

**Planning for Crime:
Exploring the Connections between Urban
Space, Development and Patterns of Crime**

by

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Abstract

The built urban environment influences the spatial distribution of criminal activity. Common activity nodes are clustered in specific urban locales, drawing individuals from within and beyond municipal boundaries for legitimate, daily needs. These key nodes are connected via the street network, and are typically concentrated along major routes. Such built urban features form the origins, destinations, and pathways used by residents and visitors alike, thereby facilitating the intersection of potential offenders and targets in both space and time. Crime events have repeatedly been found to concentrate at and near key features within the built environment, though the specific patterns of clustering can vary by urban locale and urban feature. This compilation of three inter-related studies explores the connections between crime and the physical landscape within a relatively under-studied research environment: mid-sized suburban municipalities. The first study contributes a multi-scale locally based exploration of the land use and road types associated with disproportionate crime rates. These results direct the second investigation, which analyses the areas beyond each local attractor to identify whether crime concentrates in these micro-spaces as well. The final contribution applies these locally-identified relationships within a prototype modeling framework to investigate the potential impact that urban growth and development may have on both crime, and the need for police resourcing. The collective results from this work emphasize the importance of locally-based, micro-scale analysis when exploring connections between crime and the urban environment. It further highlights the need for consideration of these results within planning and policy environments, and proposes a preliminary approach to facilitate this connection.

Keywords: Crime; Land Use; Spatial Analysis; Built Environment; Police Resourcing

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You are my focus, my distraction, my drive and my pause.
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Chapter 1.

Introduction

Criminal activity is unevenly distributed across urban environments, simultaneously constrained and supported by both the built urban structure, and the routine movements of the population. Grounded within the field of environmental criminology, three primary theoretical frameworks have discussed the complex connections between urban form and criminal activity, namely Cohen and Felson's routine activities approach, and the Brantingham's geometry of crime and pattern theories. The routine activities approach posits that in order for a criminal event to occur, a motivated offender and suitable target must intersect in time and space, in the absence of a capable guardian (Cohen and Felson, 1979). This intersection is facilitated by the normal, every-day movements of urban residents; these movement patterns are, in turn, shaped by the built urban form (Cohen and Felson, 1979; Brantingham and Brantingham, 1981). Individual routines are predictable, and largely overlap with the routine patterns of other urban residents. This results in the development of a common, shared activity space, within which crime events concentrate in predictable locations, and at predictable times (Brantingham and Brantingham, 1993c).

A strong and growing body of research has applied, tested and extended these theories to explore the impacts that land use, streets, and neighbourhood structure have on the spatial patterns of crime. Such efforts have provided substantial insight into the types of urban features that are typically associated with disproportionate volumes of criminal activity. Findings frequently emphasize the criminogenic nature of liquor serving establishments, shopping areas, schools, parks, key transit nodes, and major travel routes, to name just a few (Beavon et al., 1994; Brantingham and Brantingham, 1995; Kinney et al., 2008; McCord and Ratcliffe, 2009; Groff, 2011, 2014; Groff and McCord, 2012; Bowers, 2013; Frank et al., 2013; Curman et al., 2015). Further extensions of such research have

considered the wider spatial impact of key urban facilities, identifying that crimes often cluster in the areas surrounding criminogenic features as well (Brantingham and Brantingham, 1994; Kinney, 1999; Rengert et al., 2000, 2005; Johnson and Bowers, 2010; Groff, 2011; Ratcliffe, 2012; Groff and Lockwood, 2014).

