9.25	-	-	-	-	0.001	12.74	-	-
%G	0.048	3.06	0.004	0.19	0.026	0.57	0.017	0.49	0.033	0.40	0.075	2.13	0.051	4.03
Std.	0.021	1.74	0.080	4.06	0.176	4.33	0.228	7.01	0.150	2.50	0.155	4.90	-	-
NL	-0.218	-4.35	-0.115	-1.69	-0.402	-2.36	-0.131	-2.99	-0.094	-4.45	-0.338	-3.92	-0.174	-5.44
Std.	0.643	34.99	0.198	11.48	-	-	-	-	-	-	-	-	-	-
NMA	0.296	7.03	0.209	3.96	0.388	2.89	0.257	2.89	0.460	3.39	0.289	3.51	0.324	1.99
Std.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SR	-2.027	-5.04	-2.967	-6.20	-2.494	-1.81	-2.247	-2.62	-6.103	-2.63	-1.070	-1.15	-0.866	-1.55
Std.	0.436	5.54	-	-	8.004	14.15	-	-	-	-	0.587	3.27	5.940	2.47
RD	0.025	0.03	0.013	0.92	0.038	2.96	0.011	2.44	0.002	5.03	0.016	0.51	0.009	1.99
Std.	0.036	7.49	0.068	11.59	-	-	-	-	-	-	-	-	-	-
TX	-0.159	-1.41	-0.305	-2.41	-1.090	-2.49	-0.634	-2.50	-1.126	-1.90	-0.157	-3.61	-0.259	-3.22
Std.	0.715	13.42	-	-	-	-	-	-	-	-	-	-	-	-

Table B-2: RPT models estimation results for DAR accident rates for Norfolk site categories

Variables	NT		NE		B1		B2		RA		JN		GR	
	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t
Constant	-8.387	-21.14	-6.592	-11.79	-6.969	-6.77	-7.576	-7.19	-13.341	-3.36	-15.382	-9.24	-10.542	-3.24
Ln AADF	1.076	23.93	0.908	14.69	0.962	8.65	1.063	9.15	1.809	4.36	1.757	9.36	0.788	7.25
Std.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
%HV	0.046	5.52	0.102	8.80	0.050	2.00	0.037	1.99	0.306	3.69	0.412	8.98	0.524	3.77
Std.	0.132	22.19	0.167	21.08	-	-	0.052	4.00	1.621	6.90	0.707	13.20	-	-
SPL	-0.014	-11.48	-0.025	-9.57	-0.017	-3.12	-0.022	-4.49	-0.030	-3.13	-0.042	-5.22	-0.058	-4.81
Std.	0.001	24.56	0.008	9.50	0.003	3.68	0.026	12.96	-	-	0.056	12.45	-	-
RC	-0.001	-33.27	-0.007	-6.89	-0.005	-3.58	-0.001	-1.83	-0.008	-3.91	-0.001	-5.91	-0.004	-2.73
Std.	0.043	2.68	0.001	20.60	0.033	0.93	-	-	-	-	0.001	9.11	0.043	2.68
%G	0.153	0.31	0.127	0.46	0.134	4.26	0.259	0.62	0.306	2.44	0.166	2.92	0.425	3.31
Std.	0.653	34.66	0.077	3.45	-	-	0.234	6.58	-	-	0.247	4.93	-	-
NL	-0.324	-7.29	-0.205	-1.79	-0.161	-1.68	-0.320	-2.08	-0.205	-1.88	-0.468	-5.48	-0.242	-2.48
Std.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
NMA	0.388	4.66	0.207	3.53	0.250	2.42	0.243	2.62	0.411	3.15	0.701	5.31	0.457	4.66
Std.	-	-	-	-	-	-	-	-	-	-	-		-	-
SR	-2.009	-1.19	-2.581	-4.80	-2.934	-2.74	-2.305	-2.36	-1.925	-2.54	-0.619	-0.42	-0.735	-1.19
Std.	0.020	4.18	-	-	4.658	14.43	-	-	-	-	6.701	12.75	0.020	4.18
RD	-0.011	-0.10	-0.012	-0.69	-0.019	-2.03	-0.007	-2.25	-0.240	-1.68	-0.077	-4.43	-0.009	-3.11
Std.	0.113	2.12	0.073	10.75	-	-	-	-	-	-	-	-	0.113	2.12
TX	-0.523	-4.53	-0.259	-1.73	-0.567	-1.66	-0.483	-1.71	-0.358	-1.87	-0.249	-2.57	-0.452	-3.24
Std.	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table B-3: RPT models estimation results for WAR accident rates for Norfolk site categories

