

# Deadly Designs: The Impact of Road Design on Road Crash Patterns along Jamaica's North Coast Highway

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Master degree thesis, 30 credits in Master in Geographical Information Sciences  
Department of Physical Geography and Ecosystems Science, Lund University

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Master's thesis, 30 credits, in Geographical Information Sciences

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# Abstract

Jamaica has struggled to curb the number of road crash fatalities, having had on average 25 fatalities per month between 2010 and 2014, while many more persons have been injured. The causes of crashes are multidimensional, however this study focused on understanding one aspect of reducing crashes - safe road design. The aim of this study was to determine the relationships between road design characteristics and fatal road crash distribution along the North Coast Highway (NCH) in Jamaica. The Anselin Local Moran's I and the Getis-Ord  $G_i^*$  models were employed to look at the distribution of crash hotspots. This paper also utilised Esri's Weighted Sum Analysis tool to devise a scoring method for determining how safe or dangerous road segments were based on the presence, absence and type of road design features. The design variables selected for this study included bus stops, pedestrian crossings, traffic lights, intersections, places of interest, sidewalks, speed limit, soft shoulders, medians, lanes and roadside barriers. This study also used the zero-inflated negative binomial (ZINB) regression model to identify the empirical relationships between crash counts, crash types, road design features and safety scores. The model identified road segments with many places of interest (POIs), single lane, medians and many intersections as being significantly related to the segments with the most crash counts (irrespective of crash type). This study demonstrates how the spatial analysis of road design features and crash distribution can be used to determine how effective road design features are in advancing road safety and where to implement road safety plans.

**Keywords:** Geography, Geographical Information Systems (GIS), hot spot analysis, road design features, zero-inflated negative binomial (ZINB)

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# Chapter 1. Introduction

## 1.1 Background and context

The World Health Organization (2009) in its Global Plan for the Decade of Action for Road Safety 2011 – 2020 paints a grim picture of the current state of road deaths and injuries from a global perspective:

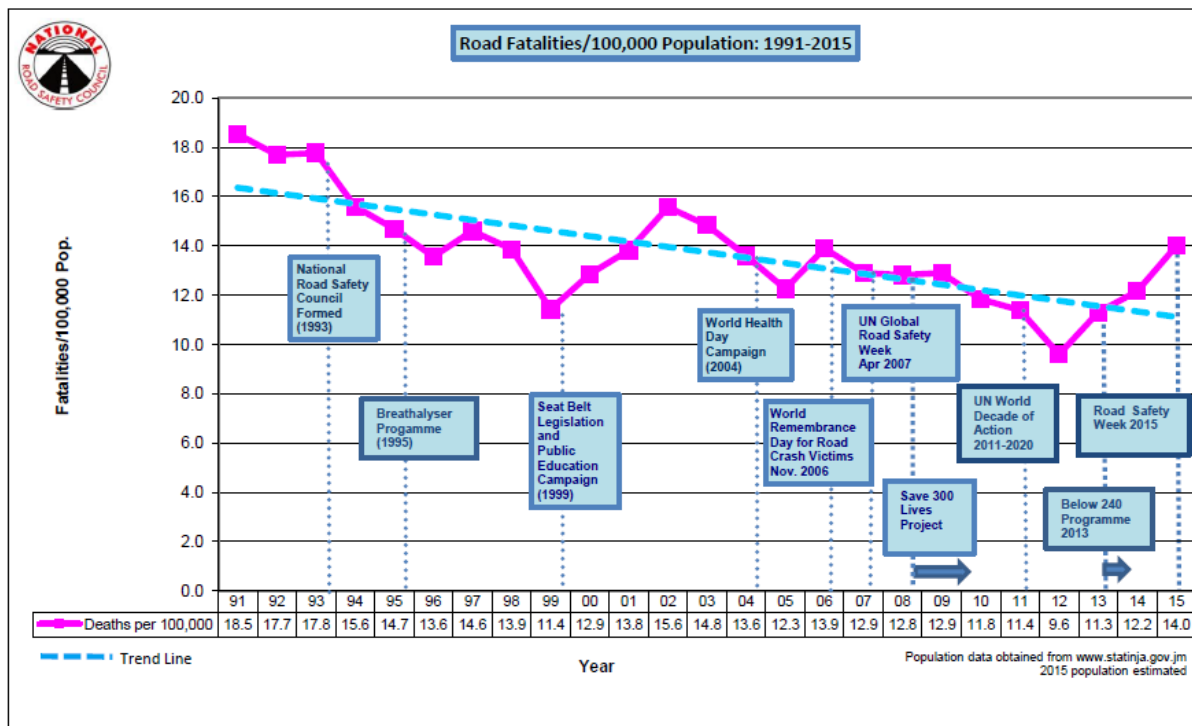
Each year nearly 1.3 million people die as a result of a road traffic collision—more than 3000 deaths each day—and more than half of these people are not travelling in a car. Twenty to fifty million more people sustain non-fatal injuries from a collision, and these injuries are an important cause of disability worldwide. Ninety percent of road traffic deaths occur in low- and middle-income countries, which claim less than half the world's registered vehicle fleet. Road traffic injuries are among the three leading causes of death for people between 5 and 44 years of age. Unless immediate and effective action is taken, road traffic injuries are predicted to become the fifth leading cause of death in the world, resulting in an estimated 2.4 million deaths each year (World Health Organization, 2009, p 3 and 4).

Locally, between 2010 and 2014, over 1,500 persons died in police reported traffic crashes and countless more were injured in Jamaica. At this rate, about 25 persons died in road crashes each month for the 5-year period, making crashes the second leading cause of violent deaths in the country (Wilks et al., 2008). According to the World Health Organization (2013a), the financial impact of crashes on Jamaica's economy is evident as about 0.2% of Jamaica's gross domestic product (GDP), which was over US\$300,000 in 2010, was lost due to road traffic crashes. Despite the efforts by the National Road Safety Council (NRSC), Jamaica continues to struggle to have a sustained reduction in road traffic crashes (Figure 1).

## 1.2 Justification and purpose

The purpose of this research is to contribute meaningful information to the relevant stakeholders in the transportation sector such that informed decisions can be made as to the allocation of resources on road sections that are most prone to crashes. Improving road safety is the overarching goal of this paper which supports the Decade of Action for road safety

(2011 – 2020) that was proclaimed by the United Nations (UN) in 2010. The aim of this UN initiative was to stabilise and reduce road fatalities globally by encouraging activities at the national, regional and global scales. The Global Plan for the Decade of Action for Road Safety 2011-2020, identifies five pillars of road safety: road safety management, safer roads and mobility, safer vehicles, safer road users and post-crash response.



**Figure 1. Road fatalities per 100,000 population for 1991 – 2015 highlighting the various efforts by the NRSC in Jamaica aimed at increasing road safety awareness (NRSC, 2015).**

This research focuses most on pillar 2, which the World Health Organization (2009, p. 12) states:

**Pillar 2: Safer roads and mobility**

Activity 3 Promote safe operation, maintenance and improvement of existing road infrastructure by requiring road authorities to:

- identify the number and location of deaths and injuries by road user type, and the key infrastructure factors that influence risk for each user group;

- identify hazardous road locations or sections where excessive numbers or severity of crashes occur and take corrective measures accordingly;
- conduct safety assessments of existing road infrastructure and implement proven engineering treatments to improve safety performance;

This research is driven by how crucial road design and safety is in realising the targeted reduction of road fatalities and injuries during the ‘Decade of Action’ in Jamaica. Generally, the human factor is given more focus than the road or vehicle components in a crash. Iyynam et al. (1997) theorises that if a roadway is properly and appropriately designed, then this may actually reduce the influence of the other factors and also cause a decrease in the number of fatalities and serious injuries. Dewees et al. (1996) suggests that the way highways are designed and maintained can influence safety as road design features are known to have some relationship with safety. Karlaftis and Golias (2002) also note how expensive highway crashes are and hence how important highway safety improvement is. Roads can be deemed dangerous due to the presence or absence of various risk factors. These roadways may benefit from safety treatments (Stephan and Newstead, 2011). This study therefore highlights the important responsibility of those tasked with designing safe road transport systems. The results from a study like this, should inform the relevant stakeholders by providing an evidence-based approach to influence strategic crash reduction methods in dangerous crash areas.

### 1.3 Research objectives

The aim of this study was **to determine the relationships between road design characteristics and fatal road crash distribution along the North Coast Highway (NCH) in Jamaica**. As a consequence, this will advance safety research and provide a new approach to safety evaluation and analysis in Jamaica.

The research objectives of this study were to:

*Objective 1:* Identify high crash areas along the NCH based on crash incidences.

*Objective 2:* Classify road segments that are susceptible to high crash counts based on road design features.

*Objective 3:* Determine the main road design features that are found on dangerous crash road segments.

*Objective 4:* Assess the relationship between road design features and dangerous crash road segments.

### 1.4 Thesis organization

This thesis has 7 chapters. Chapter 1 introduces the issue of road safety, providing a global and local perspective and also presents the research objectives which underscore the importance of studies such as these for increasing road safety. A background puts the study in a wider perspective in Chapter 2, while the location of the study area is presented in chapter 3, where the motivation for selecting this area of interest is explained. In chapter 4, the methods employed while conducting this research is discussed, and entails data collection and creation along with the approaches to spatial and statistical analyses of crashes and road design features. The results from the analyses are presented in chapter 5, where specific dangerous crash road segments are highlighted and relationships between the variables are indicated. Chapter 6 discusses the results obtained, looking also on what others have published on the matters arising out of this study and also the sources of error that were to be noted. The final chapter provides a summary of the work done for this study along with recommendations on more research that can be conducted.



## **Chapter 2. Background**

This chapter presents a review of existing literature, providing a wider perspective of how road safety has been analysed. A summary of the data and crash analysis techniques that are typically employed in this field of research are described. The benefits of this study and the voids in existing literature are also mentioned.

### **2.1 Benefits of the research**

Road safety is often assessed based on crash counts or rates and as such many studies have focused only on identifying areas with high concentrations of crashes and some focusing equally on the possible causes of these high crash areas. Greater emphasis is also usually placed on the human factor as being the cause of crashes when compared to the influence of the road and vehicle. This research goes further to examine the relationships between crashes and road design features. This approach is beneficial as it recognises the impact that the surroundings has on crashes and can therefore guide the decision-making process regarding the locations where resources are needed to lessen the occurrence and severity of crashes.

### **2.2 Geographic Information Systems and spatial datasets**

Geographic Information Systems (GIS) is used by several researchers to map, analyse and visualise crash data (Abdulhafedh, 2017; Çepni and Arslan, 2016; Adebayo, 2015; Rahman et al., 2015). The reason for the popularity of GIS in this field, when compared with other information systems, is its ability to know how crashes and other related features are geographically located (Goh, 1993). GIS software provides the ability to accurately locate hot spots and is pivotal to the work done by transportation professionals, engineers and traffic safety analysts. Good GIS methods can provide legally sound information for stakeholders to use as evidence for undertaking road safety initiatives. Typically, studies with a focus on road safety tend to utilise a combination of spatial datasets, such as crashes, road geometry and road design features. The availability, accuracy, coverage and usability of these datasets undeniably impact the choice and level of analysis that is conducted.

#### **2.2.1 Crash data**

Like several other countries, there is great underreporting of crashes which makes the analysis of crashes in Jamaica limited to just those reported crashes. Similar to Hoque et al. (2009), this shortcoming of the national crash database renders Jamaica's crash data virtually incomplete. Hauer and Hakkert (1988) estimates that most crash fatalities are reported while only 50% of injured crash victims and an even lesser percentage for property damage only

crashes are made known to the police. This obtains in Jamaica as well, whereby given the severity and the spotlight placed on fatal crashes, most of these crashes tend to be reported. There are also substantially less fatal crashes when compared to non-fatal crashes. A 10-year study done by Lyew-Ayee (2012), based on reported crashes, found that fatal crashes accounted for only about 3% of all crashes across Jamaica, while crashes resulting in property damage was around 73%. Serious crashes, where a person was hospitalized for at least 24 hours because of injuries sustained in a crash accounted for 10% of all crashes while minor crashes, which refer to crashes where a person was injured but hospitalized for less than 24 hours or not hospitalized at all accounted for 14%. Ideally, an analysis of all crash types would provide greater understanding of the road safety problem along the North Coast Highway. Based on data availability, however, only fatal crashes were studied. According to World Health Organization (2013a), road crash fatality is a person who dies immediately or within 30 days of a crash on a public road, the death being the result of the crash.

### **2.2.2 Road segmentation**

It is common to divide roadways into analysis units (segments) to address safety. There is, however, no universally accepted optimal segment length for analysis (Harwood et al., 2010). Strathman et al. (2001) notes that the determination of segment length is generally chosen based on a fixed length or road feature composition.

#### **FIXED-LENGTH SEGMENTATION**

By using the fixed-length approach, one acknowledges that there may be within-segment variation of road geometry and design features. The fixed-length approach is the less popular choice, however it has been found to be most appropriate for several studies that seek to analyse the impact of crashes on point features, such as traffic lights, speed limit signs and bus stops (Strathman et al., 2001). This method of segmentation has been used because it eliminates issues that can arise with using varying segment lengths, where there may be either too long or short road segments. If the segment length chosen is too small, this may lead to many segments recording zero crashes and consequently over-dispersion may be common. In addition, geocoding errors tend to be magnified when smaller road segments are used. The United States Road Assessment Program (usRAP) considers 2- to 3-mile segments as adequate, while studies done in Utah used quarter- and half-mile segments (Harwood et al., 2010). There are other ways segmentation can be performed, for instance, by using the sliding window method, where a predetermined size of cells/grids is used to cut the roadway by the cells into different segments (Choi and Park, 1996).

## USER DEFINED SEGMENTATION

Defining segments by road composition suggests that segments will be homogeneous as it relates to road features and hence have varying lengths, as a segment will start when the road design variables change. Determining segments by road features is more often used, especially in cross-sectional crash modelling studies (Strathman et al., 2001). A number of studies have used this approach by creating long homogeneous segments (Harwood et al., 2010; Hadi et al., 1995; Li, 2006; Bellomo-McGee Inc., 2003). Another way uses the strip analysis tool that breaks the road into segments based on a user-specified number of crashes (Johnson, 2012).

### 2.2.3 Study period

It is important to study the roadway for a sufficient amount of time, such that a representative accident sample can be studied. Hadi et al. (1995) and Cheng and Washington (2005) agree that a study period between three to five years should be sufficient for preparing crash risk maps, it is however not ideal to use a longer time period as there is a higher likelihood of significant changes to the road characteristics.

## 2.3 Typical approaches to crash analysis

Different approaches to analysing crash data have been taken, each with their own pros and cons. Similar research has been conducted in other countries and has served as a guide for this study. The unique situation in Jamaica has caused the adaptation of some of these methods.

### 2.3.1 Identification of crash hot spots

#### SLIDING WINDOW-BASED RANKING

Traditionally the non-spatial method, sliding window-based ranking, was utilised to identify crash hot spots. This approach uses a predefined window size with a fixed length or predetermined cells or grids of a fixed size, to move along a roadway calculating crash frequency, vehicle miles travelled (VMT) and other explanatory covariate values. The crash rate is determined for each cell and then ranked by rates (Federal Highway Administration, 2002; Choi and Park, 1996). The primary advantage of this scan based approach is the elimination of splitting an area with high crash averages between two sections. On the other hand, the "small area estimation" problem is one of the primary disadvantages of this method as it can bias the ranking rates (Miaou and Song, 2005). Other limitations include the absence of statistical significance, inefficient use of data (Silverman, 1986) and absence of local peak compared to neighbours (Saha, 2012).

#### FREQUENCY AND CRASH RATE METHOD

Other methods have become more popular, such as the frequency and crash rate method used by Qin and Wellner, (2011) to provide simple observational crash analyses, such as crash counts and the calculations of crash rate, density and frequency. The crash rate is calculated by normalising crash data by traffic volume (or road length, if traffic data is not available) along each road segment, which is usually expressed as crashes per million vehicle miles travelled. Crash density is determined by analysing the number of crashes by road segment length. Crash frequency incorporates time as the number of crashes occurring on a road segment is normalised by the time span over which it occurred.

#### KERNEL DENSITY ESTIMATION (KDE)

The Kernel Density Estimation (KDE) method calculates the density of crash events within a specific search bandwidth and creates a surface to represent this (Bačkalić, 2013; Truong and Somenahalli, 2011; Schneider et al., 2001). O'Sullivan and Unwin (2002) credits this method for its provision of useful outputs for visualisation as high crash intensity areas are clearly identified. A major issue with the Kernel Density Estimation method, however, is that neither the planar KDE nor network KDE can be tested for statistical significance.

#### ANSELIN LOCAL MORAN'S I AND THE GETIS-ORD $G_i^*$

The most popular local measures of spatial association used by several researchers are the Anselin Local Moran's I and the Getis-Ord  $G_i^*$  (Saha, 2012 and Khan et al., 2008). There have been several instances where both statistics have been used together (Khan et al., 2009; Ohri et al., 2015).

The Hot Spot Analysis tool, Getis-Ord  $G_i^*$  has been found useful in determining where clusters of crashes occur and also for identifying spatial autocorrelation (Kuo et al., 2013; Prasannakumar et al., 2011; Songchitruska and Zeng, 2010). This statistic assesses whether the clusters of crashes are statistically significant. A limitation of this spatial autocorrelation method is that it requires aggregated data, instead of using an individual crash point location dataset. The analysis is therefore based on a count or ratio of crashes along a roadway which is divided into smaller sections known as the modifiable area unit problem. Consequently, this analysis might produce varying results based on the scale and location of the aggregation units used (Plug et al., 2011; O'Sullivan and Unwin, 2002).

The Anselin Local Moran's I identifies clusters of crashes spatially based on their attribute similarity and difference from the surrounding crashes. The model determines statistically significant clusters of crashes. A limitation of the Anselin Local Moran's I is that spatial

autocorrelation suffers from the issue of not clearly defining specifications for the optimal number of neighbours (level of connection) and the value of weights (Anselin, 1995). Moons et al. (2008) found it difficult to define an optimal distance between two points along a roadway for which both locations would still show any connection, as this distance would vary based on the type and characteristics of the road being studied.

### **2.3.2 Road design features and identifying segments that are susceptible to high crash counts**

One is able to identify road segments that are considered more dangerous, not based on crash history but based instead on road design features. Researchers have evaluated the impact of numerous road design features on road safety. Some studies preferred a very simplistic approach, for instance Karlaftis and Golias (2002) only grouped roads into two classes, in contrast to Hadi et al. (1995) who considered several geometric design features in great detail for instance looking at the impact of different median types. Hess et al. (2004) and Naderi et al. (2008) focused on road features and their likely risk to particular road users and their influence on specific types of road crashes, where pedestrian risk at street crossings and the impact of street trees as obstacles for off-road crashes were studied, respectively.

There were few studies that took a GIS-based approach to identifying high risk areas based solely on road design features. Risk assessment tools used by the International Road Assessment Program (iRAP) have been conducted in several countries to calculate a road's risk score and provided a somewhat similar approach to the weighted sum method utilised for this study. iRAP's evidence-based risk assessment tools are sufficient to identify areas where road safety treatments should be prioritised (Stephan and Newstead, 2011; McInerney and Smith, 2009; Affum and Goudens, 2008). The risk score is based on the type of road and roadside features that may influence a roadway's crash risk. Johnson (2012) considers iRAP's *star ratings*, which is based on the inspection of roads to investigate how well they shield road users from different types of crashes, as being very useful when determining the safety hazards that exist. The star rating is enhanced by the incorporation of GIS as it provides additional information than is usually unavailable in a crash database and allows for the stimulating visualisation of results.

### **2.3.3 Relationship between crashes and road design features**

To truly assess the road safety situation in an area, one needs to focus not only on road design but also incorporate crash history or predictions into the analysis. Crashes can be considered as random events and are often times characterized by road segments with a preponderance of zeros and overdispersion. Unlike deterministic models, stochastic models such as Poisson regression, negative binomial regression, Zero-Inflated Poisson regression and the Zero-

Inflated Negative Binomial Regression models have been considered better options for modelling random events like road crashes (Poch and Mannering, 1996; Sawalha and Sayed, 2006; Sharma and Landge, 2013). Overdispersion can violate the assumptions of some common count-data modelling methods (Lord and Mannering, 2010).

Poisson regression models using quasi-likelihood estimation techniques have often been used to address the issues of overdispersion and underdispersion in crash data (Ma et al., 2014). Quasi-likelihood estimation considers crash counts by estimating the overdispersion or underdispersion parameters as part of the process (Ivan et al., 2000). With overdispersion accounted for, Severini and Staniswalis (1994) expressed confidence in this method because it provides a semiparametric method for calculating the average of selected parameters and is therefore a legitimate approach to determine risk predications. While the Quasi-Poisson and negative binomial regression models often give similar results and are best suited for the distribution of overdispersed crash counts, there are clear differences in their calculations. Several studies have noted the higher level of accuracy derived from the quasi-likelihood model, especially when working with count data, and so for some, this method is considered superior (Ver Hoef and Boveng, 2007).

Unlike the Poisson regression model, negative binomial regression allows for overdispersion and effectively quantifies numerous parameters. Further improvements in modelling, however, have been experienced with zero-inflated models which have been praised for their improved statistical fit and also their ability to handle a more significant amount of zeros. The Zero-Inflated Negative Binomial (ZINB) regression model can be used to identify an empirical relationship between crash hotspots and road design features, quantifying the effect of the various design factors on crashes based on the parameter estimates of the models. The ZINB is considered by several transportation safety analysts as being the best and fittest model to use when analysing crash data (Ayati and Abbasi, 2014; Malyshkina and Mannering, 2010; Lord et al., 2007; Lord et al., 2005; Qin et al., 2004; Kumara and Chin, 2003. Carson and Mannering (2001) and Lee and Mannering (2002) also used the ZINB model for analysing highway design attributes.

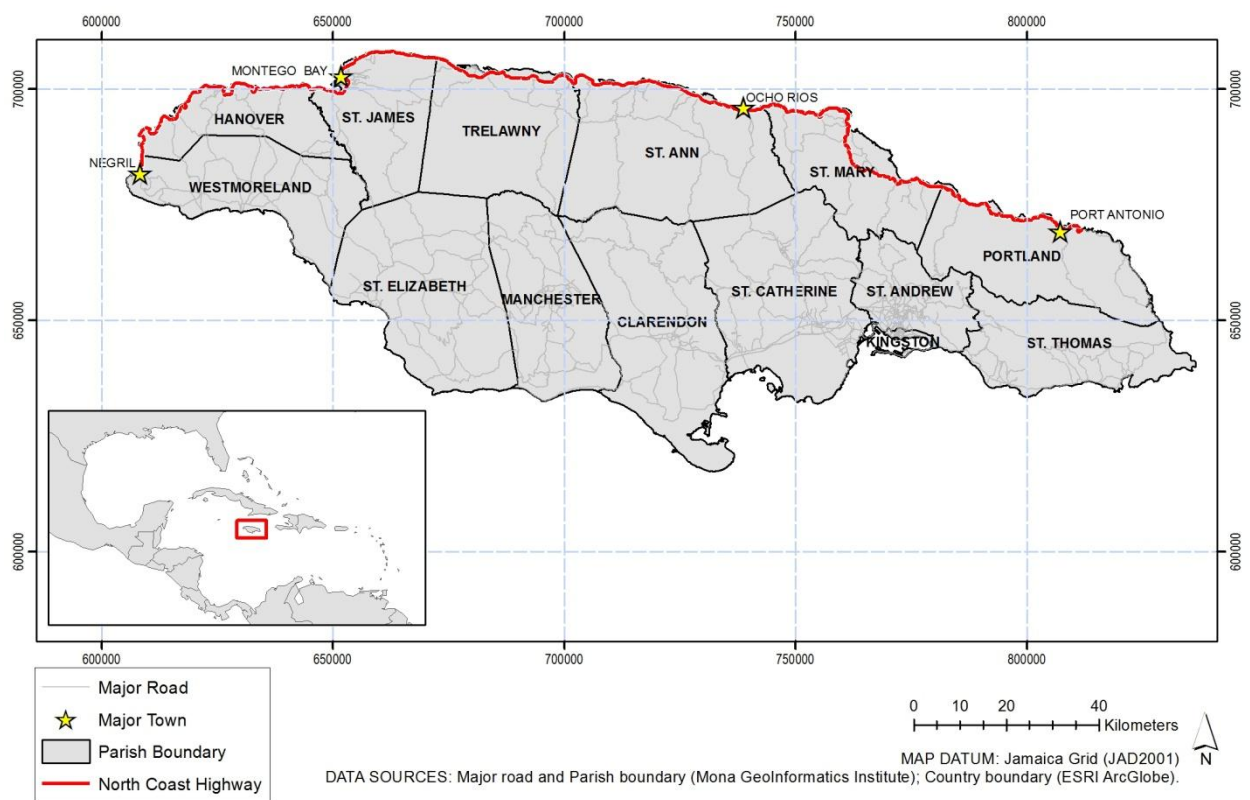
The Methodology section of this report discusses in more detail the choices made for processing and analysing the research data. The works by other authors have served as a guide and in some instances influenced the methods chosen so that the objectives of this study could be achieved.