A number of common themes emerge from within the focused body of research exploring crime within the context of built urban form. First, while consistencies exist across a number of urban areas, key environmental features can have different associations with crime patterns in different urban environments (Frank et al., 2013; Snowden and Pridemore, 2013; Song et al., 2016; Charron et al., 2008). Locally-based analysis is important in order to determine if the facility types associated with high crime concentrations in one city are also linked to crime hotspots in another. Second, just as there are unique patterns across different urban settings, there are also differences *within* urban settings (Brantingham et al., 1976; Harries, 2005; Kinney et al., 2008; Groff et al., 2010; Bowers, 2013; Groff and Lockwood, 2014). Similar environmental features may not be equally criminogenic, making multi-scale analysis important in order to identify the key sites associated with local crime. Lastly, these efforts to develop a nuanced understanding of the local level connections between crime and the urban environment have important planning and policy implications. Such relationships can provide insight into the most appropriate locations and the most fitting spatial scale for crime reduction and prevention initiatives, and can be used to inform planning and resourcing decisions at the municipal level (Brantingham and Brantingham, 1995; Groff, 2011; Ratcliffe, 2012; Haberman et al., 2013; Groff and Lockwood, 2014). However, while such findings have clear potential value to planners and policy makers alike, there remains a shortage of research that seeks to make these relationships more accessible to key stakeholders who may be able to operationalize the results (Brantingham and Brantingham, 1995; Paulsen, 2012).

These common themes highlight a need for continued research that explores crime within the context of the built environment. Further investigations are needed that focus on a variety of environmental features, in a variety of urban research settings, in order to determine how the connections between urban features and local crime patterns vary across municipalities. Guided by previous research, studies should explore crime patterns at multiple levels of analysis, and should include consideration of the areas surrounding

key environmental features. Lastly, local research should be both accessible and actionable: there continues to be a need to connect such findings with planning and policy stakeholders. This compilation seeks to address these existing research needs through a series of related studies that explore the local connections between crime and the built environment.

Three linked studies, presented below, contribute to the existing body of research. These studies seek to expand the research area by focusing on two mid-sized suburban municipalities, located within a growing metropolitan region. The first contribution, provided in Chapter 2, presents a multi-scale analysis of the local connections between the built environment and crime. This work identifies the physical features that are associated with a disproportionate amount of crime at the local level, and emphasizes the importance of locally-based analysis at multiple spatial scales. The key local crime attractors identified within this initial contribution are used to guide subsequent research, presented in Chapter 3. This study explores the wider spatial impact of the locally-identified crime attractors, investigating the areas beyond the attractor site itself to determine how crime events concentrate within these micro-spaces. Chapter 4 shifts the focus from analysis to application, by proposing the development of a modeling tool, informed by the locally-based relationships uncovered within the two previous studies. This tool presents a preliminary framework to explore the potential crime and resourcing implications associated with urban development. The final chapter discusses the individual and joint contributions of each study, and outlines areas for continued research.

1.1. Background: Situating the research

Criminal events are inseparable from the environments in which they occur. The origins, pathways, and destinations of individuals are shaped by their physical surroundings. In urban environments, in particular, the built physical form of the city encourages (and often restricts) movement along specific, planned pathways, which connect the origin and destination points – residences, workplaces, schools, shopping and entertainment areas, to name a few (Brantingham and Brantingham, 1981, 1991). As urban structure shapes patterns of movement, so too does it shape patterns of criminal activity (Brantingham and Brantingham, 1995). Changes to the built urban environments,

such as urban development, growth, decline or gentrification, are designed to shift the movement within and use of urban spaces; as such, these processes may have considerable impacts on the distribution of criminal activity.

The Canadian population is growing, with most of this growth centred in urban environments. At the time of the most recent census, nearly 70% of the national population resided within one of the country's census metropolitan areas (CMAs)¹, with this number growing at a higher rate than the overall national average (Statistics Canada, 2012b). This concentrated growth can be further focused on the periphery of Canadian CMAs, within suburban environments (Turcotte, 2001; Statistics Canada, 2012a; Gordon and Janzen, 2013). Vancouver, British Columbia, is the third-largest CMA in Canada, and is experiencing a considerable growth rate of 9.3%. While this overall growth exceeds the national rate (5.9%), this change is being driven by the suburban municipalities surrounding the city of Vancouver; the CMA core itself is growing at a much slower pace (2011 figures, provided by Statistics Canada, 2012a).