Variables	NT		NE		B1		B2		RA		JN		GR	
	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t
Constant	-7.390	-15.42	-6.531	-7.67	-12.763	-6.02	-11.058	-6.48	-7.721	-3.32	-9.228	-6.95	-4.253	-4.25
Ln AADF	0.851	16.40	0.918	10.16	1.678	6.97	1.603	8.15	0.880	3.70	0.880	6.22	0.756	4.61
Std.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
%HV	0.031	3.14	0.077	5.12	0.067	1.48	0.097	2.42	0.020	0.47	0.047	1.71	0.078	4.35
Std.	0.097	15.11	0.141	14.71	-	-	0.338	10.13	-	-	-	-	0.124	11.25
SPL	-0.012	-8.19	-0.020	-5.26	-0.050	-9.74	-0.028	-3.44	-0.007	-0.76	-0.021	-3.18	-0.001	-9.08
Std.	0.010	19.27	-	-	0.061	2.51	-	-	0.005	1.93	0.030	10.85	-	-
RC	-0.001	-18.54	$-0.732*10^{-3}$	-1.99	-0.004	-3.69	-0.005	-4.39	-0.001	-1.19	-0.001	-8.04	-0.001	-11.25
Std.	0.001	27.43	0.001	2.14	0.004	0.55	-	-	-	-	0.002	11.38	-	-
%G	0.051	2.01	0.063	1.61	0.033	1.90	0.005	1.07	0.021	0.31	0.074	1.68	0.083	1.01
Std.	0.137	8.54	0.177	5.48	0.003	9.11	0.316	2.58	0.160	3.21	-	-	0.103	5.48
NL	-0.215	-2.39	-0.307	-2.70	-0.474	-3.09	-0.261	-5.52	-0.077	-2.59	-0.270	-3.00	-0.122	-3.21
Std.	0.000	0.00	0.434	14.74	-	-	-	-	-	-	-	-	-	-
NMA	0.133	2.90	0.200	2.33	0.337	10.93	0.119	1.18	0.105	0.41	0.034	0.33	0.108	3.09
Std.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SR	-1.684	-3.72	-4.781	-6.16	-6.476	-0.95	-3.662	-0.79	-1.458	-3.05	-0.985	-1.79	-0.753	-2.34
Std.	0.955	10.28	-	-	9.866	3.17	-	-	-	-	-	-	0.519	2.81
RD	0.003	0.30	0.045	1.74	0.020	3.54	0.086	2.51	0.021	4.36	0.067	5.28	0.006	2.63
Std.	0.009	1.61	0.199	18.62	-	-	-	-	-	-	-	-	-	-
TX	-0.138	-1.08	-0.285	-3.11	-0.107	-1.75	-0.335	-5.63	-0.142	-2.28	-0.429	-2.61	-0.154	-1.08
Std.	0.116	1.95	-	-	-	-	-	-	-	-	-	-	-	-

Table B-4: RPT models estimation results for SLAR accident rates for Norfolk site categories

Variables	NT		NE		B1		B2		RA		JN		GR	
	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t
Constant	-9.567	-23.15	-7.927	-12.33	-18.190	-8.33	-7.505	-2.80	-7.704	-3.79	-7.298	-8.00	-5.169	-5.32
Ln AADF	1.246	26.54	1.228	17.11	2.949	10.03	1.082	7.10	1.155	5.37	0.761	7.43	1.062	5.41
Std.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
%HV	0.065	7.56	0.093	7.86	1.283	9.50	0.002	9.29	0.050	1.39	0.043	2.21	0.094	6.77
Std.	0.189	28.37	0.184	21.10	-	-	0.155	3.08	-	-	0.215	12.42	-	-
SPL	-0.017	-13.30	-0.050	-15.54	-0.048	-4.57	-0.020	-9.85	-0.003	-0.36	-0.018	-3.97	-0.007	-3.19
Std.	-	-	0.037	28.72	-	-	-	-	0.031	7.69	-	-	-	-
RC	-0.001	-27.73	$-0.784*10^{-4}$	-4.62	-0.013	-6.47	-0.001	-4.32	-0.003	-2.74	-0.001	-5.42	-0.007	-3.77
Std.	0.002	37.24	-	-	-	-	-	-	-	-	0.001	10.39	0.028	4.27
%G	0.022	1.35	0.035	1.17	0.180	2.66	0.015	12.23	0.056	3.78	0.070	2.03	0.076	3.25
Std.	0.123	8.56	0.046	1.84	0.597	7.83	-	-	-	-	-	-	0.055	6.85
NL	-0.174	-3.51	-0.106	-3.26	-0.890	-3.99	-0.185	-6.36	-0.063	-7.39	-0.417	-5.05	-0.476	-5.11
Std.	0.627	33.61	-	-	-	-	-	-	-	-	-	-	-	-
NMA	0.301	7.08	0.293	4.44	0.542	3.05	0.195	5.32	0.182	2.58	0.297	3.69	0.203	8.05
Std.	-	-	-	-	-	-	-	-	-	-	-		-	-
SR	-2.070	-5.02	-4.133	-6.78	-1.416	-0.72	-2.732	-2.06	-2.754	-1.69	-0.431	-0.46	-1.448	-2.05
Std.	0.223	2.74	-	-	6.073	9.27	-	-	-	-	0.366	2.04	-	-
RD	0.010	1.03	0.058	2.82	0.082	12.11	0.047	1.97	0.009	2.05	0.004	3.15	0.017	3.34
Std.	0.089	16.69	0.271	27.03	-	-	-	-	-	-	-	-	0.064	6.62
TX	-0.669	-0.56	-0.323	-1.99	-1.253	-1.74	-0.563	-3.94	-1.146	-1.85	-0.087	-2.33	-0.624	-1.05
Std.	0.396	7.30	-	-	-	-	-	-	-	-	-	-	-	-

Table B-5: RPT models estimation results for SFAR accident rates for Norfolk site categories