## Chapter 3. Study Area

The location of the North Coast Highway, its importance to the country and the motivation for choosing this roadway is explained in this chapter. The environment in which the highway is found along with the main construction details and concerns are also discussed.

### 3.1 Location and boundary

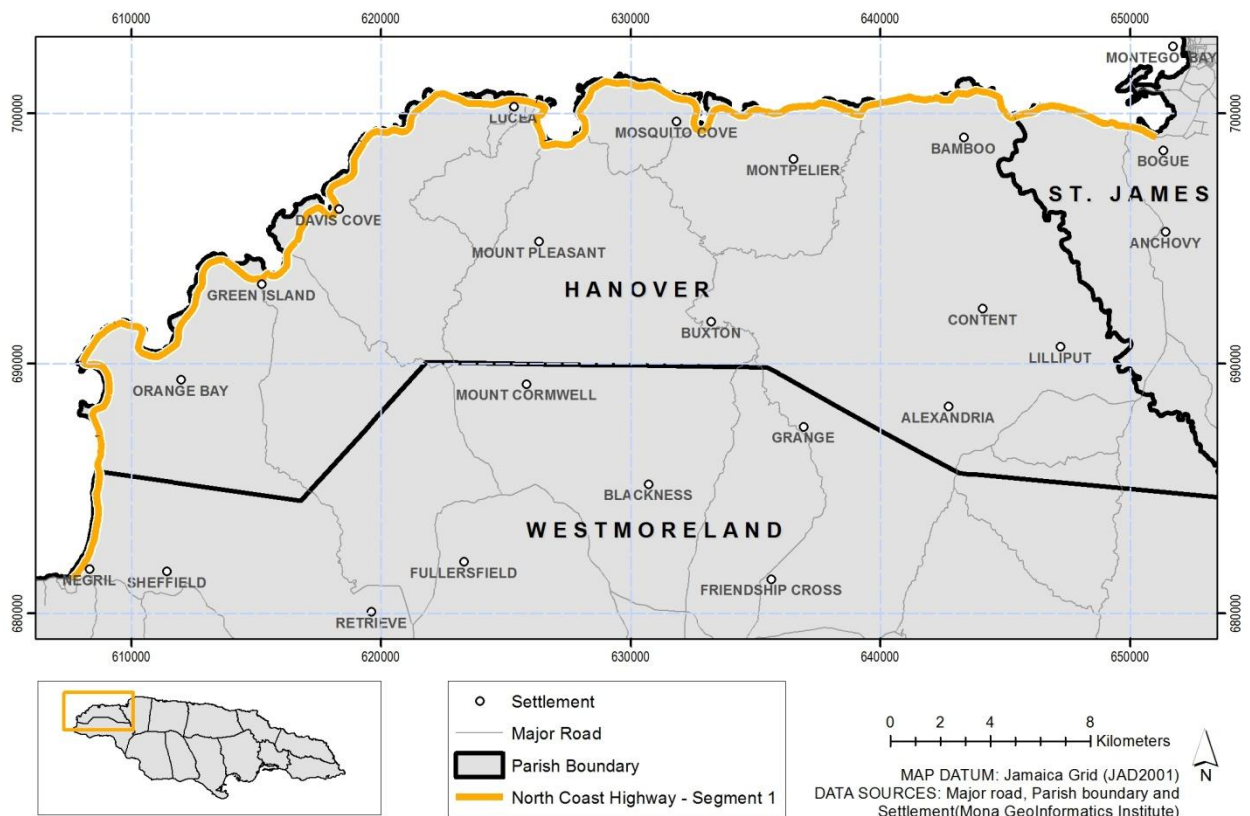
The North Coast Highway, located in Jamaica, West Indies, was selected as the study area for this research. The original road which was constructed in the 1960s and 1970s was upgraded after almost 12 years of construction improvements. This entire highway was completed in 2009 and stretches along the island's north coast, extending to about 260 km, linking the coastal towns of Negril, Montego Bay, Ocho Rios and Port Antonio (Figure 2).



**Figure 2. The North Coast Highway stretching east to west on the northern coast of the island of Jamaica is highlighted.**

The NCH was constructed in 3 segments:

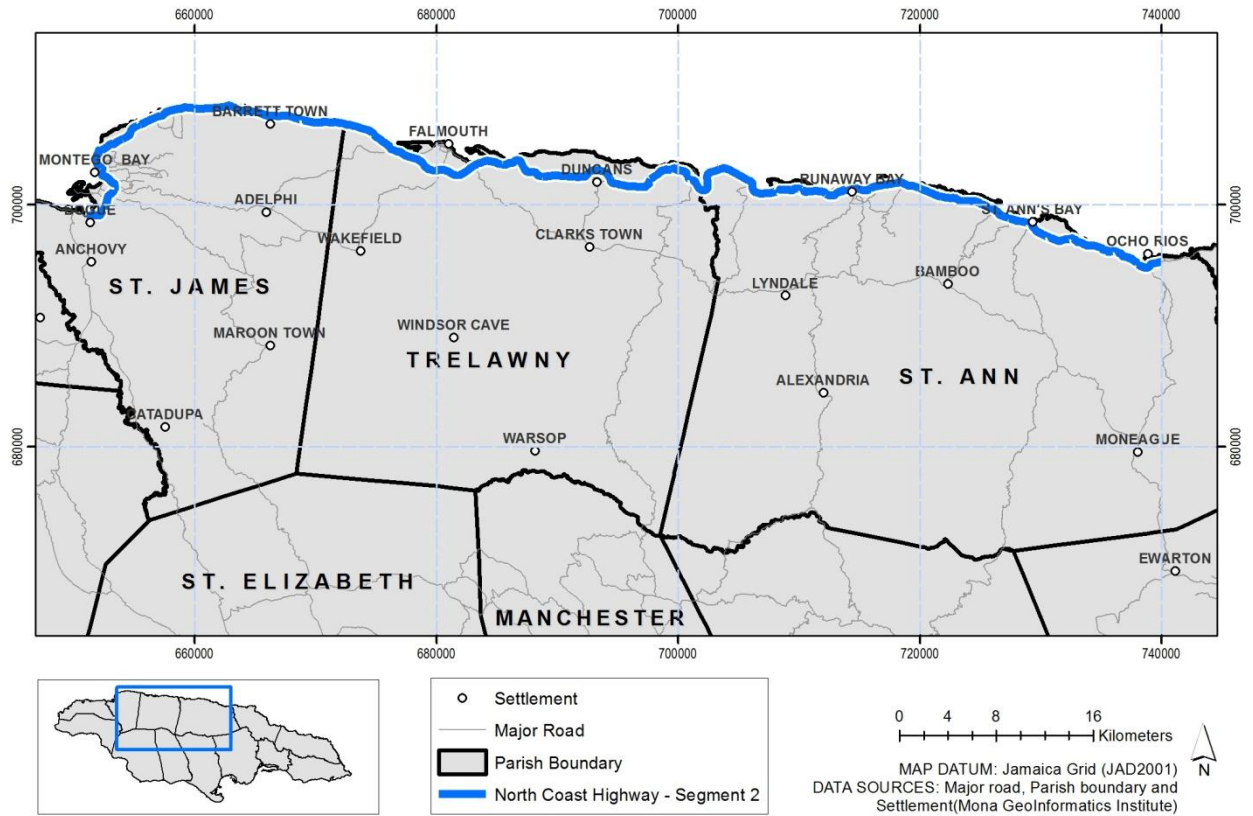
- i. **Segment One:** The National Works Agency (NWA), which was the implementing agency of the Northern Coastal Highway Improvement Project (NCHIP), demarcates segment one of the NCH as extending 71 kilometers from the Negril round-a-bout in the parish of Westmoreland to the outskirts of the Bogue Main Road in Montego Bay, St. James (National Works Agency - Jamaica, 2015a), (Figure 3).



**Figure 3. Segment 1 of the North Coast Highway.**

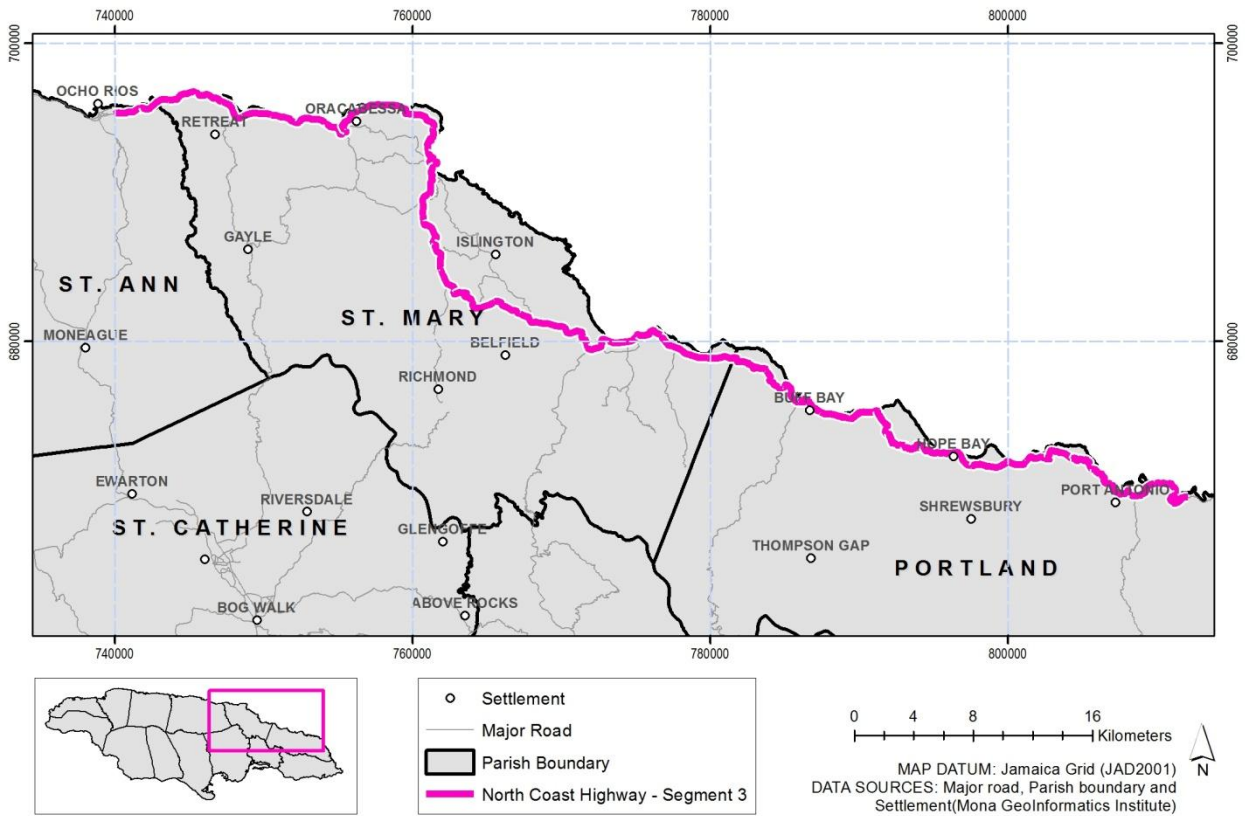


ii. **Segment Two:** This segment spans about 97 kilometres between Montego Bay in St. James to Ocho Rios in St. Ann (McNish and Morrison, 2010), (Figure 4).



**Figure 4. Segment 2 of the North Coast Highway.**

iii. **Segment Three:** This segment spans about 92 kilometres of roadway, located between Ocho Rios, St. Ann and Bryan's Bay, in Port Antonio, Portland (National Works Agency – Jamaica, 2015b), (Figure 5).



**Figure 5. Segment 3 of the North Coast Highway.**

## **3.2 Description**

### **3.2.1 Importance of the North Coast Highway (NCH)**

The Jamaican economy depends heavily on tourism, which in 2014 accounted for about 30% of the country's gross domestic product (Central Intelligence Agency, 2001). In the early 1990s the Jamaican government set out to revitalise and expand the tourism industry by encouraging several tourism-related projects along the North Coast tourism belt. The NCH also provides vital arteries for several major ports (shipping and air) which stretch along the highway, providing logistics in imports and exports and the distribution of goods. The North Coast Highway construction was considered an investment providing the movement of people, goods and services in the domestic economy and being critical to the country's economic development, effectively linking the tourist belt to the rest of the country (McNish and Morrison, 2010).

### **3.2.2 Environment along the NCH**

The North Coast Highway extends mostly along the northern coastline of the island crossing various landscapes. The corridor is found mostly on relatively flat, low and elevating land ranging between 2 - 10 metres above sea level (Plate 1). The geology comprises of alluvial sand, gravel and clay all underlain by limestone. The geological formations seemed stable for construction of the highway. Due to its coastal location, the highway may in some areas, be impacted by storm surges of 2 metres or more. In general, the highway is exposed to only a small tidal range of 0.5 meters between high and low tide. The NCH runs through marshes, mangrove swamps, woodland forest, pasture, open woodland, scrub, cultivated lands and secondary forests. In some instances, the highway passes through existing towns and urban areas, some of which are characterised by narrow roads, heavy traffic congestion and business activity (McNish and Morrison, 2010).



**Plate 1. Images along the North Coast Highway:**

**(a) Roadway along coastline**

(Photography credit: <http://www.stanleyconsultants.com/files/4113/4038/7523/13981-Ministry-of-Transport-and-Works-Jamacia-North-Coast-Highway.jpg>),

**(b) Elevated section of roadway**

(Photography credit: [http://farm4.staticflickr.com/3035/2617445621\\_5ca871f913\\_z.jpg](http://farm4.staticflickr.com/3035/2617445621_5ca871f913_z.jpg)),

**(c) Roadway passing through an urban area**

(Photography credit: <http://static.panoramio.com/photos/1920x1280/57574484.jpg>).

### **3.2.3 Construction of the NCH**

The overall project involved the reconstruction of the existing road alignment, curve flattening, road widening, installation of box culverts and ditches, repair of old bridges, the implementation of traffic control devices, right turn lanes and several bus turnouts. This highway passes through various land use zones and as such the speed limits vary among 80 km/hr (non built-up areas), 50 km/hr (built-up areas) and 30 km/hr (in school zones). The design of the NCH also varies, with regard to the number of lanes, median strips, intersections, gradient and width of road and shoulder. Due to variability in the design of this highway, it presents an opportunity to determine if certain design features impact crash occurrences.

### **3.2.4 Concerns about the NCH**

The choice of material used for the road surface was cause of great concern as the limestone aggregate used is one that creates a slippery road surface. Recommendations have been made to have these sections of the highway resurfaced instead with black stone aggregates (McNish and Morrison, 2010). With the construction of the highway, other issues of concern have arisen, such as the need for the maintenance of the roadway as road deterioration may lead to higher rates of crashes and poor road use. A Roads Maintenance Fund was established to deal with the maintenance of the highway along with funding from the Tourism Enhancement Fund (TEF) and hoteliers located along the corridor. McNish and Morrison, 2010 also mentioned issues pertaining to squatting along the corridor, as persons seek to situate themselves in close proximity to the major transportation route and the emerging tourist developments which provide employment opportunities. These developments, however, change the safety dynamic of the highway's use. With the increasing number of developments occurring along the highway, it is necessary to monitor the corridor so as to maintain a viable transportation system. Socially, the development of highway bypasses may also lead to socio-economic challenges as smaller towns experience reduced business activity which may lead to lower economic returns for these areas.

## **3.3 Motivation for study area selection**

At the opening of segment two of the North Coast Highway in December 2006, the then Minister of Works in Jamaica, Honourable Robert Pickersgill, outlined that the Highway would not only reduce travel times between Ocho Rios and Montego Bay by more than 40% but would also reduce the accident rate. Based on a study of road crashes that occurred between 2000 and 2009, Lyew-Ayee (2012) identified the North Coast Highway as the deadliest stretch of road in Jamaica, claiming 363 lives from about 5,614 reported crashes. The North Coast Highway is a very important roadway in Jamaica, traversed by many locals

and foreigners. Crashes along this highway have great impact, not only on the lives of crash victims and families, but also on the day to day movement of many people and may cause economic loss. Given its historically high number of crashes and its importance to the country's tourism sector and the local population, increasing road safety along this corridor is crucial for saving lives and resources.

## Chapter 4. Methods

This section will describe the three-part methodological approach that was employed for this cross-sectional study (Figure 6). The first section presents the data collected for this study, while the second section looks at how the data was processed so that it would be in the requisite formats for analysis. The third section explains the analytical methods employed to determine dangerous crash road segments and to examine associations between variables.

### 4.1 Data collection and variable creation

Various datasets were used for this research, the primary ones include fatal crash data, road geometry and road design features. The data collection and creation processes were conducted by the author through Global Positioning System (GPS) field mapping and desktop mapping. Other datasets were obtained from secondary sources and were used primarily as background data to facilitate the desktop mapping exercise, such as community, settlement, road and places of interest. The ArcGIS Desktop software package was used for the preparation of the spatial data and also for the spatial analyses.

All spatial data created and used in this study was referenced to the national coordinate system for Jamaica, that is, the Jamaica Grid 2001 (JAD 2001). This projected coordinate system has the following parameters:

|                               |                         |
|-------------------------------|-------------------------|
| Projection:                   | Lambert_Conformal_Conic |
| Geographic Coordinate System: | GCS_JAD_2001            |
| Datum:                        | D_Jamaica_2001          |
| Prime Meridian:               | Greenwich               |
| Angular Unit:                 | Degree                  |



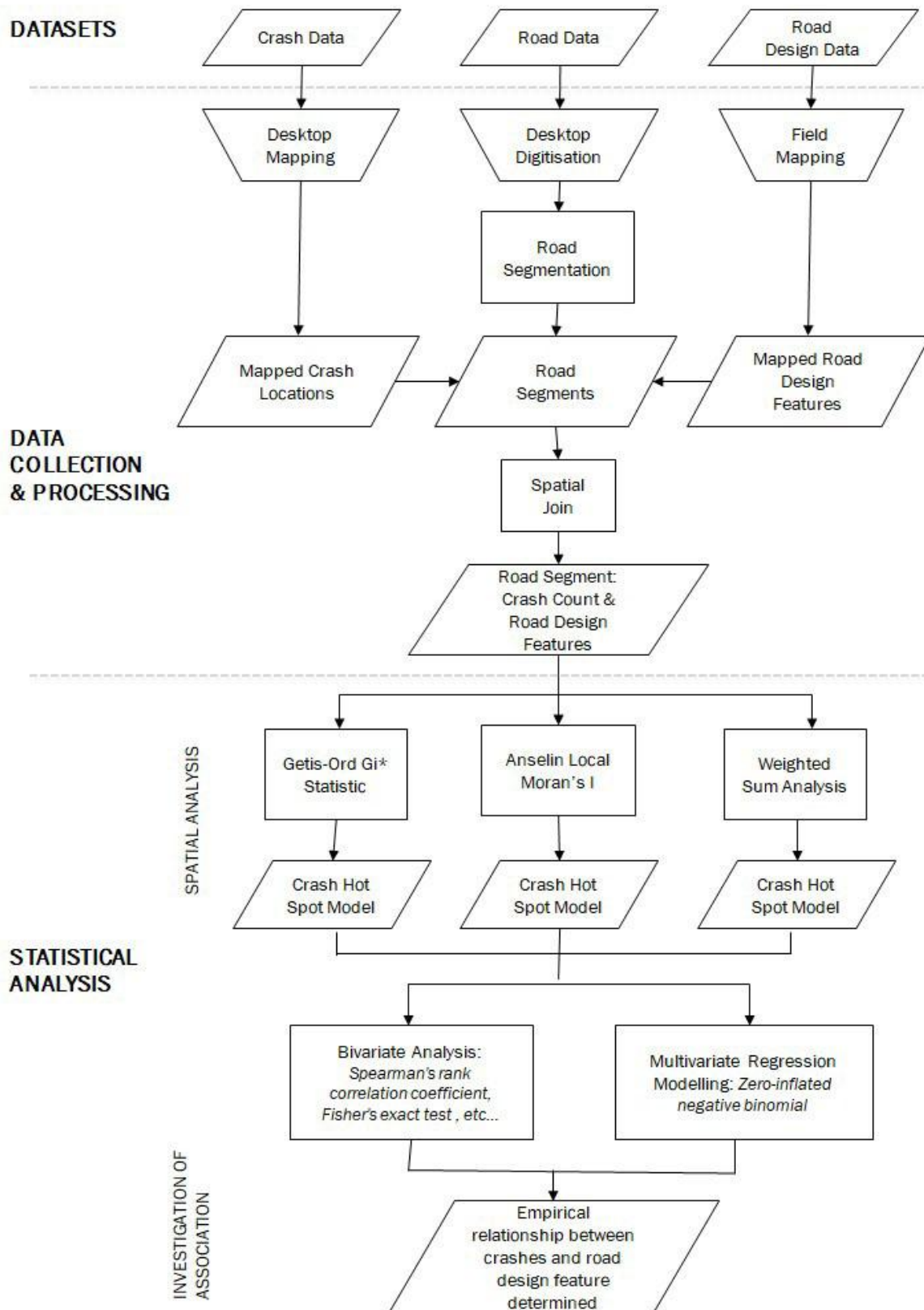


Figure 6. Flowchart showing the main data processing and analysis phases

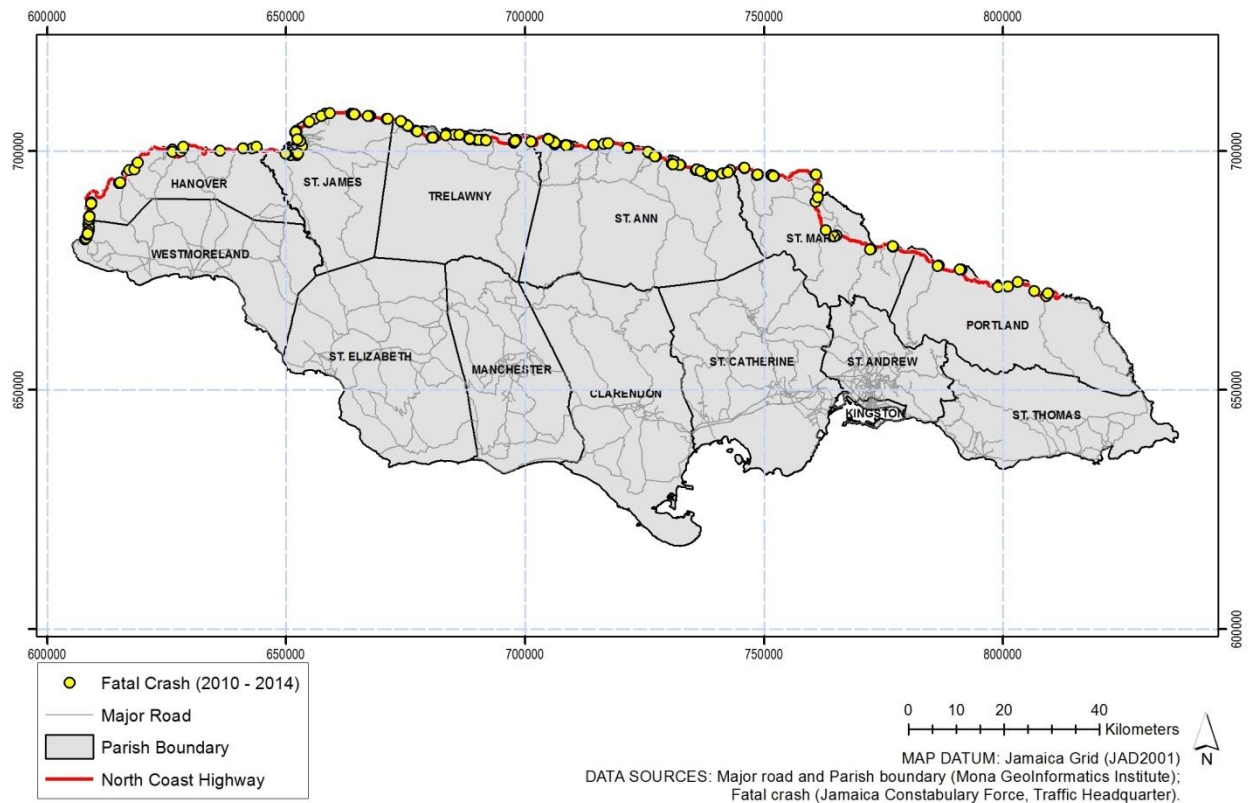


#### 4.1.1 Crash data

At the time of conducting the data collection process for this study, fatal crash data for the period 2010 to 2014 was the most recent crash data available. Crash data is generally collated by the Jamaica Constabulary Force (JCF) Traffic and Highway Patrol Division and is recorded according to crash reports made to the police. Based on the availability of crash data, the researcher was not able to access a comprehensive list of all types of crashes as only fatal crash data was readily available for the study period. The crash data was provided by the JCF as Microsoft Excel files with information for the entire island. Only those crashes occurring along the NCH were subsequently selected for this study based on the location information provided. Other crash details were also provided about each fatal crash, which included the crash type, driver's age, time of crash (day or night) and number of deaths. For this study, the crash location and type of crash were the only variables considered.