Recognizing the considerable population increases and development pressures within this dynamic urban area, Metro Vancouver has implemented a regional growth strategy. This plan has facilitated the development of a number of smaller urban centres, located outside of the CMA core, which are designed to act as downtown nodes to serve their surrounding suburban communities (Metro Vancouver, 2011). These town centres are intended to contain a mix of land uses, including shopping, services, business centres and mass transportation nodes, connecting each centre with each other, as well as to the CMA core. One such town centre is located in Coquitlam, British Columbia (Metro Vancouver, 2011; City of Coquitlam, 2008).

Coquitlam is located 15 kilometers east of the city of Vancouver. With a population of over 125,000, the city is growing at a rate that more than doubles the Vancouver core itself (Statistics Canada, 2012a) While a number of Coquitlam's neighbourhoods are growing and experiencing considerable urban development, the city centre neighbourhood

¹ Census metropolitan areas (CMAs), as defined by Statistics Canada, are one or more municipalities with a total population exceeding 100,000 residents, grouped around an urban core. The urban core must have a population of at least 50,000 residents. At the time of the last census, there were 33 CMAs (Statistics Canada, 2012b).

is identified at a regional level as an important destination for residents of the wider metropolitan area. The city centre houses a regional shopping centre and a number of community shopping centres, a large college campus, a redeveloped city hall, a library, a police station and a community cultural centre (City of Coquitlam, 2008). In addition, the area development plans include three stops on the new regional rapid transit network (the Evergreen line), slated to become operational in early 2017. The ongoing development within this compact neighbourhood continues to dramatically alter the area, drawing a diverse mix of residents and visitors to the variety of destinations concentrated here.

Given the rapid and concentrated development focused in and around Coquitlam, this area provides a compelling case study within which to explore the local relationships between crime and the built urban environment. While decades of existing research have identified the connections between environmental features and crime, there is a limited amount of research centred on suburban communities (see for example, Song et al., 2013, 2016; Frank et al., 2013; Kinney et al., 2008; Rengert et al., 2000, 2005; Brantingham and Brantingham, 1994). Of the existing studies exploring such locales, there is a repeated emphasis on the importance of locally-based analysis, highlighted by the unique relationships between crime and urban features identified in the results (Song et al., 2016; Frank et al., 2013; Kinney et al., 2008; Brantingham and Brantingham, 1994). Given the rapid development and population growth within and surrounding Coquitlam, establishing a nuanced understanding of the locally-based connections between crime and urban structure is both important and timely.

Coquitlam and neighbouring Port Coquitlam (as well as several surrounding communities) are served by the same municipal police force, the Coquitlam Detachment of the Royal Canadian Mounted Police (RCMP)². Through a collaboration with the RCMP detachment, and the municipalities of Coquitlam and Port Coquitlam, address level police records and land use data have been provided to facilitate research within the area. The primary goals of this research are threefold:

² The Coquitlam Detachment of the RCMP also serves the villages of Anmore and Belcarra, as well as surrounding rural and remote areas. These small communities have a combined population of less than 3,000 residents, and less than one percent of the total police records for 2009 were associated with these locales.

- a) To explore the local connections between the built urban environment and crime within these mid-sized suburban locales;
- b) To identify the broader spatial impact that local criminogenic features have on crime within their immediate surrounding environments; and
- c) To consider the potential crime, planning and resourcing implications of these local relationships as the area continues to grow and develop.

Each of these research goals are addressed and expanded upon within the subsequent chapters.

Chapter 2.