Variables	NT		NE		B1		B2		RA		JN		GR	
	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t
Constant	-7.678	-15.02	-7.908	-6.75	-5.544	-3.17	-13.479	-5.62	-0.248	-0.08	-22.477	-7.68	-5.247	-2.08
Ln AADF	0.755	13.34	1.147	9.09	0.919	4.86	1.679	6.18	0.311	0.97	2.083	6.83	0.907	3.55
Std.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
%HV	0.033	3.85	0.083	4.09	0.136	3.40	0.081	2.03	0.112	1.93	0.045	1.45	0.065	5.41
Std.	0.019	3.27	0.202	14.17	-	-	-	-	0.523	6.73	0.076	3.50	0.024	2.31
SPL	-0.001	-0.81	-0.011	-2.07	-0.012	-1.33	-0.051	-4.14	-0.003	-0.24	-0.039	-3.53	-0.004	-1.99
Std.	0.006	11.47	-	-	0.027	7.52	0.088	10.48	-	-	-	-	-	-
RC	-0.002	-21.68	-0.001	-5.15	-0.007	-4.03	-0.007	-3.90	-0.003	-2.25	-0.001	-3.31	-0.008	8.64
Std.	0.002	27.55	0.001	14.00	0.010	8.68	-	-	-	-	0.002	1.96	-	-
%G	0.019	0.90	0.122	2.05	0.287	3.37	0.030	0.34	0.265	2.23	3.772	10.17	0.338	2.22
Std.	0.001	2.09	0.516	10.17	0.410	6.13	-	-	-	-	6.466	11.25	0.028	3.28
NL	-0.962	-7.28	-1.718	-7.63	-0.416	-1.72	-1.304	-2.67	-1.211	-3.80	-0.449	-2.89	-0.544	-2.44
Std.	-	-	1.338	20.69	-	-	-	-	-	-	-	-	-	-
NMA	0.144	2.90	0.222	1.81	0.114	2.71	0.613	3.04	2.253	3.43	0.301	1.71	0.214	3.71
Std.	-	-	-	-	-	-	-	-	-	-	-		-	-
SR	-0.601	-7.22	-4.546	-4.27	-5.769	-3.11	-2.292	-1.13	-1.597	-0.65	-0.623	-0.31	-0.601	-1.22
Std.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
RD	0.024	2.17	0.055	1.64	0.013	2.15	0.087	2.14	0.074	1.88	0.077	2.09	0.041	7.54
Std.	0.050	7.96	0.161	11.24	-	-	-	-	-	-	-	-	-	-
TX	-0.711	-1.77	-0.924	-3.39	-1.389	-2.06	-1.228	-1.99	-0.925	-3.17	-0.715	-4.65	-0.377	-2.71
Std.	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table B-6: RPT models estimation results for TAR accident rates for Oxfordshire site categories

Variables	NT		NE		B1		B2		RA		JN		GR	
	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t
Constant	-3.153	-7.82	-8.162	-6.19	-16.028	-5.04	-4.345	-3.24	-0.293	-0.17	-1.869	-1.76	-1.057	-2.84
Ln AADF	1.318	8.39	2.233	13.12	1.176	4.57	0.546	4.88	0.993	1.40	0.701	1.07	0.419	3.17
Std.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
%HV	0.094	8.60	2.565	17.42	0.694	6.36	0.425	9.06	0.210	4.43	0.076	2.90	0.415	6.28
Std.	0.203	26.27	3.377	18.22	-	-	0.667	15.22	0.524	10.13	-	-	0.311	2.74
SPL	-0.019	-16.21	-0.040	-9.65	-0.068	-6.53	-0.008	-2.39	-0.004	-1.85	-0.004	-1.41	-0.009	-2.16
Std.	0.028	43.12	-	-	0.100	9.05	-	-	-	-	0.018	13.85	0.035	2.47
RC	$-0.154*10^{-4}$	3.55	$-0.548*10^{-4}$	-2.12	-0.004	-1.64	-0.001	-3.63	$-0.246*10^{-4}$	-2.54	-0.005	-1.08	-0.007	-3.01
Std.	0.001	16.67	0.006	1.99	0.022	3.11	-	-	-	-	0.001	10.05	-	-
%G	0.007	0.58	0.018	0.30	0.070	1.05	0.049	1.47	0.010	0.20	0.040	1.36	0.005	1.52
Std.	0.013	2.28	0.649	11.04	0.236	3.90	0.047	1.68	0.136	2.95	0.107	4.00	0.029	2.84
NL	-0.605	-16.46	-0.843	-5.46	-1.339	-4.05	-0.107	-1.73	-0.393	-3.54	-0.364	-4.10	-0.428	-4.16
Std.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
NMA	1.339	29.89	3.820	15.56	3.669	7.33	1.409	9.95	1.193	5.94	0.757	8.58	0.924	3.87
Std.	-	-	-	-	-	-	-	-	-	-	-		-	-
SR	-2.369	-3.58	-12.492	-5.67	-0.809	-0.17	-3.402	-1.73	-2.899	-1.03	-3.535	-2.17	-1.854	-1.94
Std.	-	-	-	-	-	-	-	-	-	-	0.508	2.68	-	-
RD	0.009	0.75	0.065	1.80	0.261	3.42	0.009	2.24	0.134	2.78	0.046	1.68	0.024	2.11
Std.	0.049	13.84	0.013	1.88	-	-	-	-	-	-	-	-	0.004	4.22
TX	-1.143	-1.19	-4.511	-9.63	-2.156	-2.52	-2.428	-3.15	-2.913	-4.53	-1.241	-2.38	-0.874	-9.25
Std.	1.056	16.35	-	-	-	-	-	-	-	-	-	-	-	-