#### DESKTOP MAPPING

For this research, it was necessary to have the crash locations mapped in a GIS, which was achieved by manual geocoding. Jamaica unfortunately does not benefit like other developed countries from having police officers outfitted with GPS units for mapping crash scenes. Consequently, desktop mapping was dependent solely on the crash location description information that was recorded in the police reports. This method, versus automatic geocoding, proved to be the only mapping option available as Jamaica does not have a structured addressing system where each road segment can be easily deciphered based on an organised method for street numbering. Also, it was observed that the crash location information was not written in a standard format. This was most evident in the rural areas where most addresses made reference only to a main road name, town and/or a landmark. Consequently, the desktop mapping of crashes was plagued by a reduced level of accuracy and comprehensiveness of crashes mapped as some crash location information was insufficient and vague and therefore some locations were not mapped. The researcher, however, consulted the local newspapers for additional location information about crashes that received media attention. In total there were 1,524 fatal crashes recorded across Jamaica over the 5-year period, with an average of 305 fatal road crashes each year. This study examined the location of 298 fatal crashes that were mapped along the NCH (Figure 7 and Table 1).



**Figure 7. Fatal crash locations (2010 - 2014) along the North Coast Highway.**

**Table 1. Number of fatal crashes islandwide and along the NCH by type and year.**

| Year  | Islandwide Fatal Crashes | NCH Fatal Crashes |                         |                            |                        |       |
|-------|--------------------------|-------------------|-------------------------|----------------------------|------------------------|-------|
|       | Total                    | Total             | % of Islandwide Crashes | Pedestrian-related crashes | Driver-related crashes | Other |
| 2010  | 319                      | 49                | 15%                     | 18                         | 21                     | 10    |
| 2011  | 307                      | 66                | 21%                     | 24                         | 38                     | 4     |
| 2012  | 260                      | 58                | 22%                     | 16                         | 41                     | 1     |
| 2013  | 307                      | 67                | 22%                     | 16                         | 42                     | 9     |
| 2014  | 331                      | 58                | 18%                     | 14                         | 38                     | 6     |
| Total | 1,524                    | 298               | 20% (5 yr avg.)         | 88                         | 180                    | 30    |

This mapping method was utilised given the available data, time and budget constraints associated with this research. The crash locations were mapped individually and saved as point shapefiles where one point represented one crash, with its crash details appended.

### **4.1.2 Road Data**

#### DESKTOP DIGITISATION

The highway was digitised as a road centreline shapefile from satellite imagery (circa 2014) obtained from Google Earth. These images were first georeferenced in ESRI's ArcMap software and then the highway digitised. The crash data provided from the JCF did not in all instances indicate on which side of the highway each crash occurred and as such a single centerline representing the NCH was considered sufficient for this study. The accuracy of the digitised roadway was further assessed and verified during a field visit where a Garmin GPS handheld device, which provides  $\pm 5$  m accuracy, was used to create tracks as the researcher travelled the length of the highway. The plotted tracks were then compared to the previously digitised centreline and the necessary changes made to the shapefile to allow for proper alignment.

### **4.1.3 Road Design Features**

#### FIELD MAPPING

Data for road design features was collected during a field visit to the NCH, where a GPS device was used to capture all the various features seen on both sides of the roadway. A Garmin nüviCam LMTHD, which is equipped with a built-in dash camera that continuously records the features along a route, was utilised for the field visit (Plate 2). The in-built GPS records exactly where (using geographic coordinates) and when features were seen from the device's dashboard mounting location. The researcher therefore captured in a video all the features observed along the entire length of the highway. The field visit was done in July 2015 and was completed within 1 day. The design features were chosen based on the degree to which the features were expected to influence road safety, their prevalence and also the ease of data collection. This research focused on eleven features (Table 2).

a)



b)



**Plate 2. (a) Garmin nüviCam LMTHD mounted on windshield**  
(Photography credit: <http://www.fedingas.lt/garmin-nuvcam-lmt>),  
**(b) Screen grab from nüviCam device**  
(Photography credit: Lisa-Gaye Greene, 2015).

**Table 2. Description of road design features collected for study.**

| <b>Road Design Feature</b> | <b>Description</b>  |
|----------------------------|---|
| Sidewalk                   | Sidewalks were considered to be paved areas along the roadway that was designated for use by pedestrians as they travelled along the road (Appendix 1a).  |
| Bus stop                   | Bus stops provide designated marked areas for persons to wait for, stop, board or alight from public transportation. Bus stops may be identified by a posted sign or by shed/shelter structures (Appendix 1b).                      |
| Pedestrian crossing        | Pedestrian crossings were identified by black and white stripes painted across a roadway which provide pedestrians with a designated place to cross a road (Appendix 1c).   |
| Posted speed limit         | Traffic signs that indicated the maximum speed at which vehicles were allowed to legally travel along a roadway (Appendix 2a).  |
| Soft shoulder              | The soft shoulder was represented by paved and un-paved areas along the roadway, primarily for vehicles wishing to stop (Appendix 2b).  |
| Median                     | Medians provided a central physical barrier that separated opposing lanes along a roadway. (Appendix 2c).   |
| Lane                       | A lane was a designated area on a road for a single line of vehicles travelling in the same direction, usually denoted by road surface markings (Appendix 3a). There may be several lanes observed along a roadway.                 |
| Roadside barrier           | Safety barriers, also known as guardrails were normally found at the road side. These features were constructed of various materials to dissipate impact energy and deflect when struck by an out of control vehicle (Appendix 3b). |
| Traffic Light              | Traffic lights were signalized features installed along roadways to control the flow of vehicular and pedestrian traffic along a shared roadway allowing users to pass in turn (Appendix 3c).                                       |
| Place of Interest (POIs)   | Non-residential buildings offering public and private services, which include places such as hotels, gas stations, government offices, churches and shops (Appendix 4a).  |
| Intersections              | The place at which two or more roads met or crossed was considered an intersection (Appendix 4b).   |

## **4.2 Data management and processing**

### **4.2.1 Crash data processing**

#### CRASH CATEGORIZATION

Subsequent to mapping the fatal crashes, they were divided into three categories for this study based on the different crash types indicated by the police. Pedestrian-related crashes included those crashes that were categorised as being caused by or involving pedestrians. Driver-related crashes referred to incidents involving one or more vehicles, where the driver (including motorcyclists and cyclists) were at fault or were involved in a crash. The third crash category, all crashes, is a sum of both pedestrian-related and driver-related crashes. The crash data was ultimately saved as point shapefiles consistent with the three crash categories.

#### CRASH COUNT

This research utilised crash counts, instead of a crash rate, frequency or density. The homogeneous road length segments that were chosen for this study and the lack of traffic data made this approach most suitable. Each road segment was assigned crash counts based on the number of crashes (by category) that occurred along the roadway using the Join Tool in ArcGIS (Appendix 5). The crash count (by category) ultimately formed part of the information stored for the road line shapefile.

### **4.2.2 Road Data Processing**

#### ROAD SEGMENTATION

Like Johnson (2012), this study used equal increments to segment the roadway. A simple sensitivity analysis was conducted to determine if a 1-km, 2-km or 3-km segment length would be ideal. The 2-km segment length was ultimately used, where the entire NCH was divided into 141 segments. It was determined that a 2-km segment length would be a sufficient length to conduct analyses of crashes and their relation to road design feature. This length would allow for analysis at a micro-scale without providing too many segments with zero crashes or losing important details that would otherwise be lost from using longer segment lengths. A segmented line shapefile representing the entire length of the NCH, was created so that the crash count (by category) and road design data could be joined to each segment of the highway.

### **4.2.3 Road design feature processing**

Geographic coordinates for the selected road design features were saved as point locations, such as bus stops, pedestrian crossings, traffic lights, intersections and places of interest. The

other features were processed as polyline datasets to capture the lengths of the features, which included sidewalks, speed limit road sections, soft shoulders, medians, lanes and roadside barriers. The line features were processed using the start and end geographic coordinates of these features and later joined to create polyline features in ArcGIS. Similar to the crash data, the road design features were also categorised as either pedestrian- or driver-related features.

For each road segment, the presence, absence and number of design features were coded as either ‘0’, ‘1’, ‘2’ or ‘3’ (Table 3). This numbering method was based on the concept that the higher the score - the safer the roadway, and the lower the score - the more dangerous it was. Some studies have shown for instance that the absence of bus stops and soft shoulders would cause a road segment to be more dangerous and hence segments without these features were assigned “0”. Other studies, for example Taylor et al. (2000) and Aarts & van Schagen (2006) found that driving at high speeds may often lead to a higher crash rate, crash frequency and greater severity of injuries and hence roadways with higher speed limits of 80 km/hr were assigned “0”. A similar approach was applied to the number of lanes along a road segment.

For some features, which include traffic lights, points of interest, speed limits and intersections, ‘1’, ‘2’ or ‘3’ was applied based on the perception of how safe these features made the roadway. For example, the lowest code was therefore applied to those road segments with many intersections as these segments are generally deemed more unsafe when compared to those segments with less or no intersections. The count intervals were automatically determined based on the interquartile range.

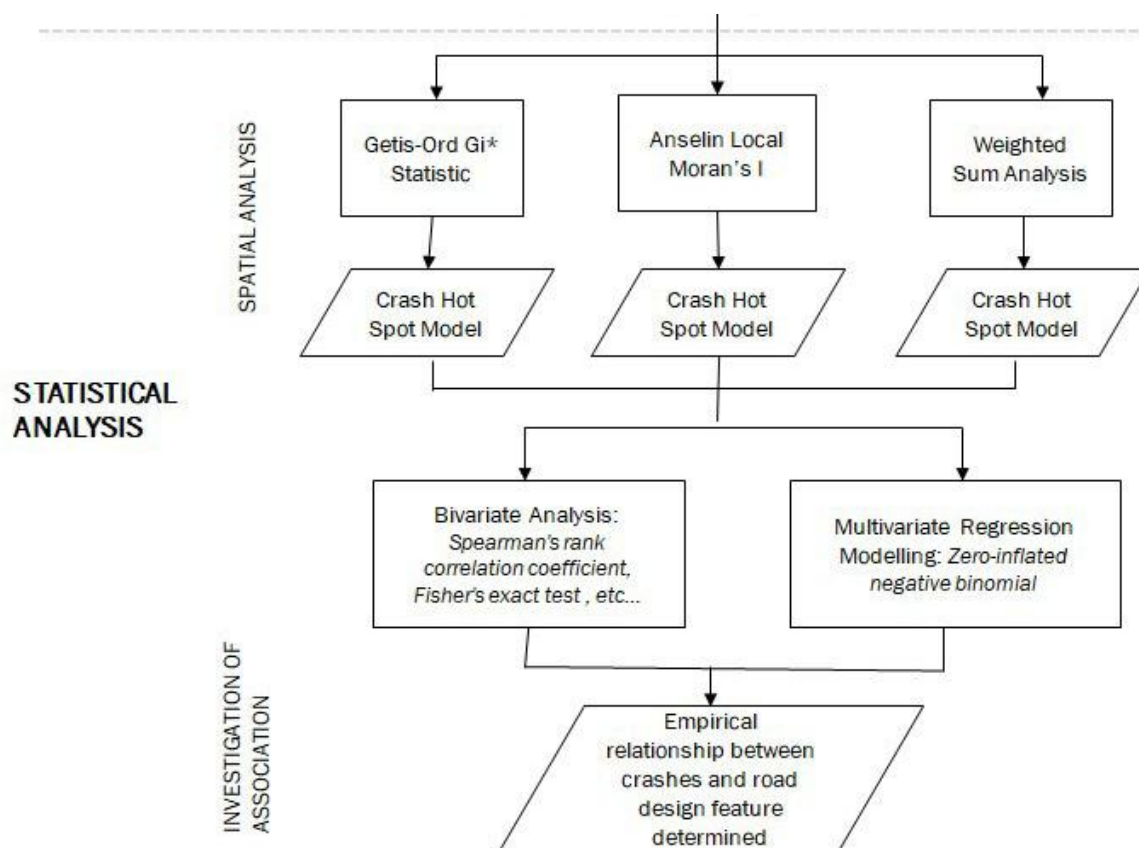
**Table 3. Description of road design data variables**

| Road Design Features               | Categorical Variables   |
|------------------------------------|---|
| <b>Pedestrian-related features</b> |   |
| Sidewalk                           | 0 - Absent, 1 - Present   |
| Bus stop                           | 0 - Absent, 1 - Present   |
| Pedestrian crossing                | 0 - Absent, 1 - Present   |
| <b>Driver-related features</b>     |   |
| Posted speed limit                 | 0 - 80 km/hr, 1 - 30 or 50 km/hr  |
| Soft shoulder                      | 0 - Absent, 1 - Present   |
| Median                             | 0 - Absent, 1 - Present   |
| Lane                               | 0 - More than one lane present, 1 - One lane or one-way lane present    |
| Roadside barrier                   | 0 - Absent, 1 - Present   |
| Traffic Light                      | 1: 0 traffic lights, 2: 1 - 2 traffic lights, 3: 3-4 traffic lights     |
| Place of Interest (POI)            | 1: 6 - 121 POIs, 2: 2 - 5 POIs, 3: 0 - 1 POI                            |
| Intersection                       | 1: 8 - 36 intersections, 2: 4 - 7 intersections, 3: 0 - 3 intersections |

## 4.3 Data analysis

### 4.3.1 Statistical methods

Inferential statistics are obtained from tests of the statistical hypotheses and allow one to make inferences from the data. For this study, inferential data analysis enabled determination of whether the occurrence of crashes was associated with any of the road design features and the identification of dangerous crash road segments. Two approaches were used to determine this, namely Spatial Analysis and Investigations of Associations (Figure 8). P-values of less than 0.05 were regarded as being statistically significant.



**Figure 8. Flowchart showing the statistical analysis phases**

#### SPATIAL ANALYSIS

This study utilised the two most popular local indicators of spatial association to analyse crash data, the Anselin Local Moran's I and the Getis-Ord  $G_i^*$  (Saha, 2012 and Khan et al., 2008). The Getis-Ord  $G_i^*$  Statistic and the Anselin Local Moran's I are standard data analysis tools in Esri's ArcMap GIS software and were employed to compare the hot spots identified by both methods. According to Esri (2012c), the Hot Spot Analysis (Getis-Ord  $G_i^*$ ) and Cluster and Outlier Analysis (Anselin Local Moran's I) have a null hypothesis that supports Complete Spatial Randomness (CSR) which would apply to the crash incidents or would be based on the attributes linked to them.



### Getis-Ord $G_i^*$ Statistic

The Hot Spot Analysis tool, Getis-Ord  $G_i^*$ , assessed whether clusters of crashes were statistically significant. In general, the  $G_i^*$  statistic investigated road segments based on the concentration of high or low crash count values. Esri (2012b) describes the Getis-Ord  $G_i^*$  statistic as a tool that considers the distribution of features (crashes) in relation to the other crash incidents that surround it. Statistical significance may be achieved if the values of the incidents are similar to the incidents surrounding it. More specifically, when the local sum for crashes is compared to the sum of all crashes, statistical significance is attained if the sums are different. The output is a z-score result.

The formulation of the local version of the *Getis-Ord  $G_i^*$*  statistic was conducted using the following equation (Esri, 2012b and Saha, 2012):

$$G_i^* = \frac{\sum_{j=1}^n W_{ij}x_j - \bar{X} \sum_{j=1}^n W_{ij}}{S \sqrt{\left(\frac{\sum_{j=1}^n W_{ij}^2 - (\sum_{j=1}^n W_{ij})^2}{n-1}\right)}} \quad (1)$$

For this study  $x_j$  represents the road segment crash count,  $w_{ij}$  is the spatial weight between road segments  $i$  and  $j$  which refer to their spatial interrelationship,  $n$  is the same as the total number of road segments,  $\bar{x}$  is the average of the crash counts per segment and  $S$  the standard deviation and:

$$\bar{X} = \frac{\sum_{j=1}^n x_j}{n} \quad (2)$$

$$S = \sqrt{\frac{\sum_{j=1}^n x_j^2}{n} - \bar{X}^2} \quad (3)$$

No other calculations are done since the  $G_i^*$  statistic is a z-score.

This method puts forward the null hypothesis that no spatial pattern exists or that spatial correlations do not exist among crashes. In ArcMap, the Getis-Ord  $G_i^*$  tool was used, with *inverse distance* being selected as the *Conceptualization of Spatial Relationships*. This indicates that the neighbouring features will have a larger influence on the computations for a target feature than features that are far away. The Euclidean Distance was selected as the Distance Method. The hot spot areas for the Getis-Ord  $G_i^*$  method were considered at the 99% and 95% confidence levels. For each road segment, a z-score and p-value was calculated from the  $G_i^*$  statistic, indicating the hot spot segments. Hot spots are evident

where the z-scores are positive and largest, while cold spots are present on segments where the z-scores are negative and smallest.

*Cluster and Outlier Analysis - Anselin Local Moran's I*

The Cluster and Outlier Analysis tool was also used to identify hot spots, where it identified clusters of road segments with high or low crash counts by measuring values similar in magnitude and location proximity. In general, the Moran's I analysis is based on the similarity of nearby features. This tool was also able to distinguish spatial outliers.

The formulation of the *Moran's Index* statistic is indicated below (Esri, 2012a):

$$I_i = \frac{x_i - \bar{X}}{S_i^2} \sum_{j=1, j \neq i}^n w_{i,j} (x_j - \bar{X}) \quad (4)$$

For this study  $x_i$  is the crash count for road segment  $i$ ,  $\bar{X}$  is the mean of the corresponding value,  $w_{i,j}$  is the distance weighting between road segment  $i$  and  $j$ , which is the inverse of the distance, while  $S_i^2$  is the variance of  $x$ , and:

$$S_i^2 = \frac{\sum_{j=1, j \neq i}^n w_{ij} x_j^2}{n-1} - \bar{X}^2 \quad (5)$$

With  $n$  being the same as the total number of road segments.

The  $z_{I_i}$  - score for the statistics are computed as:

$$z_{I_i} = \frac{I_i - E[I_i]}{\sqrt{V[I_i]}} \quad (6)$$

where:

$$E[I_i] = -\frac{\sum_{j=1, j \neq i}^n w_{ij} x_j}{n-1} \quad (7)$$

$$V[I_i] = E[I_i^2] - E[I_i]^2 \quad (8)$$

Like the Getis-Ord  $G_i^*$  tool, the *inverse distance* was selected as the *Conceptualization of Spatial Relationships* parameter. The *Distance Band/Threshold Distance* parameter was left blank such that a threshold distance was automatically generated, representing the minimum distance that ensures every feature has at least one neighbour. The Euclidean Distance was also selected as the Distance Method. The hot spot areas for the Anselin Local Moran's I method were considered at the 95% confidence level.

The tool's output was a local Moran's I index, along with a z-score, p-value, and a code representing the cluster/outlier type (COType) for each road segment. The z-score and p-value measured the statistical significance of the computed index value and essentially indicated if the spatial clustering of high or low crash values or the presence of spatial outliers was more pronounced than would be observed in a random distribution. A positive value for the index indicated that the feature was surrounded by locations with similar frequency or high or low attribute values. Such a feature was part of a cluster and could be considered as belonging to crash hot spots. A negative index value indicated that the location was surrounded by features with dissimilar values, and the feature was considered an outlier. According to Esri (2012a), the COType output field indicates four types of statistically significant conditions. The first two being HH and LL which are clusters of high values and low values respectively. The third result is HL, which in this case is a road segment with a high crash count that is surrounded by segments with mostly low crash counts and LH is *vice versa*.

#### *Weighted Sum analysis tool*

Using the Weighted Sum Analysis tool in ESRI ArcGIS, this research adopted a scoring system for the North Coast Highway based on the road design features. This score was allocated to each road segment to determine how safe or dangerous each segment was. ESRI (2011) described this tool as providing the ability to combine multiple inputs to create an integrated analysis. This tool is ideal for solving multi-criteria problems, which for this study referred to the various road design features that were considered in determining how dangerous each road segment was. For this study, the design features were placed into two categories, driver-related and pedestrian-related design features.

The scoring was based on a rating of the road features according to the level of protection for road users from death or serious injury. The higher the score, the safer the segment was (more safety design features present) and the lower the score, the more dangerous the segments were. Ultimately, the derived scores were inputted into regression models to determine correlations between road features and crash counts. The Weighted Sum Analysis tool is typically used for site selection and suitability analysis. A similar approach was taken for this study to assess the characteristics of safe road segments based on the preferred attributes or requirements they possess.

#### INVESTIGATION OF ASSOCIATION

Summary statistics in the form of counts, proportions, medians and measures of variability were estimated to describe the distribution of crash data within and across categories defined by road design features. In addition, the summary statistics was also instrumental in

determining whether over-dispersion was observed in the study data. These statistical analyses were performed in Stata 14®.

#### *Bivariate Analysis*

Bivariate analyses of the data were performed using several methods, namely the Spearman's rank correlation coefficient, Fisher's exact test and the Likelihood ratio test. The Spearman's rank correlation coefficient ( $\rho$ ) was used to test the strength and direction of association between crash types and road design features and also crash types and road design scores. The Spearman's  $\rho$  was used only for road design features with quantitative values, which were summarised using tertiles and included the number of intersections, traffic lights and places of interest (POIs) found along road segments. The Fisher's exact test was used to determine if there were non-random associations between the proportion of road segments that had zero or more crashes and the various road design features. This test would determine statistical significance in the data and confirm if there was dependency or contingency of one classification on the other. Since the outcome variables were counts (number of crashes), the Likelihood ratio test was used to determine whether the use of the negative binomial regression model was a more suitable alternative to the standard Poisson regression model in the presence of overdispersion in the data.

#### *Multiple Regression Modelling*

In addition, as a number of road segments had no crashes, results of the Vuong test were used to determine whether the zero-inflated negative binomial (ZINB) model versus the standard negative binomial model should be used to assess association between number of crashes and road design features. The ZINB model was also used to determine whether or not a single design variable had any significant association with the outcome. Road design variables that were significantly associated with number of crashes in the bivariate analyses, were then included in multiple regression analysis using ZINB models. These variables were used to arrive at the final best model based on the combinations of variables that resulted in the lowest Akaike Information Criterion (AIC). The AIC was employed to compare goodness-of-fit models. The variables that were not strongly associated were removed and the AIC was compared. The rate ratios quantifying effects of the respective road design features on occurrence of crashes, with adjustment for possible confounding variables (other road design features), were estimated from these models. The final best models that had the lower values for the Akaike Information Criterion, were then determined. Thus, a final model with adjustments for the confounding variables that best described the relationship between crashes and road design feature variables was selected. This study used the ZINB regression model to identify an empirical relationship between crash hotspots and road design features.

## Chapter 5. Results

This section begins with the results from the hot spot models that were calculated from crash counts for each of the three crash types. This is followed by the weighted sum calculation of safety scores for each road segment based on pedestrian and driver related road design features. The statistical modelling results are presented last, which describe the relationships between crashes and road design features. ArcGIS was used to visualize the crash hot spot locations and road design safety scores by way of maps.

### 5.1 Spatial analysis of crashes - Hot spot analyses

#### 5.1.1 Getis-Ord $G_i^*$ Statistic hot spot identification

The output from the  $G_i^*$  tool can be seen in Table 4, Table 5 and Table 6 where a portion of the outputs have been presented, to highlight the top road segments with clustering. Saha (2012) explains the value of  $G_iZscore$  and the  $G_iPValue$  as indicating the statistical significance of the hot spots. This is also represented by the  $G_iPValue$  in the output table. The confidence level bin field identified statistically significant hot spots. Road segments assigned +/-3 bins reflected statistical significance with a 99% confidence level. Segments in the +/-2 bins reflected a 95% confidence level.

#### ALL CRASHES

When considering all crashes in total, 7 out of 141 (5%) road segments were considered as crash hot spots based on the Getis-Ord  $G_i^*$  method. These hot spots were found in 5 of the 7 parishes in which the NCH is found with Hanover, St. James and Trelawny having 2 hot spot segments each (Table 4). The bright red colour areas in Figure 9a, represent the highest z-scores or hot spots and navy blue represents points with the lowest  $G_iZscore$ s or cold spots. The hot spot segments had the most crashes, ranging from 14 to 10 being recorded. The average number of crashes for the all crash type was 2 per segment.