Urban Crime Clusters: Identifying Local Crime Attractors and Generators in a Mid-sized Suburban Municipality

2.1. Abstract

Criminal activity is unevenly distributed across the urban landscape, both limited and supported by the physical environment. Some urban spaces are associated with disproportionate amounts of criminal events, while other areas appear to be relatively free from criminal activity. The relationship between the spatial patterns of urban crime have been increasingly explored in recent years, with studies predominantly focusing on larger urban municipalities and findings expressing the need for locally-based analysis. Few studies, however, have explored the relationships between land use and crime in mid-sized municipalities. This research addresses this shortage by exploring how criminal events concentrate within the context of the built environmental backcloth, at the macro-, meso- and micro- spatial levels. Using detailed use of land information as well as transportation network data, this chapter employs an adapted location quotient to identify the built environmental features that are associated with a disproportionate amount of criminal events, and illustrates how these relationships change alongside the spatial scale of analysis. Results support the finding that criminal events concentrate at specific features and facilities within the urban environment, and emphasize the importance of spatial scale in understanding local relationships between crime and the built urban landscape. This analysis further underscores the value of locally-informed analyses.

Keywords: land use, built environment, crime attractors, road network, location quotients

2.2. Introduction

Crime is not randomly nor uniformly distributed across the urban landscape. Rather, it appears to flourish in some areas, while largely avoiding others. Over the past

several decades, a significant and growing body of research has investigated the interconnectedness of the built urban form and patterns of criminal activity. Such studies have identified environmental features that are associated with higher volumes of crime within specific urban settings, and across multiple urban environments. Spaces and places that attract a large number of people for typical, every day activities are also frequently associated with more crime and disorder events (Brantingham and Brantingham, 1978a, 1995; Cohen and Felson, 1979).

As technology advances, micro-level data are increasingly becoming available, allowing for a more detailed exploration of the relationship between crime occurrences and urban form. Continued improvements in computing power have facilitated the collection of both police and land use data, providing a precise geo-location of police records, as well as key information about the built urban environment. Such developments have opened the door for detailed explorations of the relationship between urban form and crime.

As both police records and land use datasets continue to grow, integrating these rich sources allows for the development of a nuanced understanding of the environmental features that influence or relate to local patterns of crime and disorder (Brantingham and Brantingham, 1995). Indeed, researchers within the field of environmental criminology have identified numerous links between urban form and crime, finding that commercial areas, liquor serving establishments, parks, schools and major roads, for example, are all associated with disproportionate rates of criminal activities (Roncek and LoBosco, 1983; Brantingham and Brantingham, 1995; McCord and Ratcliffe, 2007; Kinney et al., 2008; Groff, 2011; Groff and McCord, 2012, Groff and Lockwood, 2014; Johnson and Bowers, 2010; Curman et al., 2015; Weisburd et al., 2012). These studies, though instructive, call for further testing of a greater variety of urban structures and facilities, across a variety of urban settings, in an effort to identify if and how such relationships change.

This chapter responds to the repeated call for further exploration of the relationship between crime and city form by extending the study to an under-researched urban environment: mid-sized suburban municipalities (Seasons, 2003). By aggregating and exploring land use and crime datasets at multiple scales of analysis, this research identifies both the broad and specific urban features that are associated with disproportionate counts

and rates of crime events. It further explores how these relationships change across crime types to identify the unique local connections between crime events and urban form within two suburban communities.

2.3. Background

Environmental crime theorists have been stressing the importance of both the built environment and the routine patterns of human activity for decades. Brantingham and Brantingham discuss the environmental cues that people use to navigate within their surroundings, and that criminals use to select potential targets (Brantingham and Brantingham, 1978a). Such cues include the location of potential crime sites in relationship to specific land uses and major roadways, determining the site's accessibility, privacy, and ease of escape (Brantingham and Brantingham, 1978a). Cohen and Felson label criminal behaviour as a routine activity, to be considered and studied in the same way as other everyday behaviours of the population (Cohen and Felson, 1979). The everyday travel patterns of the urban population bring individuals away from their homes, and allow for the intersection of potential offenders, targets, or guardians in space and time. In doing so, these activities can either facilitate or prevent criminal occurrences (Cohen and Felson, 1979). Such routine patterns of movement are themselves restricted by the built environment, with major transportation corridors and commercial or public locations attracting more activity and in doing so, potentially attracting more crime.