Table B-7: RPT models estimation results for DAR accident rates for Oxfordshire site categories

Variables	NT		NE		B1		B2		RA		JN		GR	
	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t
Constant	-5.611	-9.95	-3.888	-5.01	-11.365	-5.41	-4.352	-2.56	-3.169	-3.11	-2.828	-4.11	-2.611	-5.22
Ln AADF	0.706	13.37	0.645	8.48	0.822	4.82	0.588	4.11	0.322	2.72	0.153	3.36	0.204	3.77
Std.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
%HV	0.506	23.10	0.575	16.55	0.442	6.00	0.391	6.80	0.112	3.33	0.073	2.42	0.094	2.14
Std.	0.733	35.36	0.726	24.21	-	-	0.561	11.74	-	-	-	-	0.037	3.11
SPL	-0.020	-12.64	-0.024	-6.86	-0.043	-4.69	-0.012	-1.79	-0.011	-1.53	-0.009	-1.81	-0.004	-6.12
Std.	0.024	30.74	-	-	0.021	6.15	-	-	-	-	-	-	0.003	7.44
RC	-0.001	-0.04	-0.002	-0.67	$-0.211*10^{-4}$	-1.44	-0.002	-2.27	-0.007	-5.32	$-0.311*10^{-4}$	-4.15	$-0.544*10^{-4}$	-1.14
Std.	0.002	16.00	0.001	6.78	0.003	3.41	-	-	0.004	3.25	0.001	11.22	0.002	6.11
%G	0.015	0.97	0.008	2.11	0.002	0.05	0.073	1.75	0.043	3.85	0.068	1.93	0.084	1.97
Std.	0.064	4.57	-	-	0.238	5.21	-	-	-	-	0.265	7.53	0.059	5.08
NL	-0.265	-5.44	-0.142	-1.68	-0.339	-3.27	-0.321	-3.44	-0.563	-5.41	-0.081	-2.84	-0.128	-4.18
Std.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
NMA	1.683	28.75	1.330	15.19	1.667	6.58	1.671	9.12	0.722	6.11	1.127	11.19	1.027	7.85
Std.	-	-	-	-	-	-	-	-	-	-	-		-	-
SR	-1.983	-2.18	-2.178	-1.67	-10.365	-3.08	-2.915	-3.14	-5.154	-2.08	-7.251	-3.69	-3.088	1.83
Std.	-	-	-	-	-	-	-	-	-	-	1.435	6.31	-	-
RD	-0.016	-1.01	-0.056	-2.45	-0.061	-3.17	-0.065	-4.41	-0.019	-2.38	-0.067	-1.92	-0.009	-1.44
Std.	0.101	19.28	0.144	17.18	-	-	-	-	-	-	-	-	0.047	2.47
TX	-0.335	-2.07	-0.372	-1.64	-2.062	-3.47	-0.557	-4.17	-0.466	-1.88	-0.232	-2.66	-0.209	-4.99
Std.	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table B-8: RPT models estimation results for WAR accident rates for Oxfordshire site categories

Variables	NT		NE		B1		B2		RA		JN		GR	
	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t
Constant	-1.925	-11.08	-1.902	-3.10	-1.027	-3.01	-1.738	-3.88	-2.702	-2.41	-0.915	-1.93	-0.814	-8.01
Ln AADF	0.628	7.75	0.441	4.12	0.324	1.68	1.060	4.88	0.771	2.22	0.581	2.01	0.305	5.74
Std.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
%HV	0.123	5.61	0.031	2.00	0.014	3.29	0.211	2.29	0.231	4.63	0.028	3.11	0.405	6.08
Std.	0.043	3.21	0.017	1.74	-	-	-	-	0.750	10.08	-	-	0.091	2.88
SPL	-0.050	-16.87	-0.006	-2.32	-0.003	-0.35	-0.055	-3.36	-0.013	-1.51	-0.006	-2.46	-0.009	-7.06
Std.	0.069	26.69	-	-	0.010	3.34	0.024	4.58	-	-	0.003	4.60	0.008	2.35
RC	-0.007	-3.97	-0.003	-2.18	-0.015	-5.83	-0.009	-2.60	$-0.108*10^{-4}$	-2.15	-0.001	-0.13	-0.007	-1.99
Std.	0.001	15.05	0.004	3.47	0.020	9.98	-	-	-	-	0.001	9.97	-	-
%G	0.029	1.14	0.033	3.58	0.069	1.36	0.155	3.62	0.004	4.09	0.016	4.09	0.084	3.44
Std.	0.154	6.91	-	-	0.069	1.72	-	-	-	-	0.007	3.77	0.005	9.07
NL	-0.992	-11.58	-0.151	-2.10	-1.019	-4.68	-1.512	-6.21	-0.229	-1.90	-0.317	-0.93	-0.407	-5.09
Std.	3.254	27.27	-	-	-	-	-	-	-	-	-	-	-	-
NMA	2.666	22.65	0.507	8.33	1.202	4.86	4.108	1.95	0.355	2.76	0.258	2.65	0.935	1.83
Std.	-	-	-	-	-	-	-	-	-	-	-		-	-
SR	-5.607	-4.11	-3.265	-3.25	-9.668	-2.55	-10.815	-3.04	-7.090	-3.36	-3.362	-0.15	-2.006	-3.68
Std.	-	-	-	-	1.163	3.04	-	-	-	-	0.460	3.40	-	-
RD	0.120	4.96	0.147	0.62	0.391	3.68	0.582	6.73	0.109	1.80	0.155	2.09	0.098	6.05
Std.	-	-	0.025	4.70	-	-	-	-	-	-	-	-	-	-
TX	-0.190	-1.76	-0.098	-2.26	-0.425	-1.85	-0.705	-7.16	-0.803	-3.44	-0.390	-2.84	-0.082	-2.11
Std.	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table B-9: RPT models estimation results for SLAR accident rates for Oxfordshire site categories