**Table 4. Hot spot locations identified by the Getis-Ord Gi\*method for crashes in total.**

| Hot Spot Location   | Crash Count | GiZScore | GiPValue | GI_Bin |
|---|-------------|----------|----------|--------|
| Rose Hall - St. James, vicinity of Hilton Rose Hall Resort & Spa      | 14          | 3.81     | 0.00     | 3      |
| Oracabessa - St. Mary, vicinity of Boscobel Post Office               | 14          | 3.81     | 0.00     | 3      |
| Rio Bueno - Trelawny, vicinity of Braco                               | 13          | 3.49     | 0.00     | 3      |
| Lilliput - St. James, vicinity of Iberostar Hotel                     | 12          | 3.17     | 0.00     | 3      |
| Falmouth - Trelawny, Falmouth Bypass                                  | 11          | 2.85     | 0.00     | 3      |
| Jericho - Hanover, vicinity of Lucea Harbour Port                     | 11          | 2.85     | 0.00     | 3      |
| Orange Bay - Hanover and Westmoreland, vicinity of Negril Beach Villa | 10          | 2.53     | 0.01     | 2      |

**DRIVER-RELATED CRASHES**

Hot spots for driver-related crashes were found on 8 out of 141 (6%) road segments. These high crash areas were found in 5 of the 7 parishes. Trelawny had the highest number of hot spots, with 3 road segments (Table 5 and Figure 9b). The crash counts for these hot spot segments were the highest, with crashes ranging between 13 and 7. The mean crash count for driver-related crashes was 1 crash per segment.

**Table 5. Hot spot locations identified by the Getis-Ord Gi\*method for driver-related crashes.**

| Hot Spot Location   | Crash Count | GiZScore | GiPValue | GI_Bin |
|---|-------------|----------|----------|--------|
| Rio Bueno - Trelawny, vicinity of Braco                               | 13          | 4.58     | 0.00     | 3      |
| Falmouth - Trelawny, Falmouth Bypass                                  | 11          | 3.79     | 0.00     | 3      |
| Oracabessa - St. Mary, vicinity of Boscobel Post Office               | 10          | 3.39     | 0.00     | 3      |
| Jericho - Hanover, vicinity of Lucea Harbour Port                     | 10          | 3.39     | 0.00     | 3      |
| Orange Bay - Hanover and Westmoreland, vicinity of Negril Beach Villa | 9           | 2.99     | 0.00     | 3      |
| Lilliput - St. James, vicinity of Iberostar Hotel                     | 8           | 2.59     | 0.01     | 3      |
| Duncans - Trelawny, vicinity of Lancaster                             | 7           | 2.20     | 0.03     | 2      |
| Flankers - St. James, vicinity of IAM Jet Centre                      | 7           | 2.19     | 0.03     | 2      |

## PEDESTRIAN-RELATED CRASHES

Hot spot areas, based on pedestrian-related crashes, were found on 10 out of 141 (7%) road segments. When comparing the 3 crash types, pedestrian-related crashes had the most hot spots. These were found in 6 of the 7 parishes in which the NCH is found, with St. James having the most hot spot with 3 segments (Table 6 and Figure 9c). The average number of pedestrian-related crashes stood at less than 1 crash (0.6) per segment, however these hot spots had crash counts ranging from 8 to 3.

**Table 6. Hot spot locations identified by the Getis-Ord  $G_i^*$  method for pedestrian-related crashes.**

| Hot Spot Location  | Crash Count | $G_i^*$ Score | $G_i^*$ PValue | $G_i^*$ Bin |
|--|-------------|---------------|----------------|-------------|
| Rose Hall - St. James, vicinity of Hilton Rose Hall Resort & Spa           | 8           | 6.17          | 0.00           | 3           |
| Downtown, Montego Bay - St. James, Barnett Street & Howard Cooke Boulevard | 5           | 3.66          | 0.00           | 3           |
| Priory - St. Ann, vicinity of Priory Police Station                        | 4           | 2.82          | 0.00           | 3           |
| Oracabessa - St. Mary, vicinity of Boscobel Post Office                    | 4           | 2.82          | 0.00           | 3           |
| Lilliput - St. James, vicinity of Iberostar Hotel                          | 4           | 2.82          | 0.00           | 3           |
| Green Island - Hanover, vicinity of Green Island Police Station            | 4           | 2.82          | 0.00           | 3           |
| Salt Marsh - Trelawny, vicinity of Salt Marsh Church of God Prophecy       | 3           | 1.98          | 0.05           | 2           |
| Ocho Rios - St. Ann, vicinity of Ocho Rios Village Jerk Centre             | 3           | 1.99          | 0.05           | 2           |
| Negril - Westmoreland, vicinity of Grand Pineapple Beach Resort            | 3           | 1.99          | 0.05           | 2           |
| Annotto Bay - St. Mary, vicinity of Iter Boreale                           | 3           | 1.98          | 0.05           | 2           |

## SUMMARY

Sixteen (16) unique road segments along the North Coast Highway were considered hot spots by the Getis-Ord  $G_i^*$  model (Table 7 and Figure 10). With the majority of these found in parishes of St. James (4), Trelawny (4) and Hanover (3). Portland did not record any hot spot segments for this model. Lilliput in St. James in the vicinity of Iberostar Hotel and Oracabessa in St. Mary in the vicinity of Boscobel Post Office were identified as crash hot spots for the 3 crash types.

**Table 7. All unique hot spot road segments identified by the Getis-Ord Gi\* model.**

| <b>Getis-Ord Gi* Hot Spot Location</b>                                     | <b>Crash Count</b> |
|--|--------------------|
| Rose Hall - St. James, vicinity of Hilton Rose Hall Resort & Spa           | 14                 |
| Oracabessa - St. Mary, vicinity of Boscobel Post Office                    | 14                 |
| Rio Bueno - Trelawny, vicinity of Braco                                    | 13                 |
| Lilliput - St. James, vicinity of Iberostar Hotel                          | 12                 |
| Falmouth - Trelawny, Falmouth Bypass                                       | 11                 |
| Jericho - Hanover, vicinity of Lucea Harbour Port                          | 11                 |
| Orange Bay - Hanover and Westmoreland, vicinity of Negril Beach Villa      | 10                 |
| Duncans - Trelawny, vicinity of Lancaster                                  | 7                  |
| Flankers - St. James, vicinity of IAM Jet Centre                           | 7                  |
| Downtown, Montego Bay - St. James, Barnett Street & Howard Cooke Boulevard | 5                  |
| Priory - St. Ann, vicinity of Priory Police Station                        | 4                  |
| Green Island - Hanover, vicinity of Green Island Police Station            | 4                  |
| Ocho Rios - St. Ann, vicinity of Ocho Rios Village Jerk Centre             | 3                  |
| Negril - Westmoreland, vicinity of Grand Pineapple Beach Resort            | 3                  |
| Salt Marsh - Trelawny, vicinity of Salt Marsh Church of God Prophecy       | 3                  |
| Annotto Bay - St. Mary, vicinity of Iter Boreale                           | 3                  |



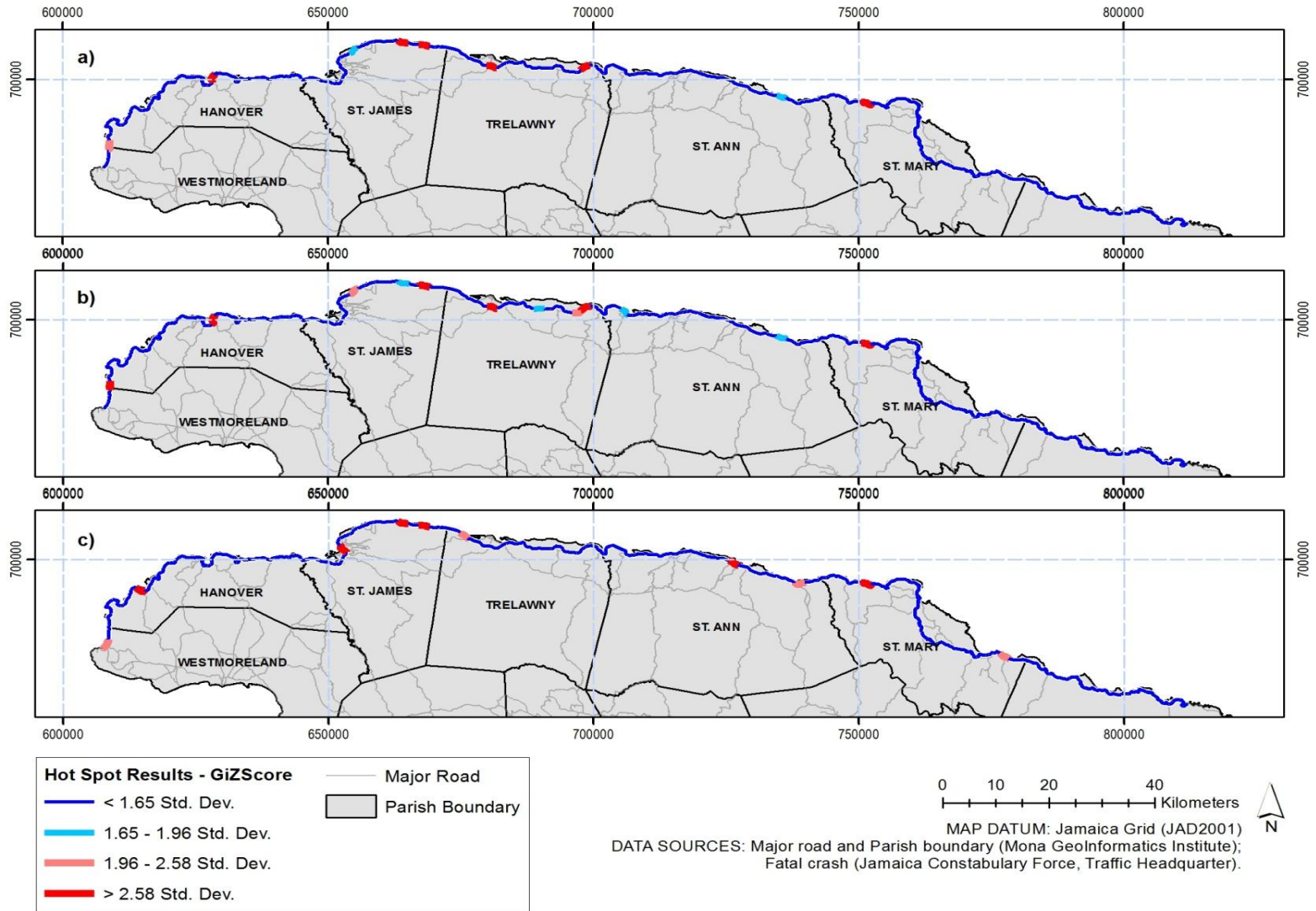
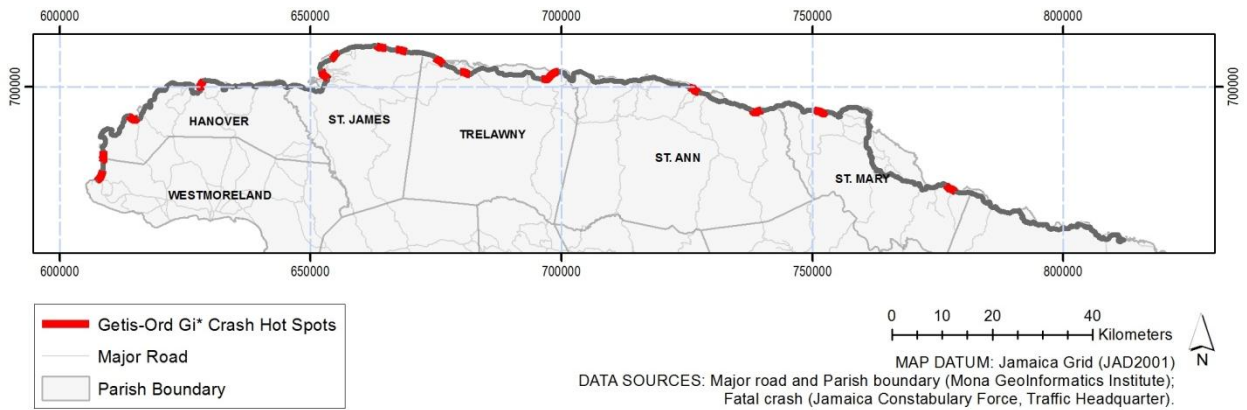


Figure 9. Hot spot GiZscore for all crash types: a) all crashes, b) driver-related crashes and c) pedestrian-related crashes.



**Figure 10. All hot spot road segments identified by the Getis-Ord Gi\* model.**

### 5.1.2 Anselin Local Moran's I Hot Spot Identification

#### ALL CRASHES

Based on the model calculations, only 6 out of 141 (4%) road segments proved to be hot spots for crashes in total. These segments were assigned a cluster/outlier type (COType) of HH and HL (Table 8 and Figure 11a). These hot spots were found in 5 parishes with Trelawny having the most with 2 segments. Unlike the Getis-Ord Gi\* method, the hot spot segments identified by the Moran's I tool did not coincide with only segments with the highest crash counts. The crash counts for these hot spots ranged from 14 to 5. There were other segments with more than 5 crashes recorded, however these were not considered as hot spots by the Moran's I tool.

**Table 8. Hot spot locations identified by the Anselin Local Moran's I method for crashes in total.**

| Hot Spot Location  | Crash Count | LMiIndex | LMiZScore | LMiPValue | COType |
|--|-------------|----------|-----------|-----------|--------|
| Duncans - Trelawny, vicinity of Lancaster                        | 7           | 0.00     | 3.23      | 0.00      | HH     |
| Negril - Westmoreland, vicinity of Grand Pineapple Beach Resort  | 5           | 0.00     | 2.73      | 0.01      | HH     |
| Rio Bueno - Trelawny, vicinity of Braco                          | 13          | 0.00     | 2.11      | 0.03      | HH     |
| Oracabessa - St. Mary, vicinity of Boscobel Post Office          | 14          | 0.00     | -2.01     | 0.04      | HL     |
| Rose Hall - St. James, vicinity of Hilton Rose Hall Resort & Spa | 14          | 0.00     | -2.60     | 0.01      | HL     |
| Jericho - Hanover, vicinity of Lucea Harbour Port                | 11          | 0.00     | -2.90     | 0.00      | HL     |

#### DRIVER-RELATED CRASHES

With regards to driver-related crashes, the model identified 5 out of 141 (4%) road segments as being hot spots (Table 9 and Figure 11b). These hot spots were found in only 3 of the 7 parishes in which the NCH is found. Most of these hot spots were found in Trelawny, with 3 segments. The driver-related crash hot spots had crash counts ranging between 13 and 4, but were not necessarily the segments with the highest crash counts.

**Table 9. Hot spot locations identified by the Anselin Local Moran's I method for driver-related crashes**

| Hot Spot Location   | Crash Count | LMiIndex | LMiZScore | LMiPValue | COType |
|---|-------------|----------|-----------|-----------|--------|
| Duncans - Trelawny, vicinity of Lancaster                       | 7           | 0.00     | 6.45      | 0.00      | HH     |
| Rio Bueno - Trelawny, vicinity of Braco                         | 13          | 0.00     | 5.12      | 0.00      | HH     |
| Negril - Westmoreland, vicinity of Grand Pineapple Beach Resort | 4           | 0.00     | 2.90      | 0.00      | HH     |
| Duncans - Trelawny, vicinity of Stewart Castle                  | 6           | 0.00     | 2.11      | 0.03      | HH     |
| Jericho - Hanover, vicinity of Lucea Harbour Port               | 10          | 0.00     | -2.81     | 0.00      | HL     |

#### PEDESTRIAN-RELATED CRASHES

The model found 4 out of 141 (3%) road segments to be pedestrian-related crash hot spots (Table 10 and Figure 11c). No HH clusters were identified. These hot spots were found in only 4 parishes and had crash counts of 8 and 4. As with the other crash types, these segments were not the only segments with high crash counts.

**Table 10. Hot spot locations identified by the Anselin Local Moran's I method for pedestrian-related crashes**

| Hot Spot Location  | Crash Count | LMiIndex | LMiZScore | LMiPValue | COType |
|--|-------------|----------|-----------|-----------|--------|
| Rose Hall - St. James, vicinity of Hilton Rose Hall Resort & Spa | 8           | 0.00     | -3.40     | 0.00      | HL     |
| Priory - St. Ann, vicinity of Priory Police Station              | 4           | 0.00     | -2.20     | 0.03      | HL     |
| Oracabessa - St. Mary, vicinity of Boscobel Post Office          | 4           | 0.00     | -2.20     | 0.03      | HL     |
| Green Island - Hanover, vicinity of Green Island Police Station  | 4           | 0.00     | -2.20     | 0.03      | HL     |

#### SUMMARY

Only nine (9) unique road segments along the North Coast Highway were considered hot spots by the Anselin Moran's I tool (Table 11 and Figure 12). The majority of these were found in Trelawny (3), followed by Hanover (2). Once again, Portland did not record any hot spot segments. There were also no similarities in the road segments identified as hot spots when comparing both driver and pedestrian related crashes.

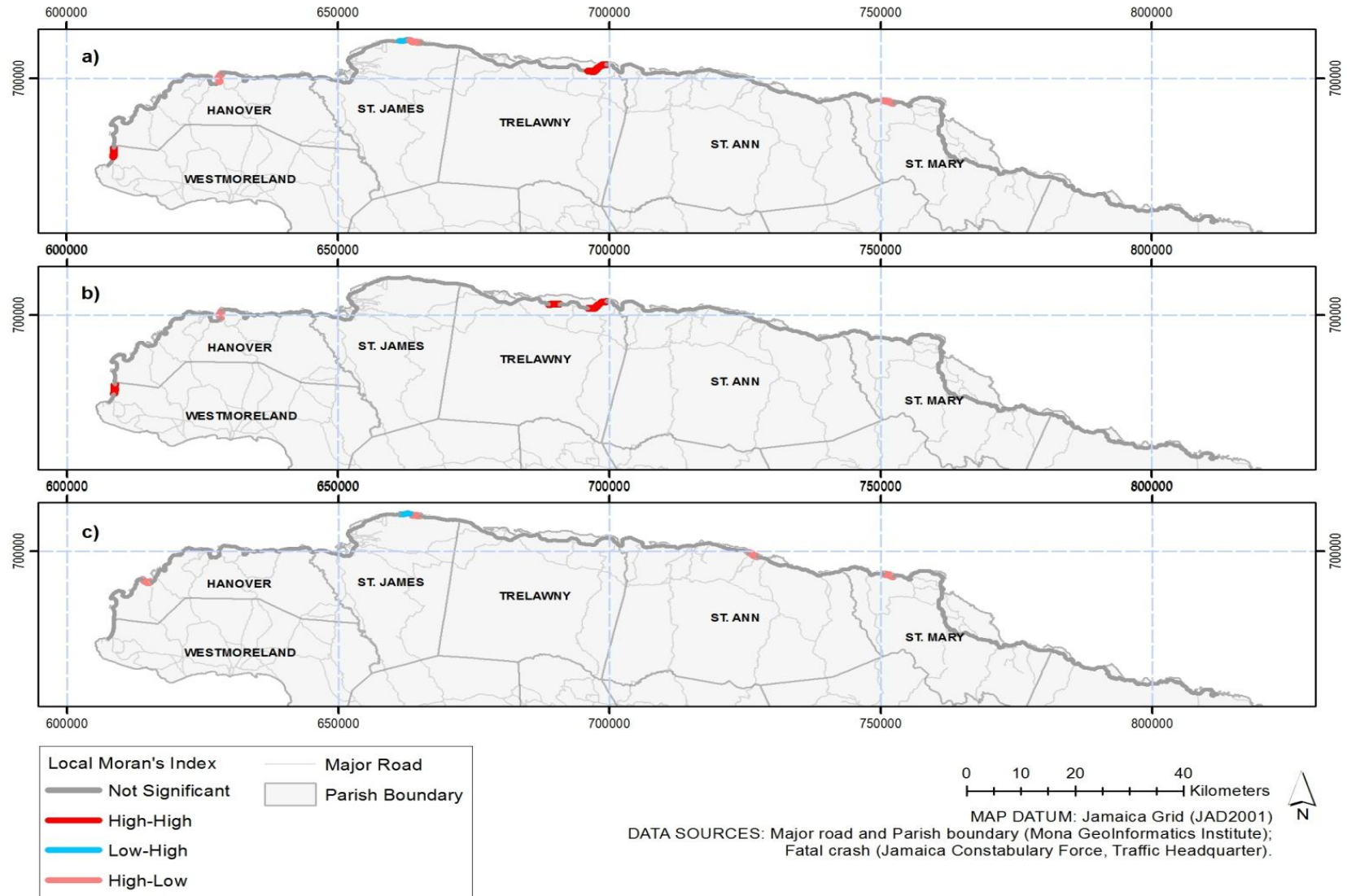
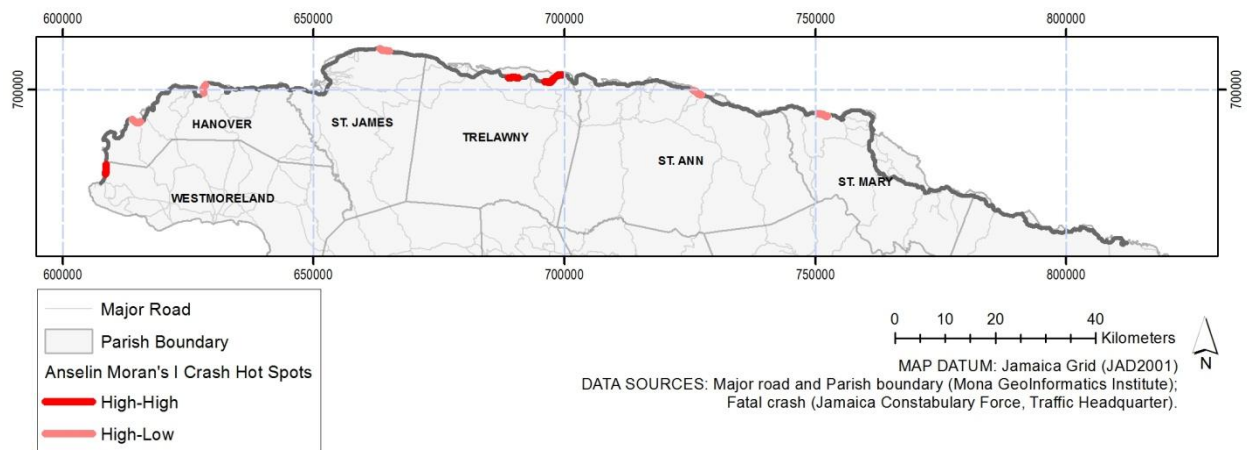


Figure 11. Hot spot Anselin Local Moran's I index for all crash types: a) all crashes, b) driver-related crashes and c) pedestrian-related crashes.

**Table 11. All unique hot spot road segments identified by the Anselin Local Moran's I model.**

| <b>Anselin Local Moran's I Hot Spot Location</b>                 | <b>Crash Count</b> |
|--|--------------------|
| Rose Hall - St. James, vicinity of Hilton Rose Hall Resort & Spa | 14                 |
| Oracabessa - St. Mary, vicinity of Boscobel Post Office          | 14                 |
| Rio Bueno - Trelawny, vicinity of Braco                          | 13                 |
| Jericho - Hanover, vicinity of Lucea Harbour Port                | 11                 |
| Duncans - Trelawny, vicinity of Lancaster                        | 7                  |
| Duncans - Trelawny, vicinity of Stewart Castle                   | 6                  |
| Negril - Westmoreland, vicinity of Grand Pineapple Beach Resort  | 5                  |
| Priory - St. Ann, vicinity of Priory Police Station              | 4                  |
| Green Island - Hanover, vicinity of Green Island Police Station  | 4                  |



**Figure 12. All hot spot road segments identified by the Anselin Local Moran's I model.**

## 5.2 Spatial Analysis of Road Design Features

### 5.2.1 Weighted sum analysis

ESRI's Weighted Sum analysis tool was utilised to determine crash safety scores. The road design features were saved as point and polyline datasets to capture the number, presence or absence and length of features (Table 12). The scores are based on 3 categories: all road design features, driver-related design features and pedestrian-related road design features. Driver-related features included posted speed limits, the presence or absence of soft shoulders, medians and road side barriers and also the number of lanes, traffic lights, places of interest and intersections. Pedestrian-related features included the presence or absence of sidewalks, bus stops and pedestrian crossings. The occurrence of crashes can be influenced by these design features and consequently the scoring method utilised for this study was able to determine which road segments were considered dangerous or safe. High scores indicated segments with a higher level of road safety (maximum score was 12), while lower scores represented dangerous road segments with lower safety (minimum score was 0).