The routine movements of offenders and non-offenders alike leads to an increased individual knowledge of specific activity nodes. Places such as one's home, work or school, and recreational nodes, as well as the pathways between these locations form an individual's activity space. This activity space, as well as the broader surrounding awareness space is created predominantly through routine and legitimate activities; individuals spend most of their time within their awareness space, and as such, offenders typically identify targets and commit offences within it. "Given a uniform distribution of targets, and a nonuniform information base, criminals will probably commit most of their offences close to home, work, shopping, their usual entertainment areas, or on paths between [these nodes]: in general, offences should occur within a criminal's awareness space" (Brantingham and Brantingham, 1991, 35).

The concept of activity and awareness spaces is extended within the Brantingham's pattern theory of crime, which further emphasizes the clustered nature of criminal activity (Brantingham and Brantingham, 1993c). They reinforce the relevance of daily travel paths, underscoring the link between an offender's routine pathways and the location of his or her criminal occurrences. Main roads, in particular, are found to be spatially related to an abundance of property crimes, because they are highly likely to be part of the awareness space of many individuals, drawing both offenders and targets in high quantities (Brantingham and Brantingham, 1993c). The ease of both access and escape via major roads shapes the distribution of property offences, which tend to occur in higher volumes both on, and within closer proximity to such routes (Beavon et al., 1994; Johnson and Bowers, 2010).

Just as main thoroughfares correspond to increased numbers of criminal occurrences, so too do major commercial areas and entertainment districts. Shopping centres and popular commercial strips consistently draw large crowds, increasing both the number of potential targets and the opportunity for criminal activity (Brantingham and Brantingham, 2000). A study by Kinney and colleagues emphasizes that properties containing commercial land uses are associated with a far higher proportion of both assaults and motor vehicle theft than other land use categories (2008). When investigating the specific type of commercial land use, shopping centres are identified as having the highest overall percentages of crime occurrences (Kinney et al., 2008). A number of studies have also emphasized the strong impact that bars and other liquor-related establishments have on local crime (Kinney, 1999; Groff, 2011; 2014; Ratcliffe, 2012), as well as local perception of crime (McCord et al., 2007). These popular destinations, along with major roadways, form parts of a common public awareness space, and as such, are associated with disproportionate rates of crime (Brantingham and Brantingham, 2000).

Due in large part to the increasing availability of high quality, detailed data, local-level analyses are helping to test and explore the specific impact that key features within the urban landscape may have on crime (Kinney, 1999; Kinney et al., 2008; McCord and Ratcliffe, 2007, 2009; Groff, 2011, 2014; Bowers, 2013; Frank et al., 2013). Such analyses have provided further confirmation of the highly clustered nature of crime. When exploring the land use types frequently identified as crime attractors and generators (bars, shopping

malls, public housing facilities and parks, for example), a small proportion of such facilities are found to be associated with a large proportion of overall crime (Brantingham et al., 1976; Kinney et al., 2008; Groff and McCord, 2012; Haberman et al., 2013; Bowers, 2013).

Crime is not uniformly spread across the urban landscape, nor is it uniformly distributed across all land use types (McCord and Ratcliffe, 2007; Kinney et al., 2008; Groff and Lockwood, 2014; Haberman and Ratcliffe, 2015). There has been a repeated call from within this growing area of study for further research to explore the impact of a wider array of criminogenic land uses (Groff, 2011; Groff and Lockwood, 2014) in a wider array of urban environments (McCord and Ratcliffe, 2007; Ratcliffe, 2012; Snowden and Pridemore, 2013). This chapter responds to these calls by exploring the interrelationship between crime and land use at the macro, meso and micro scales, in two suburban municipalities in Greater Vancouver, British Columbia. Through the use of an adapted form of the location quotient, it identifies the broad and specific land use features within the urban area which are related to a disproportionate amount of local crime events, and explores how these relationships change across spatial scales.