Variables	NT		NE		B1		B2		RA		JN		GR	
	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t
Constant	-5.336	-9.23	-1.991	-3.55	-5.211	-3.75	-5.625	-5.26	-3.594	-2.42	-2.183	-2.12	-3.528	-2.38
Ln AADF	0.659	12.18	0.382	6.92	0.311	2.61	0.713	11.16	0.096	0.81	0.143	2.45	0.083	1.99
Std.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
%HV	0.294	23.12	0.055	3.75	0.144	3.40	0.197	14.12	0.212	2.62	0.083	3.21	0.438	3.58
Std.	0.815	35.74	-	-	-	-	1.115	3.63	-	-	-	-	0.209	7.39
SPL	-0.030	-17.32	-0.010	-3.98	-0.003	-2.50	-0.023	-1.78	-0.011	-1.54	-0.010	-2.38	-0.009	-3.27
Std.	0.049	37.12	-	-	-	-	-	-	0.012	5.18	-	-	-	-
RC	$-0.308*10^{-4}$	-1.03	-0.004	-0.54	-0.001	-0.67	-0.001	-2.25	$-0.109*10^{-3}$	-2.68	$-0.233*10^{-4}$	-2.21	-0.004	-3.84
Std.	0.001	5.78	0.002	4.11	0.005	7.45	-	-	-	-	0.001	10.97	-	-
%G	0.016	0.97	0.006	0.22	0.004	0.12	0.079	1.08	0.211	3.38	0.011	0.38	0.217	1.84
Std.	0.061	4.20	0.001	1.87	0.009	2.98	0.004	6.66	0.646	8.20	0.196	6.85	-	-
NL	-0.693	-13.36	-0.185	-2.85	-0.510	-3.47	-0.194	-2.86	-0.554	-5.21	-0.217	-2.69	-0.347	-3.37
Std.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
NMA	2.177	29.99	0.953	14.69	0.978	5.57	0.705	2.54	0.814	6.47	0.691	8.61	1.088	9.25
Std.	-	-	-	-	-	-	-	-	-	-	-		-	-
SR	-3.315	-3.56	-3.923	-4.06	-0.434	-4.17	-1.634	-4.07	-4.448	-1.82	-4.957	-3.10	2.038	-2.09
Std.	-	-	-	-	-	-	-	-	-	-	0.689	3.75	-	-
RD	0.008	0.50	0.056	3.21	0.037	2.99	0.033	6.09	0.028	6.25	0.081	2.75	0.007	1.55
Std.	0.071	14.02	0.144	22.83	-	-	-	-	-	-	-	-	-	-
TX	-0.096	-3.57	-0.224	-3.30	-0.909	-2.07	-0.128	-2.60	-0.312	-4.61	-0.271	-1.91	-0.187	-4.58
Std.	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table B-10: RPT models estimation results for SFAR accident rates for Oxfordshire site categories

Variables	NT		NE		B1		B2		RA		JN		GR	
	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t
Constant	-6.993	-7.70	-1.733	-1.64	-8.121	-2.71	-2.630	-0.96	-13.173	-6.05	-0.364	-0.33	-6.993	-7.70
Ln AADF	0.555	6.33	0.405	3.97	0.679	2.61	0.696	2.60	1.119	5.71	0.214	2.00	0.555	6.33
Std.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
%HV	0.059	2.40	0.077	2.79	0.159	1.95	0.813	6.46	0.087	2.08	0.038	1.27	0.935	4.36
Std.	0.259	14.85	0.147	8.50	-	-	0.788	8.83	0.000	0.00	0.000	0.00	0.018	5.83
SPL	-0.022	-8.87	-0.017	-4.02	-0.026	-2.00	-0.028	-2.99	-0.002	-3.26	-0.008	-1.77	-0.006	-6.22
Std.	0.011	11.77	-	-	-	-	-	-	-	-	0.015	8.29	-	-
RC	-0.004	-0.40	-0.001	-10.60	-0.009	-2.72	-0.003	-1.58	-0.006	-3.05	$-0.199*10^{-4}$	-1.16	-0.009	-4.40
Std.	0.002	4.73	0.001	15.94	0.016	7.64	-	-	-	-	0.003	2.94	-	-
%G	0.102	3.54	0.155	2.88	0.162	2.62	0.230	3.39	0.071	5.65	0.114	6.97	0.308	2.93
Std.	0.293	11.05	-	-	-	-	-	-	1.792	9.02	0.250	7.44	-	-
NL	-1.097	-13.00	-0.303	-2.24	-0.275	-2.49	-0.275	-3.77	-0.046	-2.36	-0.135	-5.04	0.503	-2.77
Std.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
NMA	1.900	19.34	0.689	7.06	1.015	3.52	0.878	4.14	0.633	4.02	0.395	2.02	0.424	3.94
Std.	-	-	-	-	-	-	-	-	-	-	-		-	-
SR	-1.810	-10.04	-4.319	-2.60	-0.611	-7.13	-7.500	-1.97	-7.126	-2.30	-1.717	-0.38	-0.935	-4.01
Std.	15.564	25.47	-	-	-	-	-	-	-	-	0.077	8.48	-	-
RD	0.059	2.31	0.011	0.39	0.117	1.68	0.094	2.18	0.165	2.53	0.014	1.91	0.024	3.07
Std.	-	-	0.079	8.72	-	-	-	-	-	-	-	-	-	-
TX	-0.324	-1.96	-0.372	-3.25	-1.527	-1.78	-0.408	-2.63	-3.187	-4.72	-0.610	-1.95	-0.188	-6.25
Std.	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table B-11: RPT models estimation results for TAR accident rates for Nottinghamshire site categories