**Table 12. Number and length of road design features**

| Point Road Design Feature    |                            | No. of Locations |
|------------------------------|----------------------------|------------------|
| Bus stop                     |                            | 179              |
| Pedestrian crossing          |                            | 57               |
| Traffic light                |                            | 42               |
| Intersection                 |                            | 902              |
| Places of interest           |                            | 889              |
| Polyline Road Design Feature |                            | Length (km)      |
| Sidewalk                     |                            | 18               |
| Soft Shoulder                |                            | 161              |
| Median                       |                            | 26               |
| Roadside barrier             |                            | 214              |
| Speed Limit                  | <i>30 or 50 km/hr</i>      | 119              |
|                              | <i>80 km/hr</i>            | 165              |
| Lane                         | <i>&gt; 1 lane present</i> | 50               |
|                              | <i>1 lane or 1 way</i>     | 234              |

#### ALL DESIGN FEATURES

The safety scores, based on all road design features, were between 5 and 12, with only 4 of 141 (3%) segments getting a maximum score of 12 (safest segments) and 3 segments (2%) receiving a score of 6 and less representing the more dangerous segments (Figure 13 and Figure 17a). The majority (95%) of the roads received scores between 7 and 11. The average score was 9 out of 12. There were therefore only a few segments that were

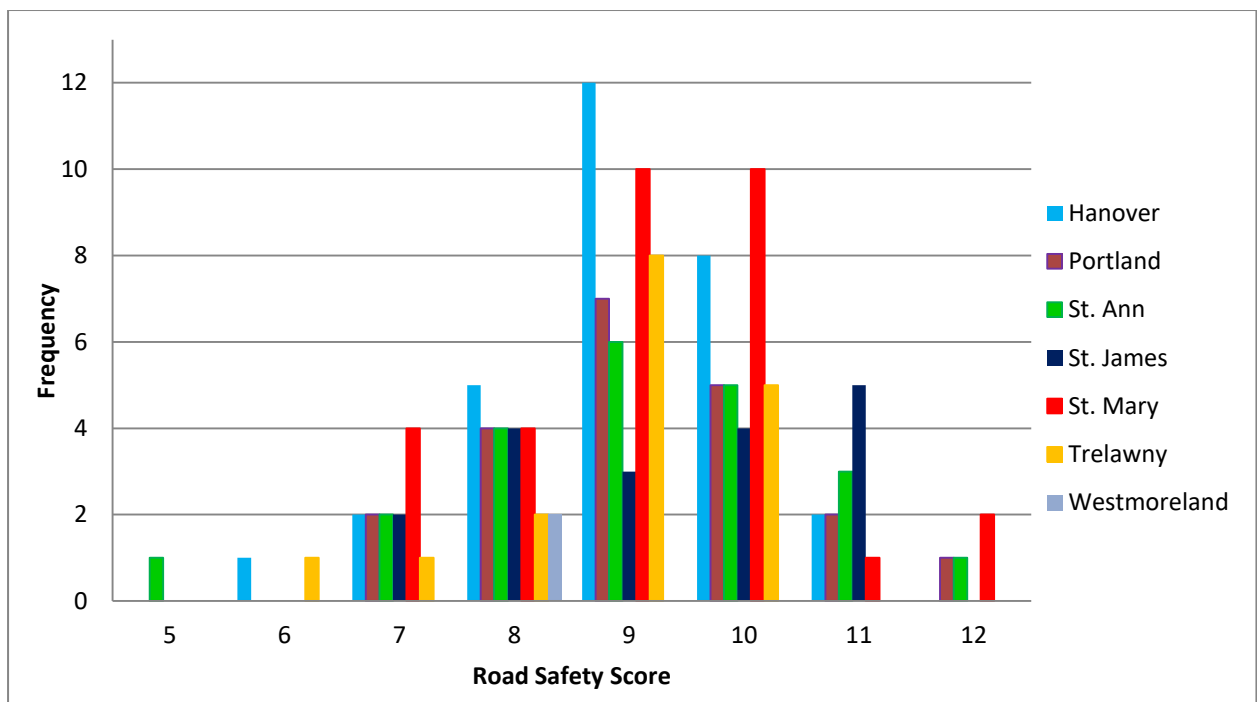
considered either very safe or very dangerous, while the majority of segments were relatively safe. The eastern parishes (St. Mary, St. Ann and Portland) had the safest road segments.

The most dangerous segments were found across 3 parishes in the following locations:

- Salt Marsh - Trelawny, vicinity of Salt Marsh Church of God Prophecy (score: 6)
- Green Island - Hanover, vicinity of Green Island Police Station (score: 6)
- Discovery Bay - St. Ann, vicinity of Red Stripe Distribution Centre (score: 5)

The safest segments were found in:

- Ocho Rios - St. Ann, vicinity of Mystic Mountain (score: 12)
- Prospect / Content Garden - St. Mary and St. Ann, vicinity of Couples San Souci (score: 12)
- Oracabessa - St. Mary, vicinity of Boscobel Basic School (score: 12)
- Snow Hill / Norwich - Portland (score: 12)



**Figure 13. Frequency of road safety scores based on all road design features by parish.**



## DRIVER-RELATED DESIGN FEATURES

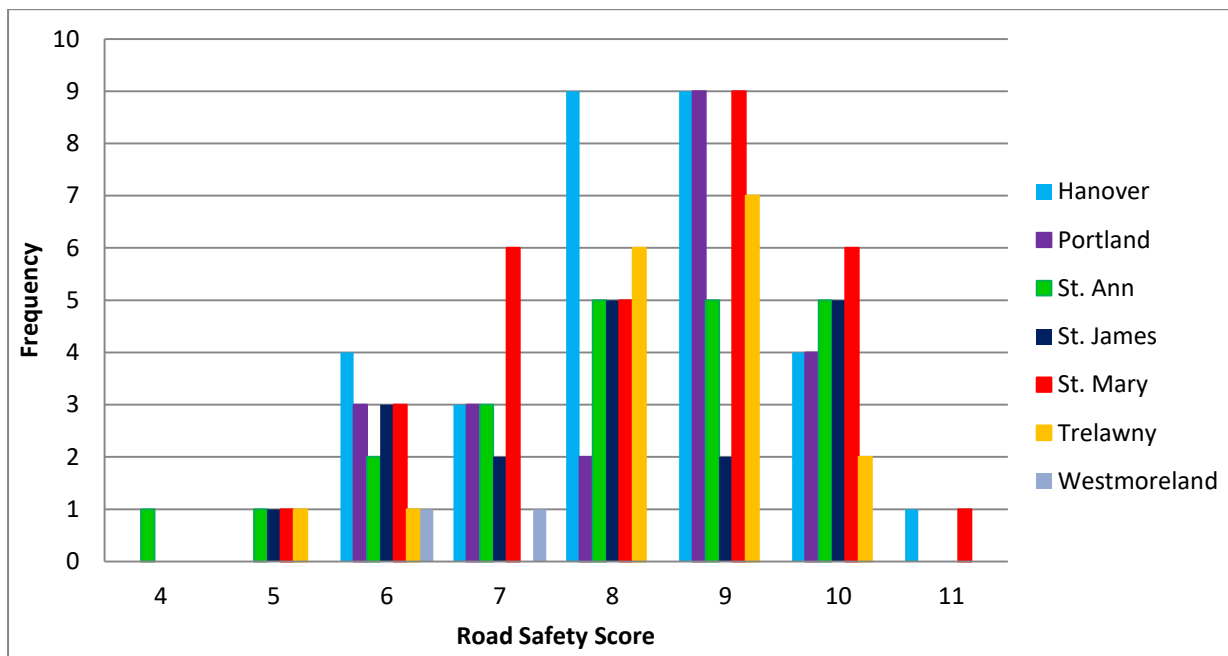
The road segments received scores between 4 and 11 based on the driver-related design features. Only 2 of 141 (1%) segments got a maximum score of 11 (safest segments) and 5 road segments (4%) were considered the most dangerous with scores of 4 and 5 (Figure 14 and Figure 17b). The average safety score was 8 out of 11. The majority of road segments were considered relatively safe with about 71% of segments received a score between 8 and 11 and only 29% of road segments were classified as dangerous with scores between 4 and 7. The most dangerous segments were found in 4 of 7 parishes, with St. Ann recording the most with 2 road segments.

The most dangerous segments were found at:

- Discovery Bay - St. Ann, vicinity of Red Stripe Distribution Centre (score: 4)
- Runaway Bay - St. Ann, vicinity of Salem Baptist Church (score: 5)
- Downtown, Montego Bay - St. James, Gloucester Avenue (score: 5)
- Salt Marsh - Trelawny, vicinity of Salt Marsh Church of God Prophecy (score: 5)
- Galina - St. Mary, vicinity of Galina Primary School (score: 5)

The safest segments were found at:

- Jericho - Hanover, between Paradise and Mosquito Cove (score: 11)
- Oracabessa - St. Mary, vicinity of Boscobel Basic School (score: 11)



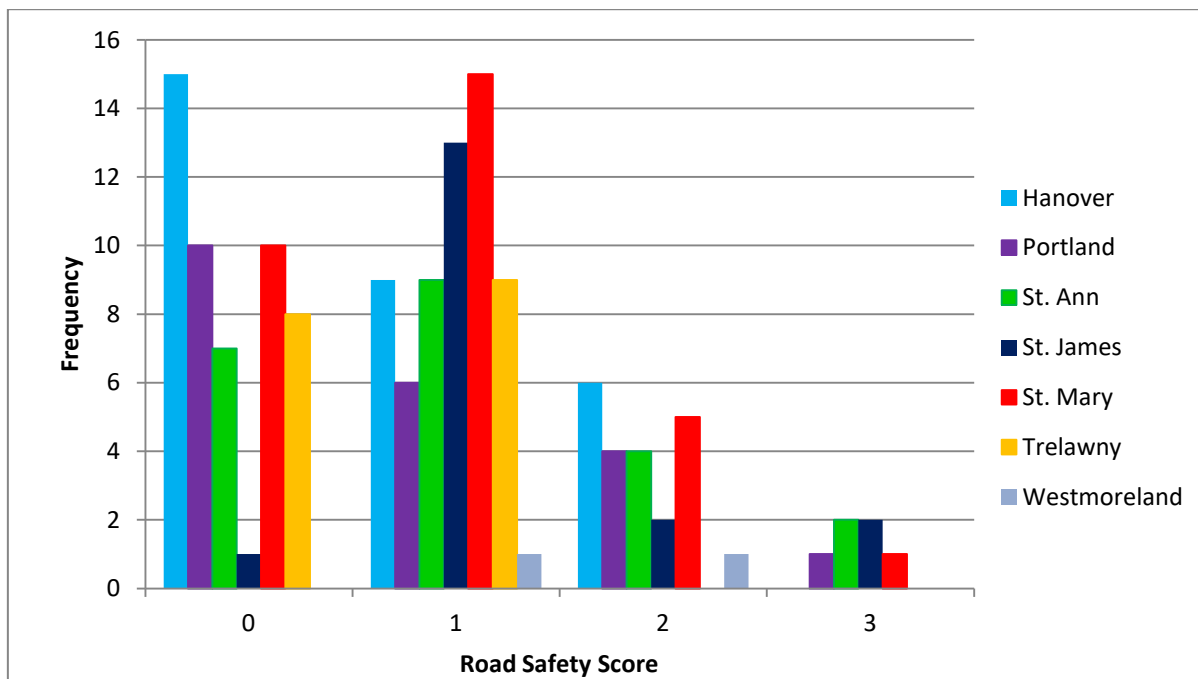
**Figure 14. Frequency of road safety scores based on driver-related road design features by parish.**

## PEDESTRIAN-RELATED DESIGN FEATURES

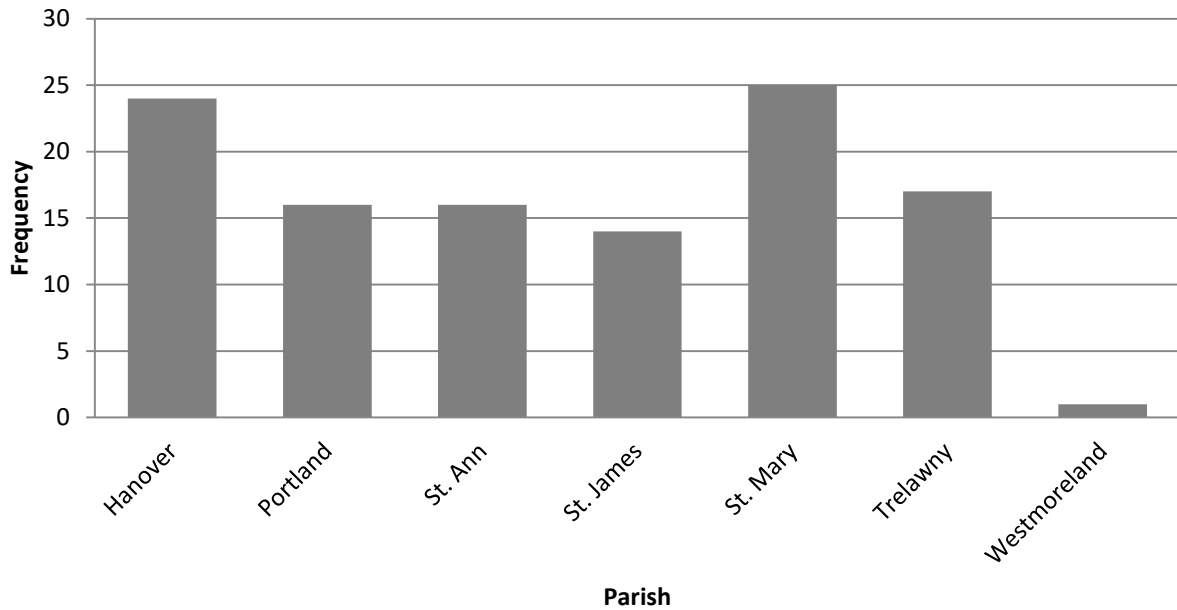
Based on the pedestrian-related design features, the scores ranged between 0 and 3, with only 6 of 141 (4%) segments getting a maximum score of 3 (safest segments) while 80% of road segments were considered dangerous for pedestrians, with scores of either 1 or 0 (Figure 15 and Figure 17c). The average score received was less than 1 (0.9). The safest segments were found across 4 parishes, with the majority being in St. Ann and St. James. The most dangerous segments were more widespread in 6 of 7 parishes through which the NCH runs. The majority of which were found in Hanover and St. Mary (Figure 16).

The safest segments were found across 4 parishes, more specifically in:

- Discovery Bay - St. Ann, vicinity of Puerto Seco Beach (score: 3)
- Ocho Rios - St. Ann, vicinity of Ocho Rios Village Jerk Centre (score: 3)
- Downtown, Montego Bay - St. James, Barnett Street and Howard Cooke Boulevard (score: 3)
- Downtown, Montego Bay - St. James, Gloucester Avenue (score: 3)
- Port Maria - St. Mary, vicinity of Port Maria Catholic Church (score: 3)
- Port Antonio - Portland, West Street, West Palm Avenue and Gideon Avenue (score: 3)



**Figure 15. Frequency of road safety scores based on pedestrian-related road design features by parish.**



**Figure 16. Frequency of most dangerous road segments (scores between 0 and 1) based on pedestrian-related road design features by parish.**

#### SUMMARY

Based on the Weighted Sum analysis tool, it was determined that the majority of road segments were comparatively safe and only a few segments were considered dangerous when all crash designs in total and driver-related road design features were considered. However, it was noticeable that unlike the other two design types, the majority of the road segments were considered dangerous based on the distribution of the pedestrian-related design features. This result could however be linked to the fact that a part of the NCH (28%) actually passes through rural areas, where pedestrian activity may be low and likewise, the presence of pedestrian-related design features may be absent or unnecessary. The safest segments were found in 5 of 7 parishes, St. Ann, St Mary, Portland, St. James and Hanover. The most dangerous segments (if pedestrian-related features were not considered) were also found in 5 of 7 parishes, St. Ann, Trelawny, Hanover, St. James and St. Mary, with one segment in Salt Marsh, Trelawny (vicinity of Salt Marsh Church of God Prophecy) being considered dangerous based on all crash designs in total and driver-related road design features.

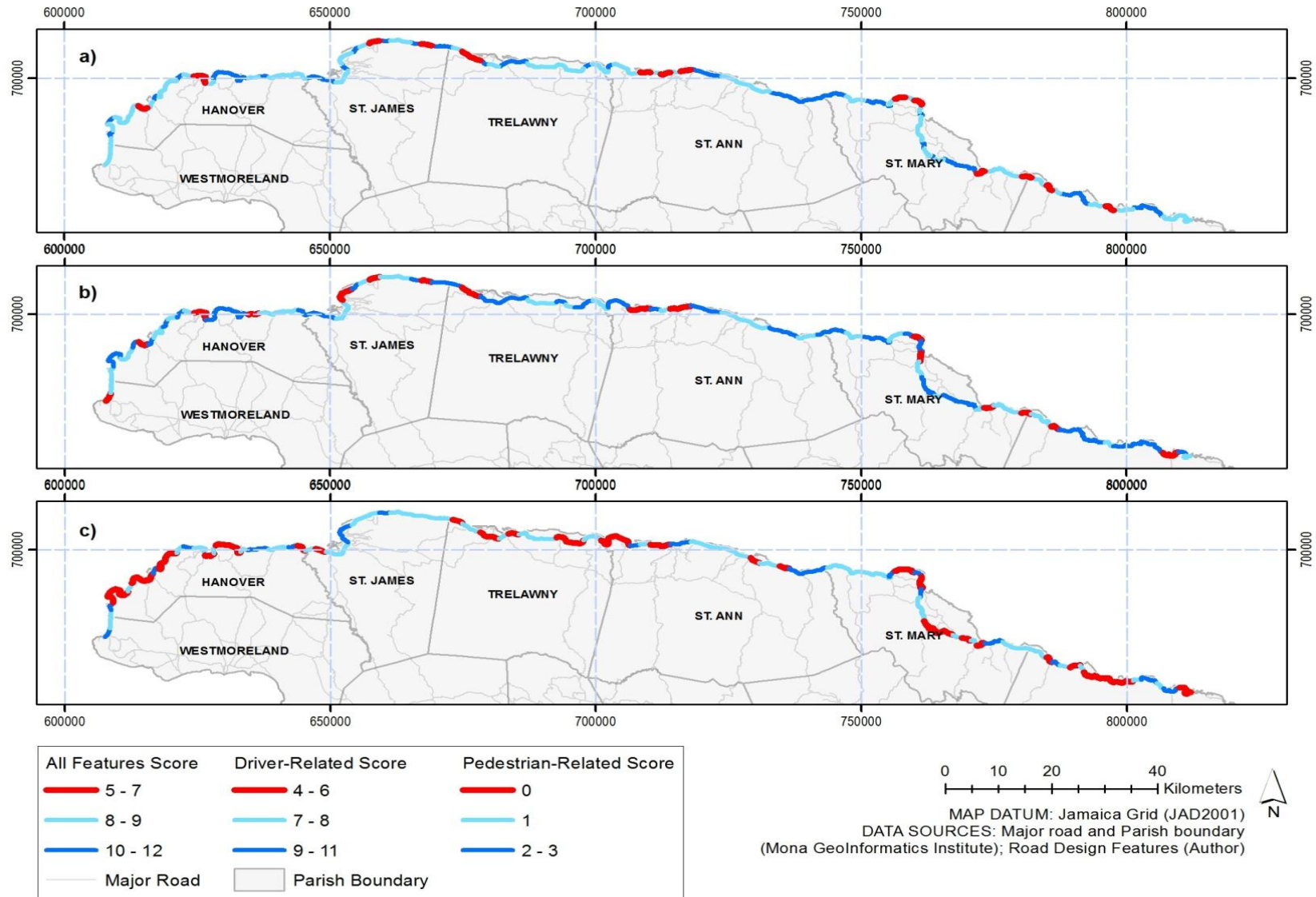


Figure 17. Weighted Overlay Score for all road design categories: a) all design features, b) driver-related features and c) pedestrian-related features.

### 5.2.2 Comparison: Hot spots and road design feature scores

For the most part, hot spots identified by the Getis-Ord  $G_i^*$  model and the Anselin Moran's  $I$  tool were similar but did not match the dangerous road segments found using the Weighted Sum analysis tool. There was however four segments that were common among the results for the 3 methods employed. A segment in Green Island, Hanover (vicinity of Green Island Police Station) was identified by both hot spot analysis methods (pedestrian crash type) and the weighted sum tool (all crash design features) as being a high crash location. Salt Marsh, Trelawny (vicinity of Salt Marsh Church of God Prophecy) was the location of a segment identified by the  $G_i^*$  statistic (pedestrian crash type) and the weighted sum tool (all crash design features). The other two road segments were however considered crash hot spots but also safe road segments based on their high safety scores. These segments were found in Ocho Rios, St. Ann (vicinity of Ocho Rios Village Jerk Centre) and Downtown Montego Bay, St. James (Barnett Street and Howard Cooke Boulevard). The Getis-Ord  $G_i^*$  model (pedestrian crash type) and the weighted sum tool (all crash design features) identified these segments with contradictory results. These results suggest that there may be other underlying factors influencing the crash situation found at these sites.

## 5.3 Investigation of Association

### 5.3.1 Summary Statistics

#### **Road design features were not evenly distributed along the North Coast Highway (NCH).**

Table 13 reveals the absence of sidewalks (94%), medians (91%), traffic lights (83%) and pedestrian crossings (74%) along the NCH road segments. On the other hand, most segments had roadside barriers (75%) and were predominantly 1 lane in each direction (82%). Soft shoulders, bus stops and speed limits ( $\leq 50$  km/h and 80 km/h) were found on about 50% of all road segments.

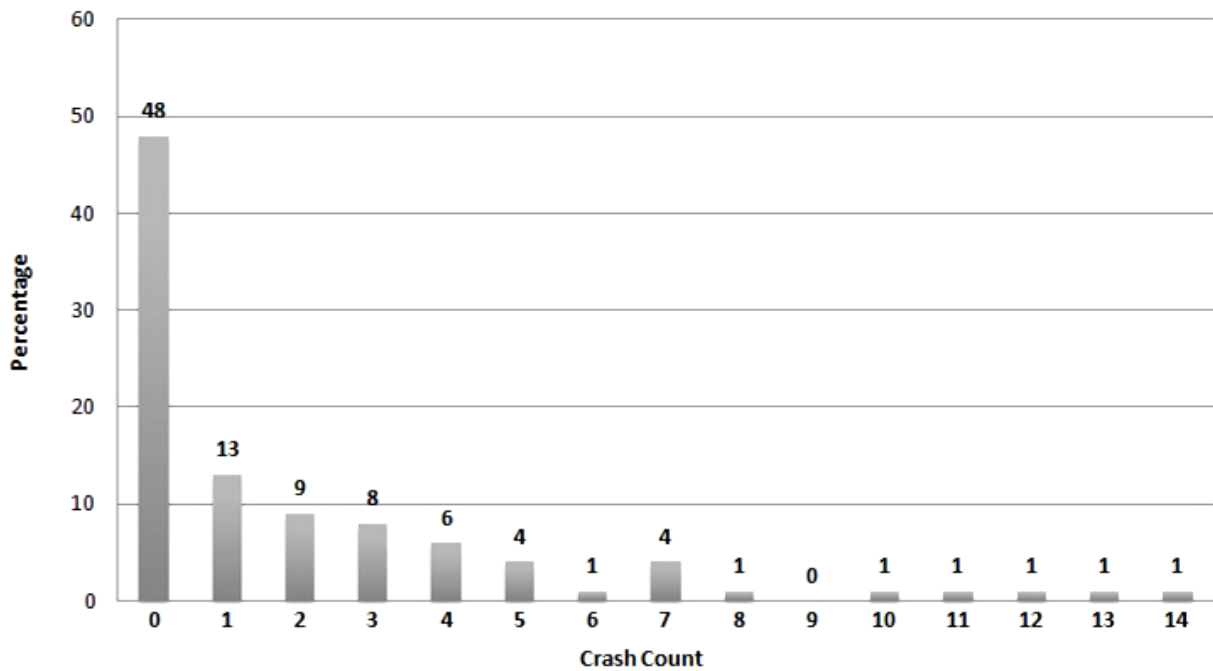
Similar to the road design features, crashes were not evenly distributed along the NCH. Table 14 shows that pedestrian-related crashes were the least distributed occurring on only 34% of road segments, while driver-related crashes were observed on more segments (43.2%). Most segments (52%) had at least one crash type. Concentrations of crashes were noticed on only a few segments, where only 5% of segments had more than 10 crashes with the maximum number of crashes found on a segment being 14 (Figure 18). Several segments (48%) had no crashes, hence the 50<sup>th</sup> percentile crash values were low, with 1 for total crashes and 0 for each of the two crash types (Table 14).