2.4. Study Site, Data Sources and Data Preparation

There is a clear and important relationship between the spatial distribution of land use, transportation networks and the patterns of criminal activity within urban environments. Further understanding of this relationship has become increasingly important in recent years, particularly within the local spatial context. Metro Vancouver, British Columbia's most densely populated urban area, is undergoing large-scale development. The significant shifts in the social and physical landscape have created a need for the construction and implementation of innovative research methods for exploring the local impact of land use developments and service delivery plans within this dynamic urban zone.

Metro Vancouver has implemented region-wide strategies to accommodate this growing urban area (Metro Vancouver, 2011). The plan has fostered the establishment of multiple "complete communities" - regional centres of high density growth, slated to become residential and commercial hubs (Metro Vancouver, 2011, p.11). Coquitlam,

British Columbia is one such centre and is experiencing dramatic urban development alongside rapid population growth. Its largest commercial zone, the city centre area, is undergoing development as a downtown core to serve the larger surrounding region. This has resulted in a significant structural change as the area grows to include a greater mix of commercial and high-density residential lots (City of Coquitlam, 2008). This is coupled with the expansion of the public transportation system to include a rapid transit line (the Evergreen Line) that will directly connect Coquitlam with other regional hubs in the wider metropolitan Vancouver area. In light of the current land use and transportation-related redevelopment occurring within the Coquitlam urban area, there is an urgent need to further explore and better understand the ongoing and potential dynamics between land use, transportation systems and crime.

Coquitlam and neighbouring Port Coquitlam are two mid-sized suburban municipalities. These municipalities, together with two smaller communities and the surrounding rural areas, form the Coquitlam Detachment of the Royal Canadian Mounted Police (RCMP). The Detachment as a whole serves a population of nearly 200,000 people (Coquitlam RCMP, 2013). Police records were provided for this analysis by the Coquitlam RCMP Detachment. This initial dataset included all records within the BC-PRIME police records management system involving the Coquitlam detachment in 2009 (n= 39,387).

The event locations within the BC-PRIME dataset were geocoded with a high success rate (94%, resulting in 37,190 records), and the data were further clipped to remove any records occurring outside of the municipalities of Coquitlam and Port Coquitlam. This includes the relatively small proportion of records that fall within the detachment's smaller communities (269 events in 2009), as well as any records occurring outside of the detachment itself (155 events, resulting in 36,766 geocoded records within the study sites).

In an effort to capture a measure of criminal events within the study municipalities, specific police records were excluded from the PRIME data based on their coded attributes. All records determined by the police to be unfounded (7,215 records), as well as all records identified as police statistics codes (16,683 records) were excluded for this analysis. Finally, all events linked to the address of either the police detachment

headquarters, or the local provincial courts, were excluded from the analysis due to known inconsistencies with data recording practices associated with these addresses (82 events; see for example, Groff, 2011). The final dataset contains all confirmed criminal events occurring within Coquitlam and Port Coquitlam in 2009 for which a usable location could be identified (n=12,786).

Figure 1, below, displays a kernel density map of the spatial distribution of the final crime dataset included in this analysis. A number of hotspots of crime appear throughout the study area, with the most prominent spot appearing near the geographic centre of the study site. This hotspot coincides with the Coquitlam city centre area, which houses the only regional shopping mall within the study site, as well as a large local college, the city hall and the local police detachment that serves both municipalities included in this study.