Variables	NT		NE		B1		B2		RA		JN		GR	
	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t
Constant	-2.988	-6.26	-2.109	-4.65	-4.082	-3.71	-4.258	-7.24	-4.217	-2.14	-3.057	-6.07	-2.148	-2.14
Ln AADF	0.467	15.02	0.418	9.50	0.476	4.64	0.444	3.58	0.305	7.03	0.256	3.86	0.172	2.75
Std.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
%HV	0.162	26.01	0.182	20.96	0.151	5.17	0.128	2.47	0.125	4.71	0.098	4.51	0.057	7.37
Std.	0.203	37.62	0.255	31.38	-	-	0.213	1.88	-	-	0.084	5.32	-	-
SPL	-0.009	-9.37	-0.006	-4.74	-0.008	-2.49	-0.003	-9.25	-0.002	-1.17	-0.003	-5.32	-0.006	-4.81
Std.	0.008	25.26	0.007	15.21	0.027	3.25	0.001	8.24	0.003	3.91	-	-	-	-
RC	-0.003	-7.67	-0.001	-13.80	$-0.254*10^{-4}$	-0.36	$-0.128*10^{-4}$	-2.74	-0.022	-9.11	$0.124*10^{-4}$	-1.58	-0.002	-3.71
Std.	0.028	22.92	0.002	3.25	0.003	4.23	0.035	1.99	-	-	0.001	6.92	0.004	6.83
%G	0.013	1.19	0.079	2.62	0.100	2.49	0.032	2.49	0.019	0.25	0.035	7.10	0.045	1.85
Std.	0.120	12.11	0.002	1.99	0.324	8.18	-	-	0.036	2.39	0.225	2.51	-	-
NL	-0.027	-1.24	-0.019	-0.63	-0.131	-1.84	-0.131	-2.99	-0.172	-5.36	-0.218	-8.25	-0.185	-4.22
Std.	0.465	39.01	0.263	18.93	-	-	0.007	3.25	-	-	-	-	-	-
NMA	0.004	3.13	0.018	5.44	0.105	7.12	0.195	8.25	0.123	1.86	0.095	7.25	0.069	6.99
Std.	-	-	-	-	-	-	-	-	-	-	-		-	-
SR	-4.592	-12.19	-5.399	-10.60	-2.365	-1.81	-1.935	-1.82	-1.223	-5.02	-0.876	-3.25	-0.836	-9.25
Std.	2.385	3.54	-	-	1.258	2.11	1.305	3.02	-	-	-	-	0.237	1.84
RD	0.005	0.55	0.013	1.02	0.033	3.06	0.021	4.36	0.063	3.28	0.045	9.06	0.006	1.58
Std.	0.009	2.25	0.011	2.16	-	-	-	-	-	-	-	-	0.002	3.65
TX	-0.373	-3.73	-0.538	-3.93	-1.670	-4.31	-0.725	-3.22	-0.596	-8.36	-0.358	-6.25	-0.638	-2.35
Std.	0.092	1.93	-	-	-	-	0.088	1.85	-	-	-	-	-	-

Table B-12: RPT models estimation results for DAR accident rates for Nottinghamshire site categories