**Table 13. Frequency distribution of road design features along the NCH.**

| ROAD DESIGN FEATURE                | NUMBER OF SEGMENTS WITH DESIGN FEATURE |            |      |
|------------------------------------|--|------------|------|
|                                    | COUNT                                  | PERCENTAGE |      |
| <i>Pedestrian-related features</i> |  |            |      |
| Sidewalk                           | present                                | 9          | 6.4  |
|                                    | absent                                 | 132        | 93.6 |
| Bus Stop                           | present                                | 78         | 55.3 |
|                                    | absent                                 | 63         | 44.7 |
| Pedestrian Crossing                | present                                | 37         | 26.2 |
|                                    | absent                                 | 104        | 73.8 |
| <i>Driver-related features</i>     |  |            |      |
| Soft Shoulder                      | present                                | 80         | 56.7 |
|                                    | absent                                 | 61         | 43.3 |
| Median                             | present                                | 13         | 9.2  |
|                                    | absent                                 | 128        | 90.8 |
| Lane                               | 1 lane/1 way                           | 116        | 82.3 |
|                                    | > 1 lane                               | 25         | 17.7 |
| Barrier                            | present                                | 106        | 75.2 |
|                                    | absent                                 | 35         | 24.8 |
| Maximum Speed Limit                | ≤50 km/hr                              | 59         | 41.8 |
|                                    | 80 km/hr                               | 82         | 58.2 |
| Number of Intersections            | 0 - 3                                  | 57         | 40.4 |
|                                    | 4 - 7                                  | 43         | 30.5 |
|                                    | 8 - 36                                 | 41         | 29.1 |
| Number of Traffic Lights           | 0                                      | 117        | 83.0 |
|                                    | 1 - 4                                  | 24         | 17.0 |
| Number of POIs                     | 0 - 1                                  | 67         | 47.5 |
|                                    | 2 - 3                                  | 28         | 19.9 |
|                                    | 4 - 121                                | 46         | 32.6 |

**Table 14. Summary statistics for number of road crashes by crash type.**

| Crash Type                 | Number of segments with crashes (%) | Minimum Crash Count | Maximum Crash Count | Median (P50) | IQR |
|----------------------------|-------------------------------------|---------------------|---------------------|--------------|-----|
| All crashes                | 74 (52.4)                           | 0                   | 14                  | 1            | 3   |
| Driver-related crashes     | 61 (43.2)                           | 0                   | 13                  | 0            | 2   |
| Pedestrian-related crashes | 48 (34.0)                           | 0                   | 8                   | 0            | 1   |



**Figure 18. Frequency distribution of crash counts along the NCH road segments.**

Road segments with certain road design features experienced more crashes relative to those segments where these features were absent. Table 15 shows that segments with bus stops, pedestrian crossings, medians, more than 1 lane, intersections (>4 features), traffic lights (1-4 features) and POIs (>2) had more crashes across all crash types relative to those segments without these features.

**Table 15. Summary statistics (50th percentile and interquartile range) for number of crashes within design feature categories.**

| ROAD DESIGN FEATURE                |              | ALL CRASHES        |     | DRIVER-RELATED CRASHES |     | PEDESTRIAN-RELATED CRASHES |     |
|------------------------------------|--------------|--------------------|-----|------------------------|-----|----------------------------|-----|
|                                    |              | MEDIAN (P25/50/75) | IQR | MEDIAN (P25/50/75)     | IQR | MEDIAN (P25/50/75)         | IQR |
| <i>Pedestrian-related features</i> |              |                    |     |                        |     |                            |     |
| Sidewalk                           | present      | 0/1/4              | 4   | 0/0/1                  | 1   | 0/0/2                      | 2   |
|                                    | absent       | 0/1/3              | 3   | 0/0/2                  | 2   | 0/0/1                      | 1   |
| Bus Stop                           | present      | 0/1/4              | 4   | 0/0/2                  | 2   | 0/0/1                      | 1   |
|                                    | absent       | 0/0/2              | 2   | 0/0/1                  | 1   | 0/0/1                      | 1   |
| Pedestrian Crossing                | present      | 0/1/4              | 4   | 0/1/2                  | 2   | 0/0/1                      | 1   |
|                                    | absent       | 0/0/3              | 3   | 0/0/2                  | 2   | 0/0/1                      | 1   |
| <i>Driver-related features</i>     |              |                    |     |                        |     |                            |     |
| Soft Shoulder                      | present      | 0/1/3              | 3   | 0/0/2                  | 2   | 0/0/1                      | 1   |
|                                    | absent       | 0/0/3              | 3   | 0/0/1                  | 1   | 0/0/1                      | 1   |
| Median                             | present      | 1/3/6              | 5   | 0/2/2                  | 2   | 0/1/2                      | 2   |
|                                    | absent       | 0/.5/3             | 3   | 0/0/2                  | 2   | 0/0/1                      | 1   |
| Lane                               | 1 lane/1 way | 0/0/3              | 3   | 0/0/2                  | 2   | 0/0/1                      | 1   |
|                                    | > 1 lane     | 1/3/6              | 5   | 0/2/5                  | 5   | 0/1/2                      | 2   |
| Barrier                            | present      | 0/1/3              | 3   | 0/0/2                  | 2   | 0/0/1                      | 1   |
|                                    | absent       | 0/2/4              | 4   | 0/0/3                  | 3   | 0/0/1                      | 1   |
| Maximum Speed Limit                | ≤50 km/hr    | 0/1/4              | 4   | 0/0/2                  | 2   | 0/0/1                      | 1   |
|                                    | 80 km/hr     | 0/1/3              | 3   | 0/0/2                  | 2   | 0/0/1                      | 1   |
| Number of Intersections            | 0 - 3        | 0/0/1              | 1   | 0/0/1                  | 1   | 0/0/0                      | 0   |
|                                    | 4 - 7        | 0/2/4              | 4   | 0/1/3                  | 3   | 0/0/1                      | 1   |
|                                    | 8 - 36       | 0/1/4              | 4   | 0/1/2                  | 2   | 0/0/2                      | 2   |
| Number of Traffic Lights           | 0            | 0/0/2              | 2   | 0/0/1                  | 1   | 0/0/1                      | 1   |
|                                    | 1 - 4        | 1/3/6.5            | 5.5 | 0/2/4                  | 4   | 0/1/2                      | 2   |
| Number of POIs                     | 0 - 1        | 0/0/2              | 2   | 0/0/1                  | 1   | 0/0/1                      | 1   |
|                                    | 2 - 3        | 0/1/5              | 5   | 0/.5/2.5               | 3   | 0/0/1.5                    | 1.5 |
|                                    | 4 - 121      | 0/2/4              | 4   | 0/1/3                  | 3   | 0/0/1                      | 1   |



### 5.3.2 Bivariate Analyses

#### SPEARMAN'S RANK COEFFICIENT

Table 16 shows that the number of segments with traffic lights and POIs, were found to have statistically significant associations with the total counts of all crash types (taken together and looked at separately). Segments with intersections were associated with the number of crash types in total and with pedestrian-related crashes but not with number of driver-related crashes.. A positive association was also found between each of the pedestrian and driver design scores and the total number of crashes ( $p = 0.0276$  and  $p = 0.0158$ , respectively). Driver design scores had a weak negative relationship with pedestrian-related crashes ( $p = 0.0275$ ).

**Table 16. Spearman's rank correlation coefficient for the association between number of road design features, road design scores and number of crashes.**

| ROAD DESIGN FEATURE      | ALL CRASHES  |               | DRIVER-RELATED CRASHES |               | PEDESTRIAN-RELATED CRASHES |               |
|--------------------------|--------------|---------------|------------------------|---------------|----------------------------|---------------|
|                          | SPEARMAN rho | p-value       | SPEARMAN rho           | p-value       | SPEARMAN rho               | p-value       |
| Number of Intersections  | 0.2163       | <b>0.01</b>   | 0.1427                 | 0.0914        | 0.2442                     | <b>0.0035</b> |
| Number of Traffic Lights | 0.2956       | <b>0.0004</b> | 0.2331                 | <b>0.0054</b> | 0.3688                     | <b>0.0000</b> |
| Number of POIs           | 0.2449       | <b>0.0034</b> | 0.2289                 | <b>0.0063</b> | 0.2246                     | <b>0.0074</b> |
| Pedestrian Design Score  | 0.1855       | <b>0.0276</b> | 0.1587                 | 0.0601        | 0.1471                     | 0.0817        |
| Driver Design Score      | -0.203       | <b>0.0158</b> | -0.1362                | 0.1072        | -0.1857                    | <b>0.0275</b> |
| Total Design Score       | -0.1383      | 0.1019        | -0.0884                | 0.2973        | -0.1159                    | 0.1709        |

Highlighted Coefficients are significant at 5%

#### FISHER'S EXACT TEST

The Fisher's Exact test was used to determine whether the distribution of segments with number of crashes equal 0, versus  $>0$ , differed significantly with the presence (or absence) or number of road design features.

**Table 17. Fisher's exact test result - Proportions of road segments with or without crashes within category defined by road design features.**

| ROAD DESIGN FEATURE                |                    | ALL CRASHES           |                       | DRIVER-RELATED CRASHES |                       | PEDESTRIAN-RELATED CRASHES |                       |
|------------------------------------|--------------------|-----------------------|-----------------------|------------------------|-----------------------|----------------------------|-----------------------|
|                                    |                    | Number of crashes > 0 | Number of crashes = 0 | Number of crashes > 0  | Number of crashes = 0 | Number of crashes > 0      | Number of crashes = 0 |
| <i>Pedestrian-related features</i> |                    |                       |                       |                        |                       |                            |                       |
| Sidewalk                           | present (9)        | 56%                   | 44%                   | 44%                    | 56%                   | 44%                        | 56%                   |
|                                    | absent (132)       | 52%                   | 48%                   | 43%                    | 57%                   | 33%                        | 67%                   |
|                                    | p-value            | 1.000                 |                       | 1.000                  |                       | 0.49                       |                       |
| Bus Stop                           | present (78)       | 60%                   | 40%                   | 49%                    | 51%                   | 40%                        | 60%                   |
|                                    | absent (63)        | 43%                   | 57%                   | 37%                    | 63%                   | 27%                        | 73%                   |
|                                    | p-value            | <b>0.044</b>          |                       | 0.173                  |                       | 0.152                      |                       |
| Pedestrian Crossing                | present (37)       | 62%                   | 38%                   | 54%                    | 46%                   | 38%                        | 62%                   |
|                                    | absent (104)       | 49%                   | 51%                   | 39%                    | 61%                   | 33%                        | 67%                   |
|                                    | p-value            | 0.185                 |                       | 0.129                  |                       | 0.687                      |                       |
| <i>Driver-related features</i>     |                    |                       |                       |                        |                       |                            |                       |
| Soft Shoulder                      | present (80)       | 55%                   | 45%                   | 48%                    | 53%                   | 33%                        | 68%                   |
|                                    | absent (61)        | 49%                   | 51%                   | 38%                    | 62%                   | 36%                        | 64%                   |
|                                    | p-value            | 0.502                 |                       | 0.304                  |                       | 0.721                      |                       |
| Median                             | present (3)        | 77%                   | 23%                   | 62%                    | 38%                   | 69%                        | 31%                   |
|                                    | absent (128)       | 50%                   | 50%                   | 41%                    | 59%                   | 30%                        | 70%                   |
|                                    | p-value            | 0.083                 |                       | 0.24                   |                       | <b>0.011</b>               |                       |
| Lane                               | 1 lane/1 way (116) | 47%                   | 53%                   | 39%                    | 61%                   | 29%                        | 71%                   |
|                                    | > 1 lane (25)      | 76%                   | 24%                   | 64%                    | 36%                   | 56%                        | 44%                   |
|                                    | p-value            | <b>0.014</b>          |                       | <b>0.026</b>           |                       | <b>0.018</b>               |                       |

|                          |                |              |     |              |     |              |     |
|--------------------------|----------------|--------------|-----|--------------|-----|--------------|-----|
| Barrier                  | present (106)  | 51%          | 49% | 42%          | 58% | 33%          | 67% |
|                          | absent (35)    | 57%          | 43% | 46%          | 54% | 37%          | 63% |
|                          | p-value        | 0.563        |     | 0.844        |     | 0.684        |     |
| Maximum Speed Limit      | ≤50 km/hr (59) | 51%          | 49% | 46%          | 54% | 39%          | 61% |
|                          | 80 km/hr (82)  | 54%          | 46% | 41%          | 59% | 30%          | 70% |
|                          | p-value        | 0.864        |     | 0.731        |     | 0.368        |     |
| Number of Intersections  | 0 - 3 (57)     | 37%          | 63% | 32%          | 68% | 21%          | 79% |
|                          | 4 - 7 (43)     | 65%          | 35% | 51%          | 49% | 42%          | 58% |
|                          | 8 - 36 (41)    | 61%          | 39% | 51%          | 49% | 44%          | 56% |
|                          | p-value        | <b>0.01</b>  |     | 0.07         |     | <b>0.025</b> |     |
| Number of Traffic Lights | 0 (117)        | 47%          | 53% | 38%          | 62% | 27%          | 74% |
|                          | 1 - 4 (24)     | 79%          | 21% | 67%          | 33% | 71%          | 29% |
|                          | p-value        | <b>0.006</b> |     | <b>0.013</b> |     | <b>0.000</b> |     |
| Number of POIs           | 0 - 1 (67)     | 42%          | 58% | 31%          | 69% | 25%          | 75% |
|                          | 2 - 3 (28)     | 54%          | 46% | 50%          | 50% | 36%          | 64% |
|                          | 4 - 121 (46)   | 67%          | 33% | 57%          | 43% | 46%          | 54% |
|                          | p-value        | <b>0.03</b>  |     | <b>0.02</b>  |     | 0.079        |     |

51  
51

Highlighted Coefficients are significant at 5%

The results from the Fisher's exact test are seen in Table 17 and are summarised as follow:

- The presence of bus stops was significantly associated with the number of crashes (in total) with 60% of segments with bus stops present having crashes, while only 43% of segments without bus stops had crashes. The presence of medians was significantly associated with the number of pedestrian-related crashes, as 69% of segments that had a median had crashes and only 30% of segments without medians had crashes.
- Single lane segments were significantly associated with all crash types where the percentage of single-lane segments with no crashes (in total) was 53%, while driver-related crashes was 61% and pedestrian-related crashes was 71%. Similarly a larger percentage of segments without traffic lights had no crashes in all crash categories. The percentage of segments without traffic lights was 53% for total crashes, 62% for driver-related crashes and 74% for pedestrian-related crashes.
- The number of intersections was significantly associated with the number of total crashes and pedestrian-related crashes. This was evident as 61% of segments with >8 intersections and 65% of segments with 4-7 intersections had more than one crash (in total). Only 37% of segments with <3 intersections had >1 crash (in total). For pedestrian-related crashes, 79% of segments with 0-3 intersections had no crashes while 58% of segments with 4-7 intersections and 56% of segments with 8-36 intersections had no crashes. The number of POIs was significantly associated with the number of total crashes and driver-related crashes. This is evident as 67% of segments with >4 POIs had more than one crash (in total) while 54% and 42% of segments with 2-3 POIs and 0-1 POIs respectively, had more than 0 crashes (in total). Similarly, for driver-related crashes, 57% of segments with >4 POIs had more than one crash while 50% and 31% of segments with 2-3 POIs and 0-1 POIs respectively, had more than 0 crashes.

#### IDENTIFICATION OF APPROPRIATE MODELS

Similar to Ayati and Abassi (2014), the goodness-of-fit evaluation was used for this study and followed the modelling that identified the road design features that influenced the occurrence of fatal crashes along the NCH. The likelihood ratio test and Vuong test were employed to evaluate the significance dispersion parameter. The likelihood test confirmed that overdispersion was evident and consequently, the negative binomial regression model was found to be more appropriate than the

standard Poisson regression model. The Vuong test was used to test for the relevance of the zero-inflated negative binomial versus the standard negative binomial regression models. Table 18 shows that the Vuong test statistics achieved had statistical significance, with borderline statistical significance seen for only pedestrian score and driver-related crashes ( $p=0.0514$ ). Based on this test, it was determined that the zero-inflated negative binomial (ZINB) model was most suitable when compared to the standard negative binomial model.

**Table 18. Test results for Vuong Test.**

| ROAD FEATURE     | ALL CRASHES |         | DRIVER-RELATED CRASHES |         | PEDESTRIAN-RELATED CRASHES |         |
|------------------|-------------|---------|------------------------|---------|----------------------------|---------|
|                  | z           | p-value | z                      | p-value | z                          | p-value |
| Driver Score     | 1.91        | 0.0283  | 1.65                   | 0.0493  | 2.01                       | 0.0223  |
| Pedestrian Score | 1.95        | 0.0258  | 1.63                   | 0.0514  | 2.08                       | 0.0188  |
| Overall Score    | 2.00        | 0.023   | 1.71                   | 0.0436  | 2.16                       | 0.0154  |

#### ZERO-INFLATED NEGATIVE BINOMIAL MODEL

Bivariate analyses were done to assess whether the numbers of crashes of a specific type or all types were related to design safety scores using the zero-inflated negative binomial (ZINB) model. Using guidelines suggested by Montgomery and Peck (1992),  $p < 0.2$  was used (instead of  $p = 0.05$ ) as part of the model building process to indicate which features were to be included in subsequent multiple regression models. Results from the ZINB regression model revealed that there was a statistically significant relationship between driver design scores and pedestrian-related crashes ( $p = 0.04$ ), (Table 19). There was no significant relationship between the road feature design scores and either one of total number of crashes or number of driver-related crashes. As the respective p-values for association of number of pedestrian-related crashes with design scores fell below 0.2, the score variables were used in subsequent models as part of the model building process.

**Table 19 – Unadjusted crash rate ratio for design scores and crash types.**

| ROAD FEATURE            | ALL CRASHES                     |         | DRIVER-RELATED CRASHES          |         | PEDESTRIAN-RELATED CRASHES      |             |
|-------------------------|---------------------------------|---------|---------------------------------|---------|---------------------------------|-------------|
|                         | Crash Rate Ratio (CRR (95% CI)) | p-value | Crash Rate Ratio (CRR (95% CI)) | p-value | Crash Rate Ratio (CRR (95% CI)) | p-value     |
| Driver Design Score     | 0.96 (0.81 - 1.13)              | 0.6     | 1.01 (0.84 - 1.21)              | 0.9     | 0.82 (0.67 - 0.99)              | <b>0.04</b> |
| Pedestrian Design Score | 1.11 (0.81 - 1.54)              | 0.52    | 1.04 (0.69 - 1.55)              | 0.86    | 1.28 (0.91 - 1.79)              | 0.15        |
| Total Design Score      | 0.98 (0.83 - 1.16)              | 0.85    | 1.02 (0.84 - 1.24)              | 0.83    | 0.87 (0.71 - 1.06)              | 0.17        |

The Crash Rate Ratio (CRR) estimated from the ZINB models also determined whether the occurrences of crashes were higher in places with certain design features when compared to segments without (or with lesser counts) of the feature. The results from the ZINB models are seen in Table 20 and are summarised as follow:

- There was a statistically significant relationship between segments with median and pedestrian-related crashes. Segments with medians present had about double the number of pedestrian-related crashes than segments without medians.
- Statistically significant relationships were also observed between pedestrian-related crashes and segments with single lanes, segments with 8-36 intersections and segments with 1-4 traffic lights. Road segments with single lanes had 50% more crashes than those with those segments with multiple lanes. Segments with 8-36 intersections had about 3 times more pedestrian-related crashes than segments with fewer intersections. It was also found that pedestrian-related crashes doubled on segments with 1-4 traffic lights versus those segments with no traffic lights.
- There were also significant statistical relationships between POIs and crashes in total, as there were 2 times more crashes (in total) present on segments with 2-3 POIs present versus those segments with less POIs. There was a statistically significant relationship also seen between POIs and pedestrian-related crashes, where segments with 2-3 POIs had about 4 times more pedestrian-related crashes than those segments with less POIs and also segments with 4-121 POIs had double the pedestrian-related crashes than those segments with fewer POIs.

While only design features with  $p < 0.05$  were considered statistically significant, those features with  $p < 0.2$  were included in variables used for building the final best model for each crash outcome, thus, bus stops, soft shoulders, medians, lanes, intersections, traffic lights and POIs were used in different models.

**Table 20. Crash rate ratio for design features and number of road crashes by crash type.**

| ROAD FEATURE                       | ALL CRASHES                     |                 | DRIVER-RELATED CRASHES          |                 | PEDESTRIAN-RELATED CRASHES      |                 |             |
|------------------------------------|---------------------------------|-----------------|---------------------------------|-----------------|---------------------------------|-----------------|-------------|
|                                    | Crash Rate Ratio (CRR (95% CI)) | P-value         | Crash Rate Ratio (CRR (95% CI)) | P-value         | Crash Rate Ratio (CRR (95% CI)) | P-value         |             |
| <i>Pedestrian-related features</i> |                                 |                 |                                 |                 |                                 |                 |             |
| Sidewalk                           | present (1)                     | 1.0 (0.4 - 2.5) | 1                               | 0.6 (0.2 - 1.8) | 0.34                            | 1.7 (0.7 - 4.2) | 0.29        |
| Bus Stop                           | present (1)                     | 1.2 (0.7 - 2.0) | 0.45                            | 1.1 (0.6 - 2.0) | 0.68                            | 1.6 (0.8 - 2.9) | 0.17        |
| Pedestrian Crossing                | present (1)                     | 1.1 (0.6 - 1.8) | 0.77                            | 1.1 (0.6 - 2.0) | 0.8                             | 1.2 (0.6 - 2.3) | 0.57        |
| <i>Driver-related features</i>     |                                 |                 |                                 |                 |                                 |                 |             |
| Soft Shoulder                      | present (1)                     | 1.2 (0.8 - 2.0) | 0.37                            | 1.7 (1.0 - 2.9) | 0.06                            | 0.7 (0.4 - 1.2) | 0.17        |
| Median                             | present (1)                     | 1.4 (0.7 - 2.8) | 0.31                            | 1.1 (0.5 - 2.4) | 0.89                            | 2.3 (1.1 - 4.8) | <b>0.03</b> |
| Lane                               | 1 lane/1 way                    | 0.7 (0.4 - 1.1) | 0.12                            | 0.7 (0.4 - 1.3) | 0.23                            | 0.5 (0.3 - 0.9) | <b>0.03</b> |
| Barrier                            | present (1)                     | 0.9 (0.5 - 1.4) | 0.56                            | 0.8 (0.5 - 1.5) | 0.54                            | 0.9 (0.5 - 1.7) | 0.81        |
| Max Speed                          | 80 km/hr                        | 0.7 (0.5 - 1.2) | 0.24                            | 0.9 (0.5 - 1.5) | 0.64                            | 0.9 (0.5 - 1.6) | 0.63        |
| Number of Intersections            | 0 - 3                           | 1               |                                 |                 |                                 |                 |             |
|                                    | 4 - 7                           | 1.5 (0.8 - 2.6) | 0.19                            | 1.4 (0.7 - 2.7) | 0.33                            | 2.1 (1.0 - 4.6) | 0.06        |
|                                    | 8 - 36                          | 1.3 (0.7 - 2.4) | 0.36                            | 0.9 (0.5 - 1.8) | 0.78                            | 2.7 (1.3 - 5.8) | <b>0.01</b> |
| Number of Traffic Lights           | 0                               | 1               |                                 |                 |                                 |                 |             |
|                                    | 1 - 4                           | 1.5 (0.9 - 2.6) | 0.14                            | 1.2 (0.6 - 2.3) | 0.63                            | 2.2 (1.2 - 4.1) | <b>0.02</b> |
|                                    | 0 - 1                           | 1               |                                 |                 |                                 |                 |             |
| Number of POIs                     | 2 - 3                           | 2.2 (1.2 - 4.1) | <b>0.01</b>                     | 1.6 (0.8 - 3.4) | 0.22                            | 4.2 (2.0 - 9.0) | <b>0</b>    |
|                                    | 4 - 121                         | 1.5 (0.9 - 2.4) | 0.14                            | 1.2 (0.6 - 2.4) | 0.6                             | 2.3 (1.2 - 4.6) | <b>0.01</b> |

For the all crashes outcome, the following variables which had  $p < 0.2$  were included into the model: single lane segments, segments with 4-7 intersections, 1-4 traffic lights and 4–121 POIs, in addition to segments with 2-3 POIs, which had  $p < 0.05$ . For the pedestrian-related crash outcome, segments with bus stops and soft shoulders were the variables which had  $p < 0.2$  and were included into the model, in addition to single lane segments, segments with medians, 8-36 intersections, 1-4 traffic lights, 2-3 and 4-121 POIs, which had  $p < 0.05$  (Table 20).