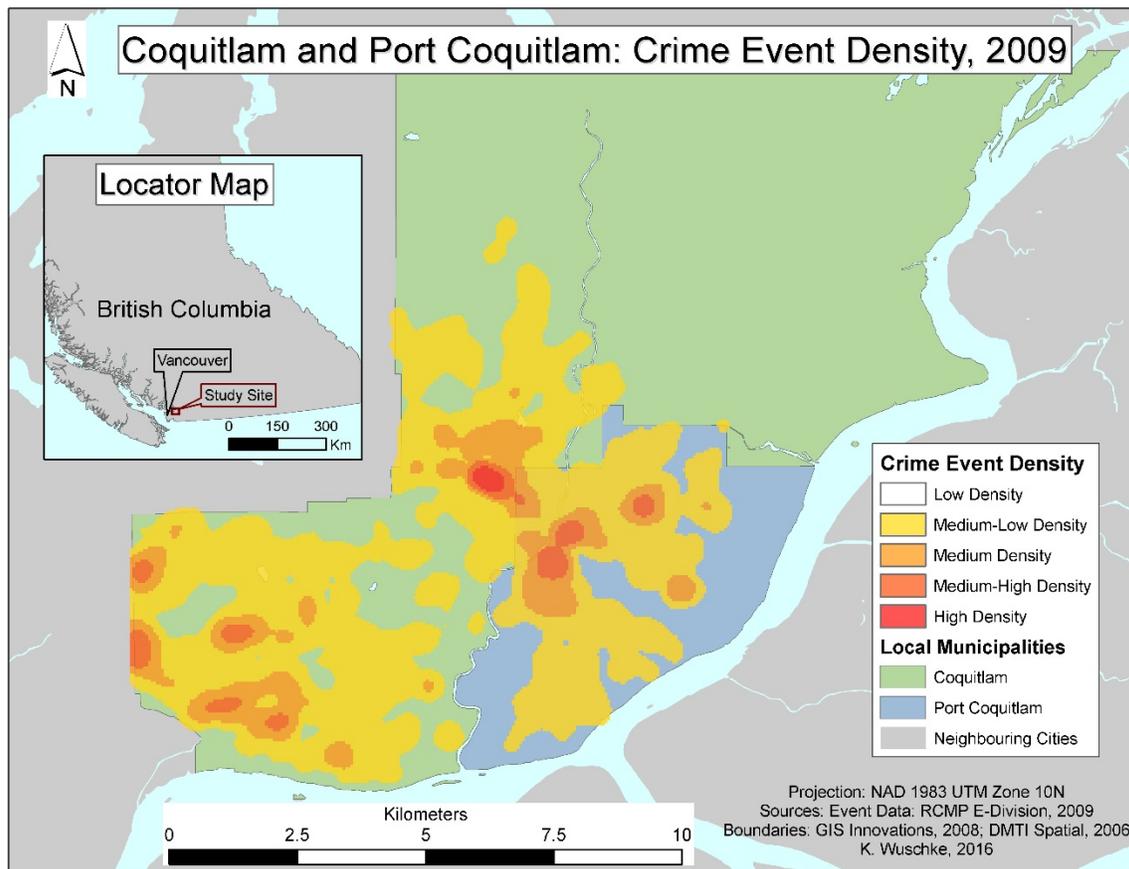


Figure 1: Crime event density across the study site, 2009.

Two additional datasets were used to represent the built urban environment within the cities of Coquitlam and Port Coquitlam: a road network and a land use dataset. The

local road network was provided by the RCMP, and is the network upon which all police records are geocoded. The network was developed in 2008 by a private company (GIS Innovations) and includes 776 kilometers of categorized roadways spanning both municipalities. Land use data was acquired from the British Columbia Assessment Authority, which is a provincial crown corporation that collects actual use information about each individually-owned property unit within the province for the purposes of taxation (BC Assessment, 2015). This detailed, point-level information classifies all properties into one of seven broad land use categories: residential; farm; commercial; stratified operational facilities areas (SOFA: common properties within stratified housing complexes); industrial; transportation, communication and utility (TCU); and civic, institutional and recreational (CIR: a broad category including a range of land use types such as government buildings, parks, schools and hospitals). In addition, each property is further categorized into a detailed actual use sub-category within its broader land use classification. The dataset is updated yearly. The 2009 BC Assessment data were retrieved from both the City of Coquitlam and the City of Port Coquitlam, and resulted in a combined dataset of 59,711 records. The address associated with each BC Assessment record geocoded at a high success rate (99%), resulting in a final dataset containing 59,286 records.