Variables	NT		NE		B1		B2		RA		JN		GR	
	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t
Constant	-3.673	-8.14	-3.384	-6.03	-3.652	-2.89	-4.193	-3.34	-3.847	-3.06	-8.366	-4.99	-4.118	-6.05
Ln AADF	0.759	16.85	0.510	9.38	0.508	4.44	0.682	5.85	0.051	0.45	0.615	3.92	0.573	8.14
Std.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
%HV	0.397	32.01	0.294	22.60	0.321	6.91	0.389	3.03	0.271	3.10	0.774	11.51	0.428	11.25
Std.	0.459	39.57	0.353	29.79	-	-	-	-	0.006	2.08	0.117	15.14	0.092	5.73
SPL	-0.015	-11.26	-0.007	-4.37	-0.016	-4.09	-0.013	-3.47	-0.032	-1.83	-0.007	-1.68	-0.029	-7.35
Std.	0.017	31.09	0.003	13.09	0.012	8.31	-	-	-	-	-	-	-	-
RC	-0.002	-5.25	-0.001	-11.87	-0.009	-3.17	-0.007	-3.47	$-0.173*10^{-5}$	-2.77	$-0.107*10^{-5}$	-3.41	-0.006	-4.08
Std.	0.001	24.54	0.008	5.85	0.001	4.36	0.219	2.86	-	-	0.001	2.61	-	-
%G	0.004	0.30	0.041	3.09	0.075	1.73	0.079	1.94	0.007	4.24	0.111	2.47	0.209	4.11
Std.	0.162	11.79	-	-	0.220	5.51	-	-	0.016	3.11	-	-	0.062	7.91
NL	-0.061	-2.11	-0.081	-2.43	-0.219	-2.87	-0.025	-2.35	-0.074	-3.44	-0.449	-5.37	-0.038	-1.88
Std.	0.609	34.17	-	-	-	-	-	-	-	-	-	-	-	-
NMA	0.075	1.89	0.055	4.10	0.120	2.13	0.103	2.98	0.098	3.08	0.140	1.88	0.063	2.41
Std.	-	-	-	-	-	-	-	-	-	-	-		-	-
SR	-2.417	-12.17	-3.981	-6.53	-2.964	-2.00	-1.709	-2.49	-1.077	-4.25	-2.441	-3.74	-1.037	-7.09
Std.	4.376	35.35	-	-	-	-	-	-	-	-	-	-	-	-
RD	-0.009	-2.79	-0.058	-3.73	-0.041	-3.10	-0.044	-5.43	-0.022	-1.78	-0.077	-2.31	-0.003	-1.79
Std.	-	-	0.178	22.80	-	-	-	-	-	-	-	-	-	-
TX	-0.412	-2.95	-0.747	-4.38	-0.684	-1.71	-1.694	-8.33	-0.922	-1.75	-2.208	-5.98	-1.194	-4.44
Std.	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table B-13: RPT models estimation results for WAR accident rates for Nottinghamshire site categories

Variables	NT		NE		B1		B2		RA		JN		GR	
	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t
Constant	-3.413	-6.63	-2.109	-3.91	-4.932	-3.92	-6.097	-3.82	-8.834	-4.37	-3.464	-3.11	-1.315	-2.61
Ln AADF	0.837	15.81	0.355	6.75	0.801	4.10	2.282	5.71	1.524	5.74	0.434	3.37	0.309	8.34
Std.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
%HV	0.171	18.62	0.127	12.97	0.252	4.76	0.114	2.49	0.109	2.77	0.147	4.56	0.237	6.28
Std.	0.134	19.76	0.134	19.85	-	-	-	-	0.009	3.49	0.395	2.24	0.029	3.08
SPL	-0.028	-16.57	-0.008	-5.11	-0.019	-3.16	-0.216	-7.56	-0.038	-9.81	-0.013	-3.37	-0.007	-5.17
Std.	0.031	36.00	0.005	9.57	0.002	2.13	0.188	7.98	0.002	1.68	0.007	2.11	0.009	4.22
RC	-0.001	-8.34	-0.003	-8.99	-0.002	-0.89	-0.009	-3.69	-0.004	-4.15	-0.007	-0.48	-0.008	-8.34
Std.	0.002	2.98	-	-	0.002	3.88	-	-	-	-	0.004	3.44	-	-
%G	0.028	1.65	0.084	2.35	0.002	0.04	0.366	3.24	0.025	9.84	0.002	1.06	0.052	3.55
Std.	0.197	12.47	-	-	0.098	1.91	-	-	0.174	3.62	0.127	3.60	-	-
NL	-0.103	-3.26	-0.128	-2.63	-0.188	-2.89	-0.157	-1.94	-0.199	-8.86	-0.189	-2.67	-0.094	-2.47
Std.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
NMA	0.251	2.56	0.351	1.77	0.337	2.02	0.350	2.36	0.147	1.75	0.109	2.07	0.073	2.56
Std.	-	-	-	-	-	-	-	-	-	-	-		-	-
SR	-12.211	-18.94	-4.794	-8.73	-2.611	-1.14	-9.370	-2.46	-5.143	3.44	-8.526	-5.83	-4.187	-9.14
Std.	8.195	39.28	-	-	6.049	9.84	-	-	-	-	11.112	16.77	3.114	2.84
RD	0.012	2.71	0.008	2.52	0.097	3.83	0.168	2.09	0.034	2.77	0.054	1.88	0.009	2.77
Std.	-	-	-	-	-	-	-	-	-	-	-		0.047	1.79
TX	-0.669	-4.03	-0.448	-2.69	-1.297	-2.05	-1.692	-5.21	-0.377	-1.78	-0.784	-1.86	-0.399	-3.74
Std.	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table B-14: RPT models estimation results for SLAR accident rates for Nottinghamshire site categories