## REGRESSION MODELLING

### *Final Best Model*

Where, in bivariate analysis, crash rate ratios for association of road safety design features with number of crashes had p values  $<0.2$ , these road safety design features/scores were used in multiple regression models to determine the best final regression model. For the best model, the variables that were found to have statistically significant relationships included: bus stops, soft shoulders, medians, lanes, intersections, traffic lights and POIs in relation to the various crash types (Table 20). These variables were used to arrive at the final best model based on the combinations of variables that resulted in the lowest Akaike Information Criterion (AIC).

Table 21 shows the final model best described by the relationship between crash type, road design features and scores and is summarised as follows:

- Road segments with 2-3 POIs and 1 lane (or 1 way) had statistically significant relationships with segments with the most crashes in total. It was observed that segments with 2-3 POIs had doubled the number of crashes (in total) when compared with segments that had less or more POIs. Single lane road segments had 0.6 more crashes (in total) than segments with multiple lane roads.
- For pedestrian-related crashes, significant relationships were also observed for segments with medians present, segments with 2-3 POIs and segments with more than 3 intersections. Road segments with medians present had 2 times more crashes than those without medians. Segments where there were 2-3 POIs present had about 4 times more crashes than segments with fewer or more POIs. The number of crashes on segments with 4-7 intersections were doubled when compared to segments with lesser intersections, while segments with  $>7$  intersections had 1.2 more crashes than segments with lesser intersections.
- Driver and pedestrian design scores also had statistically significant relationships with pedestrian-related crashes. Segments with lower design scores, which were the more dangerous segments with fewer safety design features, had higher crash rates. Soft shoulders were found to have a borderline statistical relationship with driver-related crashes, where segments with soft shoulders had almost doubled the number of driver-related crashes when compared to segments without soft shoulders.



**Table 21 - Final Best Model for explaining variation in variables modelled.**

| <b>ROAD FEATURE</b>               |                                  | <b>Crash Rate Ratio<br/>(CRR (95% CI))</b> | <b>p-value</b> |
|-----------------------------------|----------------------------------|--|----------------|
| <b>ALL CRASHES</b>                |                                  |  |                |
|                                   | 0 - 1                            | 1.0  | -              |
| POIs                              | 2 - 3                            | 2.2 (1.2 - 4.1)                            | <b>0.01</b>    |
|                                   | 4 - 121                          | 1.5 (0.9 - 2.4)                            | 0.14           |
| Lanes                             | One lane/one-way<br>lane present | 0.6 (0.4 - 1.1)                            | <b>0.00</b>    |
| <b>PEDESTRIAN-RELATED CRASHES</b> |                                  |  |                |
| Median                            | present                          | 2.3 (1.1 - 4.8)                            | <b>0.01</b>    |
|                                   | 0 - 1                            | -  | -              |
| POIs                              | 2 - 3                            | 3.9 (2.0 - 7.6)                            | <b>0.00</b>    |
|                                   | 4 - 121                          | 1.9 (1.0 - 3.7)                            | 0.06           |
|                                   | 0 - 3                            | -  | -              |
| Intersections                     | 4 - 7                            | 2.1 (1.0 - 4.6)                            | <b>0.03</b>    |
|                                   | 8 - 36                           | 1.2 (1.2 - 4.5)                            | <b>0.01</b>    |
| Driver Design Score               |                                  | 0.8 (0.7 - 1.0)                            | <b>0.04</b>    |
| Pedestrian Design Score           |                                  | 1.3 (0.9 - 1.8)                            | <b>0.15</b>    |
| <b>DRIVER-RELATED CRASHES</b>     |                                  |  |                |
| Soft Shoulder                     |                                  | 1.7 (1.0 - 2.9)                            | 0.06           |

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## Chapter 6. Discussion

The overarching goal of this study was to determine the influence of road design features on road crashes, with the view to promote an informed approach to road safety initiatives.

The objectives included:

1. Identifying high crash areas along the North Coast Highway based on crash incidences
2. Classifying road segments that are susceptible to high crash counts based on road design features
3. Determining the main road design features that were found on dangerous crash road segments *and*
4. Assessing the relationships between road design features and dangerous crash road segments

The rest of this Discussion chapter will provide a comparison of the findings with other existing research, strengths and limitations of this study, the importance of this study and road safety implications.

### 6.1 Comparison of this study's findings with other existing research

Road safety studies in Jamaica have focused primarily on identifying areas with high concentrations of crashes, such as Lyew-Ayee (2012) and Hare et al. (2008) and some studies aimed to understand crash victims, for instance Crandon et al. (2009) and Crawford and McGrowder (2009). No publicly accessible studies that assessed the impact of road design features on road crashes have been found for Jamaica, therefore a direct comparison with previous research in Jamaica was not possible. Studies done in other countries however provided ground upon which to compare the findings.

This research corroborated the work done by many other studies that suggest that some road design features influenced how prone a roadway was to crashes. The high crash counts along some NCH road segments was explained given the type of road design features found at these locations, while the existence or absence of some features provided no reasonable explanation as to why a hot spot was determined. It was surprising that most of the design features that were found on the hot spot segments identified by the spatial models did not have the features that were found to

have strong relationships with crashes, based on the regression models. The following outlines the findings from other studies, as it relates to the influence of road design features on crashes.

### **6.1.1 Points of interest**

This study found that segments that had between 2 and 3 POIs experienced a higher occurrence of pedestrian-related crashes and crashes in total. POIs can present very complex and high roadside friction environments, where places such as restaurants, grocery stores and gas stations line a road corridor. These POIs tend to attract pedestrians and traffic which further complicates the road safety dynamics in an area. There are several other studies that had similar findings, such as Priyantha et al. (2006) and Jaworski (2012) who realised from their research that an increase in retail entities led to an increase in pedestrian incidents because land use that increases the population density will lead to an increase in pedestrian traffic. Dumbaugh and Li (2010) go further to indicate that each strip of commercial land use caused a 3% increase in pedestrian incidents, which was attributed to the increased interaction between pedestrians and automobiles. It has been said that increasing population density along a roadway will lead to increased pedestrian crash incidents unless supplementary safety measures in the built environment also come with density increase (Miranda-Moreno et al., 2011).

### **6.1.2 Intersections**

The regression modelling conducted for this research found that road segments with a high number of intersections to experience higher incidents of pedestrian-related crashes. Generally, other studies found that crashes were often times concentrated at intersections, because intersections are the points along the roadway system where traffic movements most frequently conflict with one another, where two or more roads cross each other and turning activities present opportunities for conflicts, resulting in crashes (Choi, 2010). Like this study, other researchers such as Hadi et al. (1995) and Bernardo and Ivan (1998) found a relationship between crashes and intersections, as the presence of more intersections on highways increased crash rates significantly.

Two things were however noticeable, firstly other studies did not necessarily find a relationship between intersections and pedestrian-related crashes, instead just an increase in crashes in general. Secondly, unlike this study, others considered the relationships between crashes and intersections with signalization and those without and also the impact of intersection geometric elements (Agbelie and Roshandeh,

2014; Bagloee and Asadi, 2016; Huang et al., 2017). Generally, intersection crashes were found to increase with signal installation, although the crashes tended to be less severe and led to a shift in crash types, with more rear-end collisions occurring (NCHRP, n.d.).

Zegeer and Bushell (2012) along with others have suggested the conversion of un-signalised intersections to roundabouts as a safety measure to reduce the number of crashes at intersections. This suggestion was supported by SWOV (2009), as roundabouts were considered to be safer than a traditional 3- or 4-arm intersection as there are fewer conflict locations.

### **6.1.3 Medians**

This research found that two times more pedestrian-related crashes were observed on road segments with medians. Generally this finding differed from the majority of other research, where medians were typically seen as being safety features. Harwood et al. (2010) recognised that there was an increased risk inherent in the absence of a median. Iyynam et al. (1997) also found that the presence of a median on a highway contributed positively to road safety. Hoque et al. (2012) considered the high overtaking demand on highways and saw where very little median separation contributed to a high risk of serious head-on crashes. In addition, it has also been stated by Bahar et al. (2008) that raised medians have been found to reduce motor vehicle crashes by 15 percent. As it relates to pedestrians, Hoque et al. (2012) also saw medians as a way to prevent pedestrians from wantonly crossing carriageways, consequently putting their lives and those of other road users at risk.

On the other hand there is also an argument that suggests that while medians are capable of preventing nearly all cross-median collisions, they are fixed objects and their installation can result in collisions that might not otherwise occur (Caltrans, 2012). The results from a study done by Elvik (1995) also found that median barriers caused an increase in crash frequency, but reduced severity. These findings also bring into focus the influence of different types of medians and the materials they are made of, which were not considered for this research.

### **6.1.4 Lanes**

This study found that dangerous road segments along the NCH were associated with roads having only 1 lane in each direction. The results from other studies differ. Strathman et al. (2001) found that holding traffic volume constant, crash frequencies were estimated to increase with the number of lanes. This finding most likely

highlighted the hazards associated with lane changing manoeuvres. Sawalha et al. (2000), Milton and Mannering (1998) and Shankar et al. (1997) also found an increase in crash frequency being related to the increasing number of lanes present along a roadway. According to iRAP (2013), risk is assumed to be greatly reduced if more than one lane is in each direction and goes further to state that risk is assumed to be halved if there are 2-lanes in one direction. More specifically, Bauer and Harwood (2000) found that an increase in the number of lanes was associated with a decrease in motorcycle crashes. Elvik et al. (2009) also found that generally the number of crashes may increase as road lanes increase, but crash severity may decrease.

### **6.1.5 Soft shoulders**

The results from this study, found road segments with soft shoulders had borderline statistical relationship with driver-related crashes, whereby few more crashes occurred on segments where soft shoulders were present. This deviates from other studies that indicate that these features tend to increase road safety. Soft shoulders provide a recovery space for vehicles that run off the carriageway and they also provide an area for defective vehicles to be attended to, which may otherwise cause an obstruction along a roadway. A study by Gan et al. (2005) found that where soft shoulders were installed, that roadway experienced a reduction in certain crashes by up to 75%. Hoque et al. (2012) mentioned that soft shoulders limit the friction between road users who have to share the carriageway as this space also provides recovery and manoeuvring space. It has also been found that creating paved shoulders helped to reduce pedestrian-crash rates (RISER consortium, 2006; Zegeer and Bushell, 2012). A report by Zegeer et al. (1981) also indicated that a paved shoulder that is widened 2 feet on each side of a roadway would reduce crashes by 16%. The width or condition of the soft shoulder was not considered for this research, but this is something that could be explored in future studies.

### **6.1.6 Sidewalks**

Sidewalks provide a designated space for pedestrians to use as they travel along the roadway. This research however did not find a statistically significant relationship between fatal crashes and sidewalks. This finding was somewhat unexpected considering that several studies have shown a considerable association between crashes and this design feature. According to the Federal Highway Administration (1987), roadways without sidewalks are more than twice as likely to have pedestrian crashes as sites with sidewalks on both sides of the street. It goes further to state that vehicle-pedestrian collisions are 1.5 to 2 times more likely to occur on roadways without sidewalks. Up to 88% of crashes where pedestrians were killed while

"walking along the roadway" could have been prevented by providing designated walkways or sidewalks separated from the travel lanes (Federal Highway Administration, 2002). The World Health Organization (2013b) similarly suggests that to improve pedestrian safety several measures, such as sidewalks, need to be utilised.

### **6.1.7 Traffic lights**

Traffic signals facilitate the smooth and orderly flow of people and vehicles by directing traffic movements along segments, especially at intersections. While a statistically significant relationship was observed between crashes and intersections, this was not the case for traffic lights. This finding is contrary to the results from several other studies, for instance Kennedy et al. (1998) found that on average the presence of traffic lights reduced collisions by up to 30% at some junctions. These design features were even found to reduce frequency and severity of certain types of crashes, especially right-angle collisions. Research by Datta (1991) and Agent (1988) also found that the presence of traffic signals reduced the number of crashes. Corben (1989) went further to specify that traffic signals were found to be effective in reducing crashes involving vehicles on intersecting roads. Some researchers have even posited that intersections controlled by roundabouts, instead of traffic lights, generally exhibit higher safety performance (Elivik, 2017; Ambros and Janoška, 2015; Gross et al., 2013; Lord et al., 2007).

### **6.1.8 Roadside barriers**

Roadside barriers are typically installed to prevent errant vehicles from colliding with hazardous roadside objects, such as cliffs, bodies of water, poles and culverts, thereby making them features that promote road safety. This study did not find any relationship between crashes and the location of roadside barriers. Strathman et al. (2001) however found these features to have a positive effect on all highway types. Elvik (1995) also found that guardrails along the edge of the road and crash cushions reduced both the accident rate and accident severity. For the most part, traffic barriers were found to reduce the severity of crashes that occur when a vehicle departs from the roadway.

Shankar et al. (1997), however, found significant increases in crash frequency for segments with roadside walls. Generally, it has been found that in some cases these features (for example rigid concrete barriers) can constitute a hazard as they become objects that can be struck by vehicles, especially motorcycles, causing greater crash

severity and crash frequency. Collision with a roadside barrier may result in a less severe collision than with an unshielded object, but consideration must be given to the possibility of a rebounding vehicle entering the opposing traffic lanes, which may result in an even more severe crash.

#### **6.1.9 Pedestrian crossings**

According to this study, pedestrian crossings did not have a strong relationship with crashes, which differs from the majority of similar studies where pedestrian crossings have been regarded worldwide as being a road safety feature as it helps pedestrians to cross roads safely. In many instances, they were absent along the NCH and pedestrians were left to wantonly cross the roadway. Several studies found a strong relationship between the lack of pedestrian crossings and crashes, for instance Schuurman et al. (2009) realised that the absence of marked and signalized crosswalks was associated with an increase in the risk of collisions between pedestrians and vehicles. Other studies focused on a range of other treatments along with pedestrian crossings that have assisted with crossing a roadway safely, such as the use of signalised pedestrian crossings and yield pavement markings. Koepsell et al. (2002) also found that well-marked crosswalks with a pedestrian-controlled signal can reduce pedestrian-vehicle conflicts. Huybers et al. (2004) also saw a reduction in pedestrian/motor vehicle conflicts when "yield here to pedestrians" signs and advance yield pavement markings were utilised.

Pedestrian crossings may however be considered inappropriate for roads carrying large volumes of traffic, such as the NCH and instead other safety features, such as overhead bridges should be constructed. Other studies have also shown opposite results, for instance Sawalha et al. (2000) saw an increase in crash frequency being related to the presence of crosswalks.

#### **6.1.10 Posted speed limits**

Speed limit signs are posted in an effort to control drivers' speed and consequently to prevent speeding. It is generally thought that driving at high speeds may lead to a higher crash rate, also with a greater likelihood of a severer outcome (Aarts & van Schagen, 2006). It is assumed that when motorists drive at the posted speed limit, this will prevent crashes and reduce the severity of injuries. Several studies support this notion, for instance Taylor et al. (2000) who states that the frequency of accidents increases with the speed of traffic, and the higher the speed the more rapidly does accident frequency rise.



This study, however, along with a few others have found that the posted speed limit or the speed at which people drive has no effect or has a statistically insignificant relationship to the occurrence of crashes. For instance, Kockelman and Ma (2007) found no statistically discernible relationship between the fatality rate and average speed. Garber and Gadiraju (1989) noted that drivers tend to drive at increasing speeds as the road conditions improve, regardless of the posted speed limit, and that accident rates do not necessarily increase with an increase in average speed but do increase with an increase in speed variance. It was observed that most motorists along the NCH did not observe the speed limits posted. The roadway is in relatively good condition and as such persons were seen exceeding the speed limits especially along the very straight segments, slowing down only if they observed a police presence or if they encountered traffic.

#### **6.1.11 Bus stops**

Safety for pedestrians are enhanced by the placement of bus stops, as these features prevent the haphazard boarding and alighting from public passenger vehicles, especially in hazardous locations, such as intersections. Bus stops are sometimes placed in a designated area, such as a lay-by, preventing the obstruction of the regular flow of traffic and reducing the need for dangerous manoeuvres by other vehicles that may need to pass. Despite, however, the safety benefit of bus stops, there are studies that found a strong correlation between bus stops and crashes. Walgren (1998) found that in Seattle, 89% of high crash locations were within 150 ft of a bus stop. This correlation between bus stops and pedestrian crashes may have been due to visual impairments caused by buses that stopped to allow pedestrians to cross the road. Truong and Somenahalli (2011) found that issues of pedestrian-vehicle crashes and bus stop safety are, in fact, raised by the lack of appropriate pedestrian facilities and high turning movements at the sites. Similarly, the findings by Hess et al. (2004) show a positive relationship between bus stop usage and pedestrian accident locations and suggest that bus stops with high numbers of bus riders may need to accommodate people walking safely along and across the roadway so that crash counts are reduced. Unlike these studies, this research did not observe a strong relationship between crash types and bus stop locations.

#### **6.1.12 Summary**

Most of the findings from this research were unexpected, as only four of eleven design features were found to have a statistically significant relationship with the different crash types, these included the presence of single lane roads and medians and a high number of intersections and POIs. Some of the other design features, such

as pedestrian crossings and sidewalks have been found by other studies to have a positive impact on road safety, more specifically for reducing crashes. Some of the unexpected results may be explained by the homeostasis theory put forward by Wilde (1989). He posits that people's perception of a hazard tends to cause an adjustment to their behaviour. This is further explained with the example where the presence of wide soft shoulders and lanes would encourage safety as more space is available in the case of avoiding a crash or recovering from a crash. In these instances, however, some motorists counteract these environments that seem safer by driving faster, tailgating and drive less cautiously. This behaviour diminishes the improvement in road safety that is expected given the safety features that were implemented. One may contend therefore that based on the risk homeostasis theory the results of this study may reflect an adjustment in motorist and pedestrian behaviour along the NCH based on their reduced perception of how dangerous a road segment was. Observations of road users along the NCH also revealed dangerous road behaviour which may have contributed significantly to the number of crashes, even more so than the impact of the highway's road design. Road user behaviour was improved when the police was present, by way of spot checks, which suggest that with continued police surveillance bad road behaviour could be curtailed along this highway.

## **6.2 Strengths and limitations of the study**

This study offered a new dimension to how road safety was analysed in Jamaica, being the first of its kind to examine the relationship between road design features and fatal crashes. The detailed inventory of road design features along the North Coast Highway and the spatial and statistical analyses to assess for relationships were the main strengths of this study. There were, however, several limitations that are worthy of mention that influenced the accuracy and comprehensiveness of the analyses conducted. The researcher made efforts to address some of these issues, however uncontrollably some remained.

### **6.2.1 Identifying high crash areas along the highway based on crash incidences**

#### **AVAILABILITY OF CRASH DATA**

Ideally, an analysis of both fatal and non-fatal crashes would provide greater understanding of the road safety problem along the North Coast Highway. Based on data availability, however, only fatal crashes were studied, which according to Lyew-Ayee (2012) accounts for only 3% of all crashes in Jamaica. This focus on only fatal

crashes therefore rendered this research incomplete in truly assessing the crash problem along the NCH.

#### CRASH LOCATION ACCURACY

This study was not immune to the inclusion of inaccurate or vague crash locations based on the data provided by the police. Due care was taken to correctly map the crash locations provided, however with the lack of specific location information (such as GPS coordinates or detailed addresses), many locations were not mapped with pinpoint accuracy and were instead placed as close to the reference point mentioned in the crash report. It was also noticed that the crash data provided from the JCF did not in all instances indicate on which side of the highway the crash occurred. This information can be useful and should be recorded for all crashes. Other studies, for instance Austin (1995) found that about 20% of crash locations may be incorrectly mapped due to the provision of inaccurate location information. Inaccurately mapped crash locations can negatively affect a study's findings. Studies benefit from GPS mapped crash locations being provided from the police, who visit the scenes of crashes, therefore providing data with greater location accuracy and subsequently enabling better analysis (Graettinger et al., 2001). In the absence of GPS units, the importance of recording detailed location information for crashes should be reinforced among police officers, so that more crashes can be mapped from the information provided and with greater accuracy.

#### SEGMENTATION OF ROADWAY

Like Johnson (2012), this study used equal increments to segment the entire NCH as a way to better provide micro-scale information. Using a fixed length was also utilised in an effort to prevent inequality in how many crashes were counted along the highway, where the roadway could have very long and short segments based on other criteria for segmentation. The choice to use fixed length segments may be considered disadvantageous by some researchers as it causes within-segment variation of road geometry and design features. The more criteria used to determine road segment lengths will result in greater control over extraneous factors that could cause a potential bias based on the estimated effects of road design on crash frequency (Strathman et al., 2001). There is however no universally accepted optimal segment length for analysis (Harwood et al., 2010). There may be some benefit to explore the determination of segments by road features, where varying road segment lengths would be used instead to examine a different perspective by which to analyse how dangerous the road segments along the NCH are. Another approach could include the

segmentation of the roadway based on morphology, allowing the shape of the road to dictate how the road is divided.

#### INFLUENCE OF TIME ON THE STUDY

The road design features used were captured in 2015 and may not reflect the exact conditions found along the NCH during the study period (2010 - 2014). With time, features along the corridor may have changed as new developments emerged. Thus the results from this study may not be entirely accurate in describing the situation along each segment throughout the study period.

In addition this study did not consider the temporal distribution of crashes, that is, distinguishing crash hot spots by the time of day or simply, day versus night or year by year. Stakleff (2015) recognised that hot spots are often times analysed as if all crashes occurred at the same time. Spatio-temporal hot spots however are more useful as crashes will differ over time and space.

#### NON-INCLUSION OF TRAFFIC VOLUME DATA

Upon review of the national traffic volume dataset that was available, a decision was made to not include it in this study. The main problem stemmed from the traffic information not being continuous along the entire stretch of the North Coast Highway and there was temporal mismatch of the data. The traffic data was available for time periods prior, during and after the 5-year study period chosen. Using this data may have biased the results as traffic volumes varied based on the year the data was captured. The exclusion of traffic volume and pedestrian volume data in the analysis may also have influenced the results as some studies, such as Strathman et al. (2001) found that crash frequencies increased with traffic volume. One believes this study could have benefitted from the calculation of crash rates, which incorporate traffic (and pedestrian) volumes to decipher the factors that cause crashes or make roads dangerous. In lieu, however, of not having reliable traffic data, crash counts were used.

#### HISTORICAL AND PREDICTIVE MODELLING OF CRASH DATA

This study focused on the historical modelling of crash locations which some may argue is a reactive approach as opposed to a proactive one (Stakleff, 2015). Incorporating a predictive approach, using spatio-temporal data about crashes and the environment in which they occur may provide an innovative approach to understanding the pattern of crash distribution.

#### THE USE OF EUCLIDEAN DISTANCE

By selecting the Euclidean Distance as the *Distance Method* in the hot spot models may have introduced biases in the results. In some sections, the geometry of the roadway may have distorted the true distance to neighbouring road segments when using the Euclidean Distance. On the other hand, the use of Network distance (or Manhattan Distance) may have provided more accurate results, as the distances between segments would have followed the roadway.

For this research, crashes along a single highway way were studied instead of looking at crashes over a more complete road network. Calculating clusters of crashes based on neighbouring road segments, to the left or right only, does not factor in the influence of crashes on adjoining roads and this may introduce biases and affect the results.

#### **6.2.2 Classifying road segments that are susceptible to high crash counts based on road design features**

##### HIGHWAY DESIGN FEATURES CHOSEN

Another limitation of this study was that it did not consider the full range of highway design attributes. Only eleven were considered, while many other studies have looked at more geometric and road conditions, such as road curvature, incline, road surface condition and soft shoulder width. Strathman et al. (2001) suggested that a cross sectional study such as this one, may suffer from potential “omitted variable” specification bias as all the possible highway design features were not studied. Future studies would benefit from the collection of more detailed data, for instance knowing the type of median or material from which it was made could prove useful in generating more accurate models for determining relationships between design features and crashes. The additional design features were not incorporated in this study due to a lack of resources, notably measuring equipment, time, money and the expertise required to capture particular datasets, since this data does not already exist.

This study considered all design features as being equal in weight, that is, all features had the same impact on whether crashes occurred or not. It may prove useful to conduct the Weighted Sum Analysis with varying weights for the design features based on the statistical associations identified from the preliminary results. This recalculation may identify other road segments that are considered safe or dangerous. This may also explain the contradictions found in the research findings.

One agrees with Strathman et al. (2001) in that it is not possible to separate the effect of road design features from other crash determinants, for instance environmental conditions along a roadway or driver and pedestrian characteristics. Like Hauer (1997) one also acknowledges that in reality many other factors aside from road design features, including conditions that change naturally over time (traffic, weather and road user behaviour) could be associated with the pattern of crash counts.