Variables	NT		NE		B1		B2		RA		JN		GR	
	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t
Constant	-3.093	-7.53	-3.130	-6.27	-4.594	-4.00	-2.050	-1.90	-2.046	-3.03	-3.588	-3.49	-2.074	-3.41
Ln AADF	0.784	18.68	0.520	10.58	0.567	5.24	0.442	4.49	0.505	2.98	0.327	3.31	0.726	6.13
Std.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
%HV	0.277	29.39	0.218	21.42	0.161	5.11	0.027	1.08	0.084	2.97	0.203	6.81	0.314	3.17
Std.	0.380	40.30	0.306	31.36	-	-	-	-	0.063	3.35	0.792	18.16	-	-
SPL	-0.017	-13.43	-0.008	-5.79	-0.011	-3.04	-0.015	-4.58	-0.015	-3.33	-0.008	-2.82	-0.005	-1.89
Std.	0.009	21.01	-	-	-	-	-	-	-	-	0.005	4.84	0.018	7.09
RC	$-0.378*10^{-4}$	-7.95	-0.001	-13.27	-0.009	-1.37	-0.008	-2.43	$0.217*10^{-4}$	-2.19	-0.002	-3.15	-0.005	-7.95
Std.	0.001	21.79	0.002	3.25	0.002	2.65	-	-	-	-	-	-	-	-
%G	0.028	2.07	0.084	2.53	0.041	1.03	0.065	1.53	0.311	4.40	0.031	2.04	0.079	7.05
Std.	0.121	9.73	-	-	0.230	6.28	0.250	6.60	0.869	9.52	-	-	-	-
NL	-0.120	-4.64	-0.022	-0.71	-0.156	-2.10	-0.038	-3.60	-0.067	-2.30	-0.188	-3.44	-0.048	-2.77
Std.	-	-	0.299	19.79	-	-	-	-	-	-	-	-	-	-
NMA	0.070	1.88	0.041	2.02	0.156	2.45	0.158	1.69	0.278	1.81	0.152	2.08	0.058	2.17
Std.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SR	-9.335	-18.13	-4.990	-9.06	-1.719	-1.26	-1.713	-2.34	-9.168	-4.99	-2.259	-2.02	-1.392	3.22
Std.	6.921	45.21	-	-	2.122	8.27	-	-	-	-	-	-	-	-
RD	0.002	2.17	0.024	1.74	0.003	3.09	0.023	1.87	0.004	4.10	0.040	2.53	0.005	7.14
Std.	-	-	0.048	8.27	-	-	-	-	-	-	-	-	0.021	2.58
TX	-0.262	-2.03	-0.417	-2.81	-1.628	-3.86	-3.549	-7.78	-0.208	-4.42	-1.531	-4.64	-0.149	-3.47
Std.	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table B-15: RPT models estimation results for SFAR accident rates for Nottinghamshire site categories

Variables	NT		NE		B1		B2		RA		JN		GR	
	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t
Constant	-2.036	-3.74	-1.989	-2.91	-6.930	-2.63	-6.367	-3.09	-1.214	-0.13	-1.185	-0.05	-0.917	-7.14
Ln AADF	0.404	7.65	0.226	3.38	0.544	2.26	0.679	3.51	0.381	2.64	0.218	1.88	0.314	6.57
Std.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
%HV	0.178	16.62	0.111	10.04	0.339	4.31	0.092	1.88	0.072	3.14	0.186	4.37	0.195	6.54
Std.	0.028	3.90	-	-	-	-	-	-	0.004	4.08	-	-	-	-
SPL	-0.016	-9.88	-0.009	-4.48	-0.062	-5.82	-0.010	-1.86	-0.012	-7.98	-0.025	-4.93	-0.124	-2.14
Std.	0.025	32.21	0.016	21.01	0.062	8.83	0.051	1.87	0.041	3.27	0.050	13.05	0.057	2.35
RC	-0.001	-4.44	-0.003	-4.93	-0.009	-2.68	-0.005	-2.47	-0.003	-2.47	-0.002	-10.14	-0.007	-3.58
Std.	0.015	5.58	0.002	3.11	0.007	3.44	-	-	-	-	0.004	13.22	0.028	1.99
%G	0.042	2.23	0.063	2.36	0.097	2.36	0.076	2.67	0.049	1.76	0.066	2.40	0.328	3.55
Std.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
NL	-0.132	-0.38	-0.152	-1.27	-0.277	-1.75	-0.302	-2.31	-0.459	-3.57	-0.254	-2.90	-0.093	-1.97
Std.	0.368	21.37	0.025	2.48	-	-	-	-	-	-	-	-	-	-
NMA	0.066	2.45	0.020	3.32	0.063	3.03	0.182	7.24	0.095	1.88	0.148	2.29	0.035	3.66
Std.	-	-	-	-	-	-	-	-	-	-	-		-	-
SR	-7.007	-11.47	-3.047	-4.47	-8.468	-2.62	-3.633	-2.23	-1.834	-3.52	-1.559	-0.88	-3.208	-7.28
Std.	5.126	32.69	-	-	4.225	2.55	-	-	-	-	1.228	2.25	-	-
RD	0.022	1.49	0.032	1.66	0.199	2.75	0.098	1.86	0.041	2.18	0.029	1.68	0.018	1.04
Std.	0.082	12.14	0.114	13.49	-	-	-	-	-	-	-	-	0.025	2.43
TX	-0.565	-3.27	-0.746	-3.49	-0.599	-1.78	-0.648	-2.93	-0.259	-2.18	-1.215	-2.22	-0.355	-2.51
Std.	0.048	2.19	-	-	-	-	-	-	-	-	-	-	-	-