### **6.2.3 Assessing the relationships between road design features and dangerous crash road segments**

#### **USING CRASH COUNTS VERSUS HOT SPOT RESULTS**

For future studies, one could analyse the associations between crashes and road design features by using the actual calculated values from the hot spot models (z-score) instead of crash counts. This would allow for the incorporation of true crash hot spot data into the regression models. This research used a simpler approach by using only the crash counts and safety scores to determine associations between crashes and design features.

## **6.3 Road safety implications and importance of study restated**

There is a need to reduce all road crashes across Jamaica, not only fatalities. Efforts have been made by international, national and private entities to do so; Jamaica however still struggles to maintain a steady decrease in the number of crashes. One acknowledges that death, injury and loss from road crashes are multidimensional, spanning the five pillars of road safety: road safety management, safer roads and mobility, safer vehicles, safer road users and post-crash response. A study like this provides an opportunity to better understand one aspect of the problem of reducing crashes, by focusing on safer road design.

When a roadway is constructed it is expected to conform to international standards and be maintained so that these standards are upheld. A part of that maintenance process should entail an evaluation of the effectiveness of the road's safety design mechanisms. It is not sufficient to only identify hot spots based on crashes, one needs to be able to also identify what features exist along these dangerous crash segments. This research, though limited in its scope of design features studied, was able to identify crash hot spots along with the presence and absence of certain road design features that contributed to the high number of crashes observed. This kind of information should provide the basis for determining how effective are the road safety

mechanisms, and where to implement road safety plans. A roadway such as the NCH is an important one for Jamaica, as this major corridor connects several parishes in the north that spans the major tourism belt on the island. As such, the necessary resources should be sought to increase the safety of this roadway along with the many other major roads that connect the island. The results from this study can inform stakeholders as to where to target their resources and what issues need to be addressed at these locations. This makes for better use of funds as specific areas are remedied as opposed to a blanket approach to a road safety.

Jamaica should keep at pace with the methods of improving road safety utilised in other countries, such as the use of traffic enforcement cameras and even the more traditional approaches such as delineators and rumble strips. The effectiveness, however, of these devices in reducing crashes is dependent on where they are deployed. The local entities responsible for maintaining and evaluating the NCH should find a study like this useful, if even as a starting point in a data limited country, as a means of identifying specific locations that may warrant specific types of interventions. An evidence-based approach to identifying problems and finding solutions is recommended to ensure resources are utilised efficiently, for instance, this study indicated that segments with several POIs and intersections experienced more pedestrian-related crashes. Armed with this type of information, one may implement solutions that will regulate these areas so they are safer for road users.

The Decade of Action for road safety (2011 – 2020) which was proclaimed by the United Nations in 2010 is fast coming to an end and Jamaica needs to take the necessary steps to stabilise and reduce road fatalities one road segment at a time. It is hoped that this research presents a method, that may be adopted as is or improved upon, and consequently be employed on other roads across Jamaica so improved road safety can be achieved.

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## Chapter 7. Conclusion

This study has investigated the spatial and statistical relationship between crash activity and roadway design attributes along the North Coast Highway. This approach was used to ultimately identify dangerous crash road segments that would require attention by the relevant stakeholders in making them safer.

The spatial analyses utilised the Anselin Local Moran's I and Getis-Ord  $G_i^*$  models to identify crash hot spots and the Weighted Sum tool was used to assign scores to segments that were considered to be very dangerous based on the presence or absence of road design features. The statistical approach included the use of the zero-inflated negative binomial distribution model to determine which design features were correlated with crash activity. The results from each method chosen were compared and assessed to identify the truly dangerous segments. Each method produced different results, however one was able to identify four of eleven design attributes that were strongly related to the different crash types. These road design features included POIs, lanes (single lane), medians and intersections. A few of the findings from this research were found to be consistent with other studies.

Some of the results of this study were unexpected given the contrasting results seen for similar research studies. In particular, the lack of statistically significant relationships between the various crash types and sidewalks, pedestrian crossings, soft shoulders, medians and intersections defied expectations of the researcher, given the results from many other studies that proved otherwise. On the other hand, the relationships observed between the presence of places of interest and pedestrian-related crashes stood out as an expected outcome from the study. One may consider, however, these results as an indication that factors besides road design features may have contributed to the occurrence of crashes along the NCH. Further studies to address the other 4 pillars of road safety are recommended to better understand the true cause of crashes along the NCH.

This research demonstrates how the spatial analysis of data can be used to remove bias that may be involved in determining which roadways should receive road safety initiatives. The research findings provide a foundation for extending similar research. It is necessary to conduct further research to better understand the various factors that may cause high crash counts along the highway and also analyze the effectiveness of road features in reducing rates of crash fatalities in areas highlighted in this study. Specifically, more design features can be assessed in relation to crashes and a

comparative study done to assess the impact of road design changes - before and after studies.

The lessons learnt from this research will hopefully serve as a platform upon which further studies of this nature can be built upon. Issues pertaining to data availability and accuracy, for instance the lack of reliable traffic and pedestrian volume data, should be addressed in order to produce relevant and useful bodies of work. With the limitations addressed, one can see this type of research being applied to other important local roadways on the island and also overseas.

The relevant stakeholders should find this and future studies of this nature useful in understanding the road safety problem in Jamaica. A study like this is ultimately geared towards informing the decision-making process, in particular determining what engineering measures are required to reduce crashes in hot spot areas. One agrees with the approach suggested by Hoque et al. (2012) which entails a reactive and proactive approach, where the former refers to the treatment of hazardous locations and the latter to perform road safety audits, inspections and assessments periodically to account for any shifts in the road safety situation in an area. This research provides the impetus and concrete evidence to warrant a reactive approach with a repeat of a similar study in the future to demonstrate a proactive approach to support the UN Decade of Action for road safety programme.

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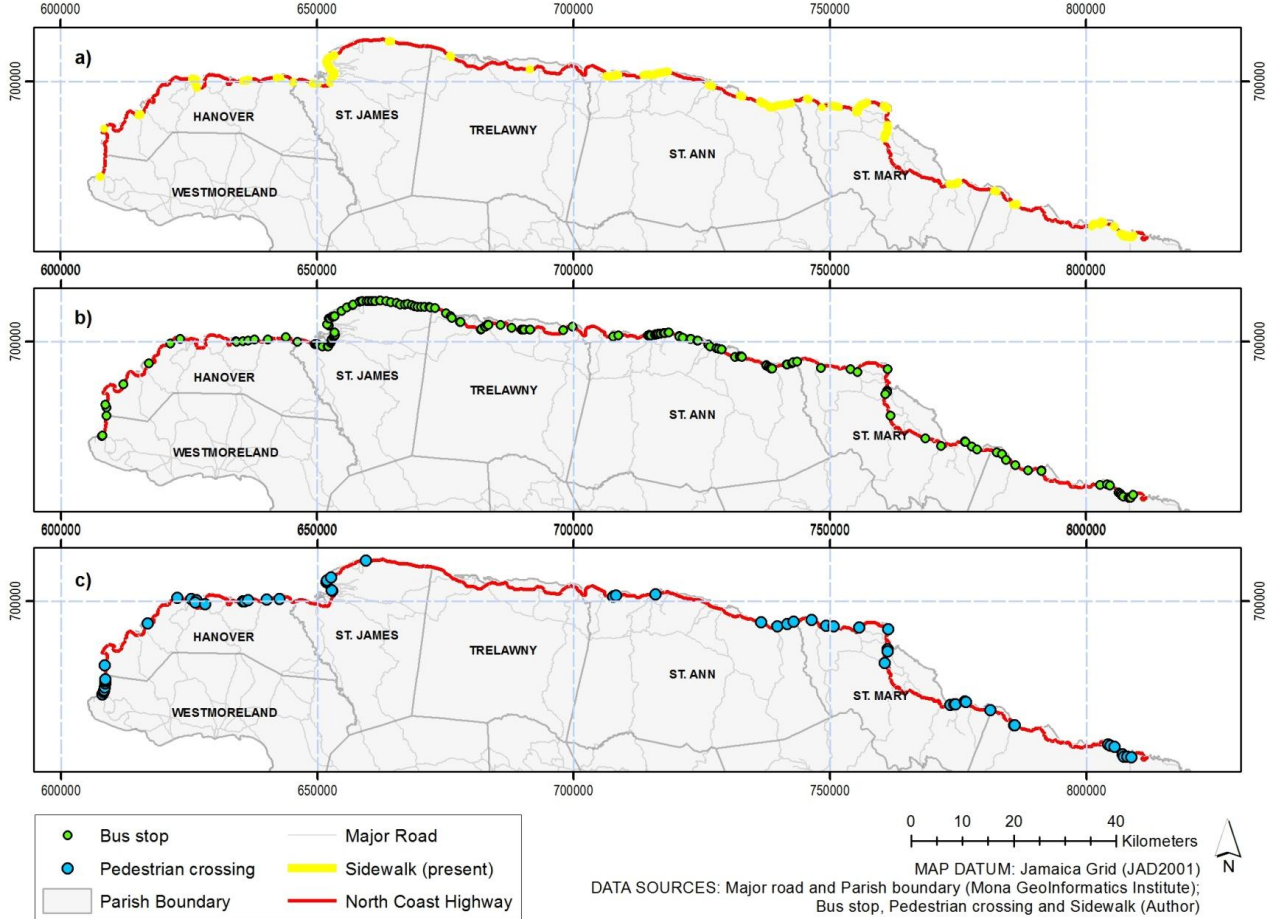
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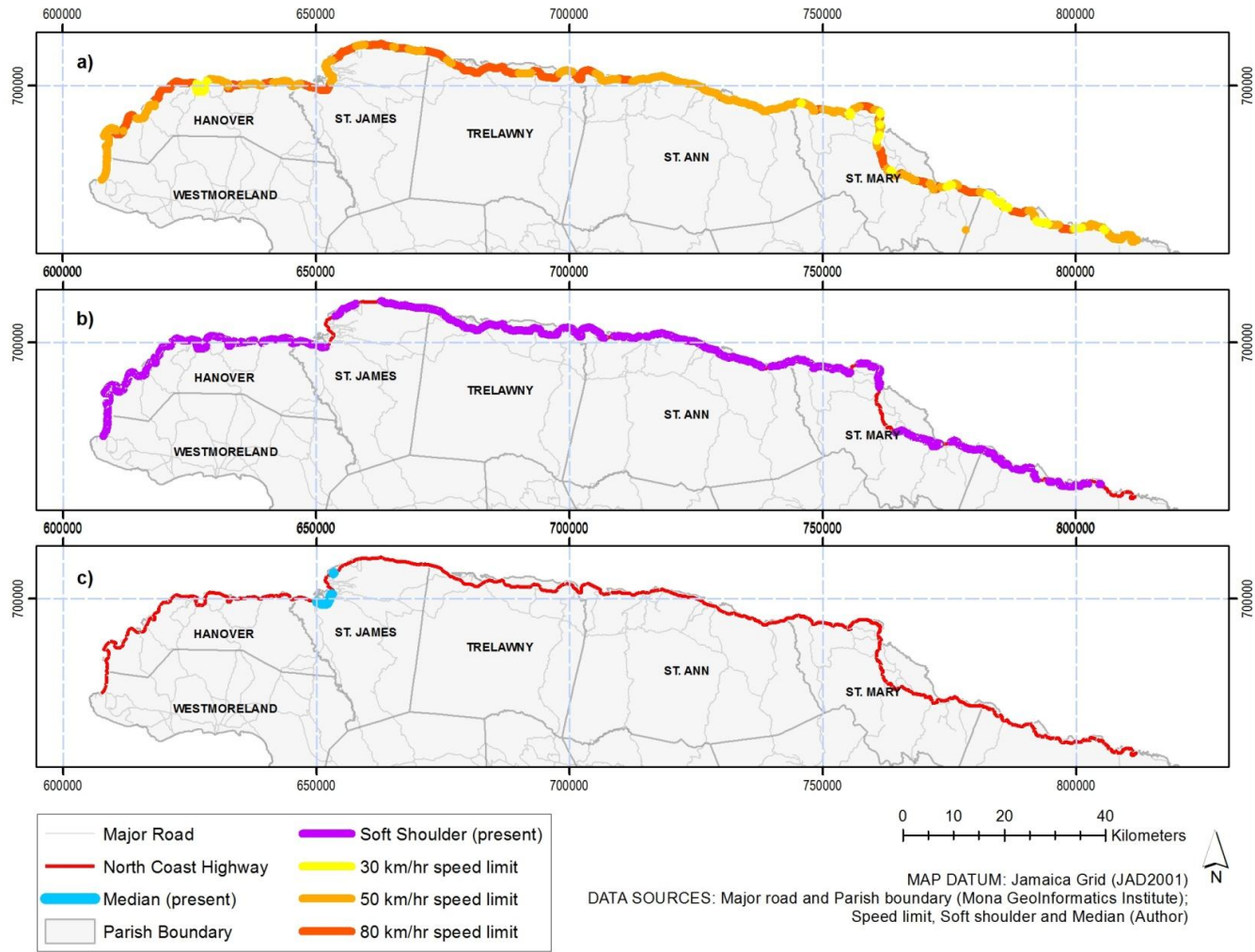
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# Appendices

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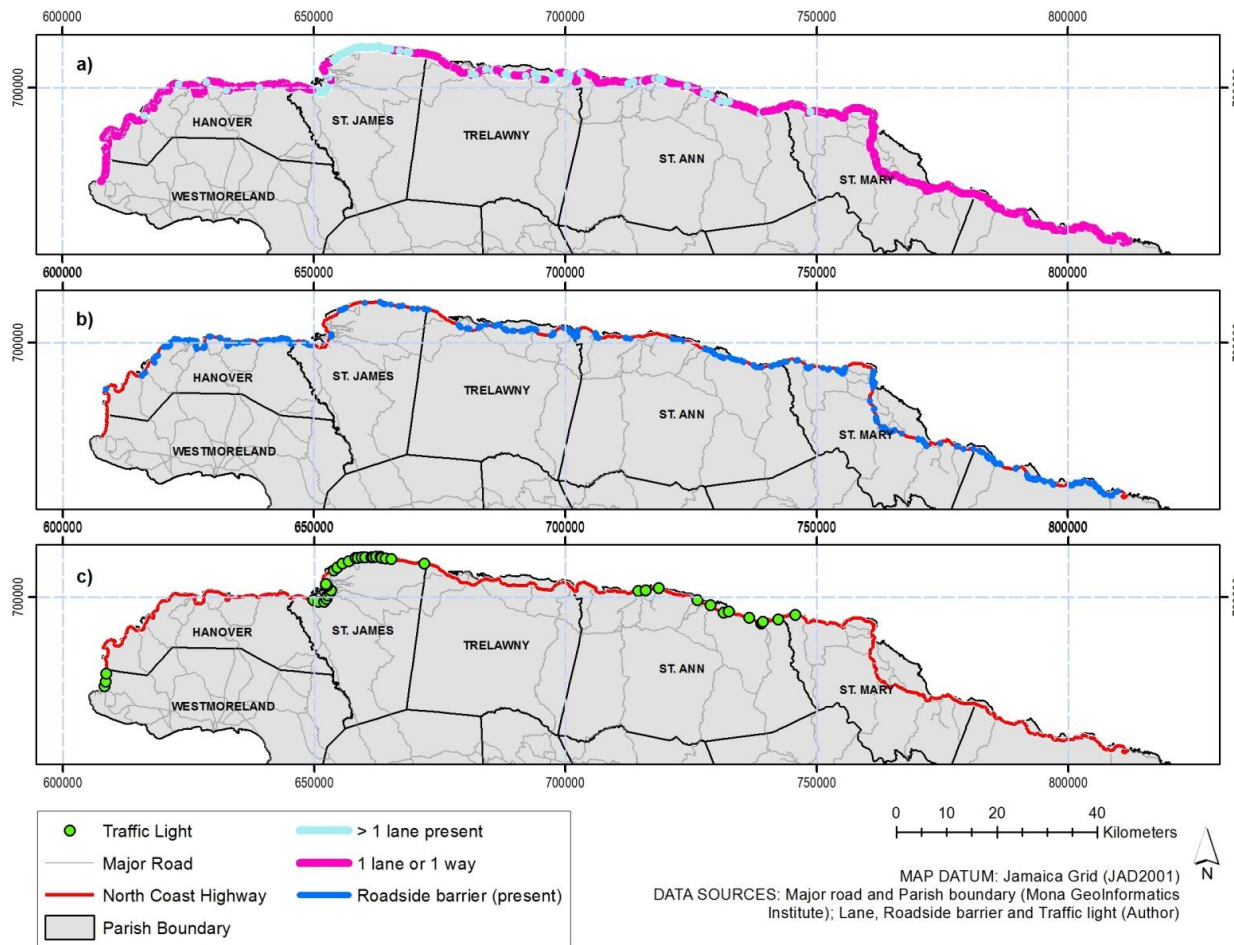


**Appendix 1. Locations of pedestrian-related road design features, with the following features present: a) sidewalks, b) bus stops and c) pedestrian crossings.**

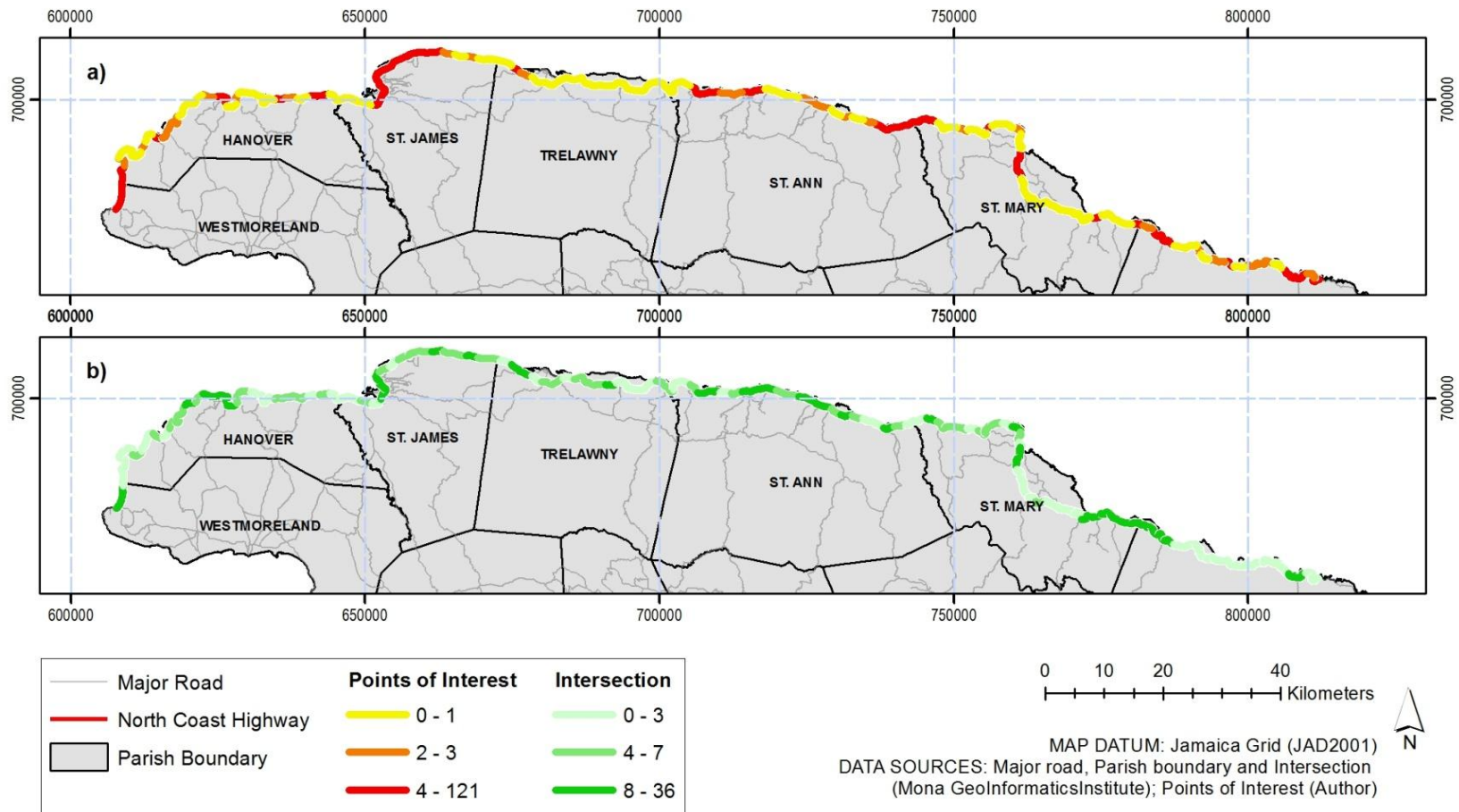


Appendix 2. Locations of driver-related road design features, with the following features present: a) speed limits, b) soft shoulders and c) medians.

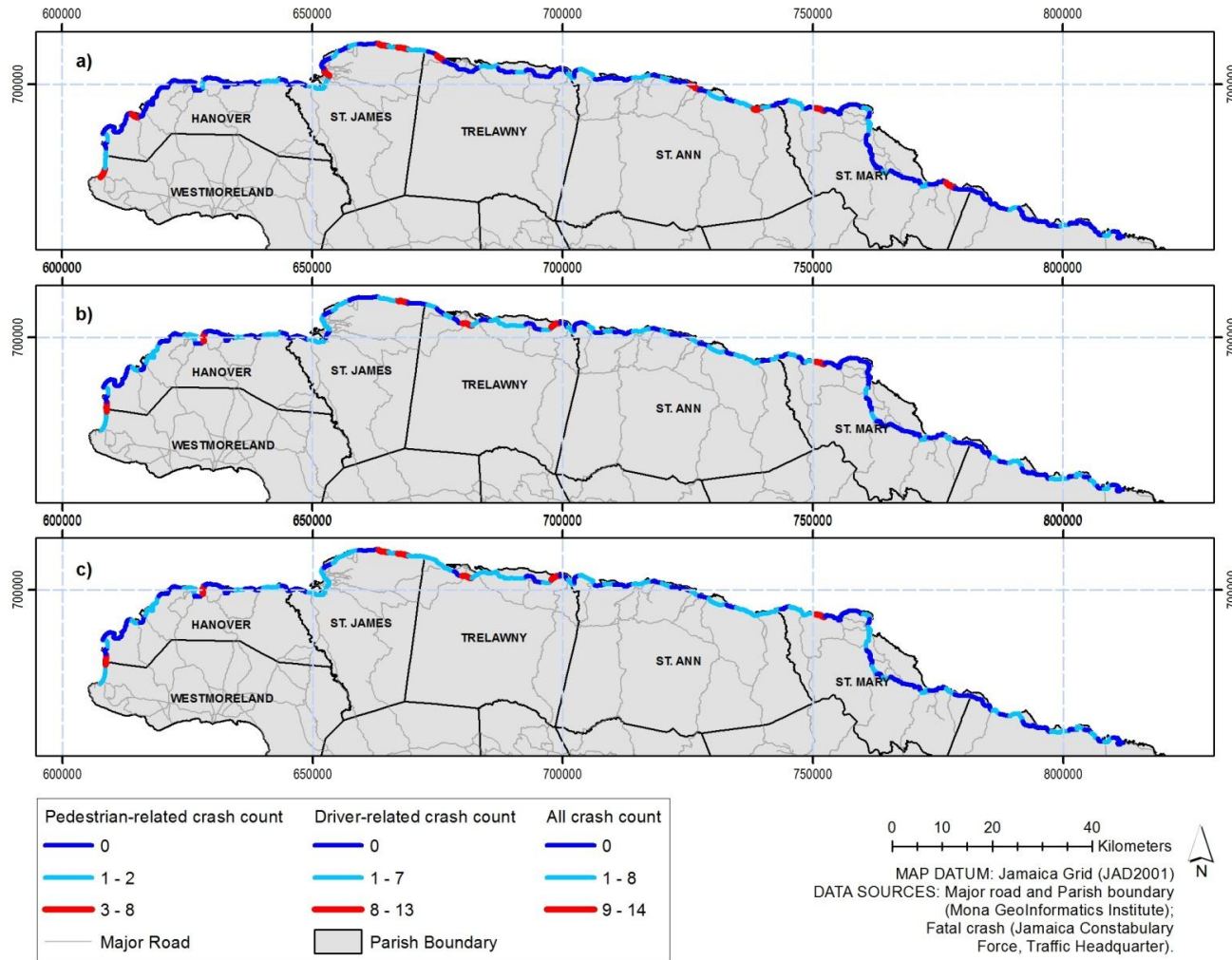




**Appendix 3. Locations of driver-related road design features, with the following features present: a) number of lanes, b) roadside barriers and c) traffic lights.**



**Appendix 4. Locations of driver-related road design features: a) points of interest count by road segment and b) intersection count by road segment.**



Appendix 5. Crash count by crash type: a) pedestrian-related crashes, b) driver-related crashes and c) all crash type.

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