While the BC Assessment dataset provides a detailed and unique insight into the local urban structure, there are some challenges associated with it. As the data is collected for taxation purposes, each record within the BC Assessment dataset is associated with an individually-owned property. In the case of a stratified condominium, this means that each individual unit has a unique record. However, when considering a rented apartment complex owned by one individual or company, the entire property will include only one record. This discrepancy is also found when considering high-density commercial units: some shopping complexes are aggregations of individually-owned stores, while others are commercial rental properties owned by one company. This inconsistency makes some comparisons between otherwise similar land uses difficult. In an effort to gain consistency across such multi-unit complexes, the BC Assessment dataset was dissolved by both individual address and detailed land use. All units within condominiums, then, were merged into one record; all individually-owned commercial properties within a single shopping complex were reduced to one record – each represented by a single spatial point. While

this resulted in the generalization and loss of some data, it allowed for clarity in comparison of similar property types³. The final land use dataset contained 37,039 individual records.

These three individual datasets – the PRIME crime event data, the road network, and the land use dataset, formed the basis of the data analysis undertaken within this chapter. In preparation of analyzing the links between the crime event data and the built environmental features, the datasets were joined following a number of different steps. First, the complete road network was spatially joined to the crime event data to provide the road type associated with each event location⁴. Next, the BC Assessment land use data was joined to all crime events with a full street address (9,593 events), providing detailed land use information for each precise address location. Where exact land use matches were not available (3,193 events), as in the case of events reported at the 100-block level or the intersection, the crime data were analyzed based on street segment, but not based on land use match⁵.

³ An ideal dataset would provide further detail about the number of sub-units or occupants within all structures; however, as a consistently detailed level of data was not available for multi-unit complexes, the aforementioned data dissolve reduced the complexity of multi-owner complexes. While this dissolve enables some comparisons across similarly typed units (privately owned condominiums and high-density rental apartments, for example), care must be taken when comparing across different land use (sub) types – for example, one single family dwelling is represented by the same number of records as one apartment complex and one condominium. Further, as the current BCAA dataset is available at the point-level for this study and does not include the cadastral-level area parcels, the relative structure size is also not represented in this data. The use of land must be taken into account when comparing land use types and sub-types.

⁴ The spatial join process within ArcGIS links the street segment attribute data to the crime events occurring on the street. In the case of intersections ($n = 1883$), there are several street segments in contact with the same point. Rather than excluding this data, which makes up a considerable 15% of the overall crime events within the study site, this analysis accepted ArcGIS's method for responding to this uncertainty and randomly assigned the attributes of one of the contacting street segments to crime events at intersections. Several alternative approaches have been used to deal with such mismatches, including excluding intersection data (Weisburd et al., 2009, 2012; Curman et al., 2015), analyzing intersection data separately (Braga et al., 2010; Andresen and Curman, 2016) and allocating intersection crime proportionally to adjacent street segments (Hibdon and Groff, 2014).

⁵ A spatial join was considered as a method to include the unmatched crime events into the land use analysis. Careful investigation of the results of this process identified a number of data concerns, wherein some crime events were joined to the nearest recorded land use, but this land use was located a considerable distance from the event location. This introduced additional uncertainty into the analysis, producing matches between events and land use that were less reliable. While the road type is clearer, within this subset, the land use type was not. As such, this proportion was excluded.

Lastly, in addition to adding the built environmental data onto the crime data, the opposite connection was also made: the 12,786 crime event records were joined to the road network, and the 9,593 events linked with a precise street address were joined to the land use dataset. These additional data joins allowed for the calculation of a count of the number and types crime events occurring at each street segment and on each property, without excluding the segments and properties that are associated with no criminal events. These enriched datasets formed the basis for local analyses of records by road type and land use category. Figure 2 displays both the land use data, as well as the road networks within Coquitlam and Port Coquitlam.

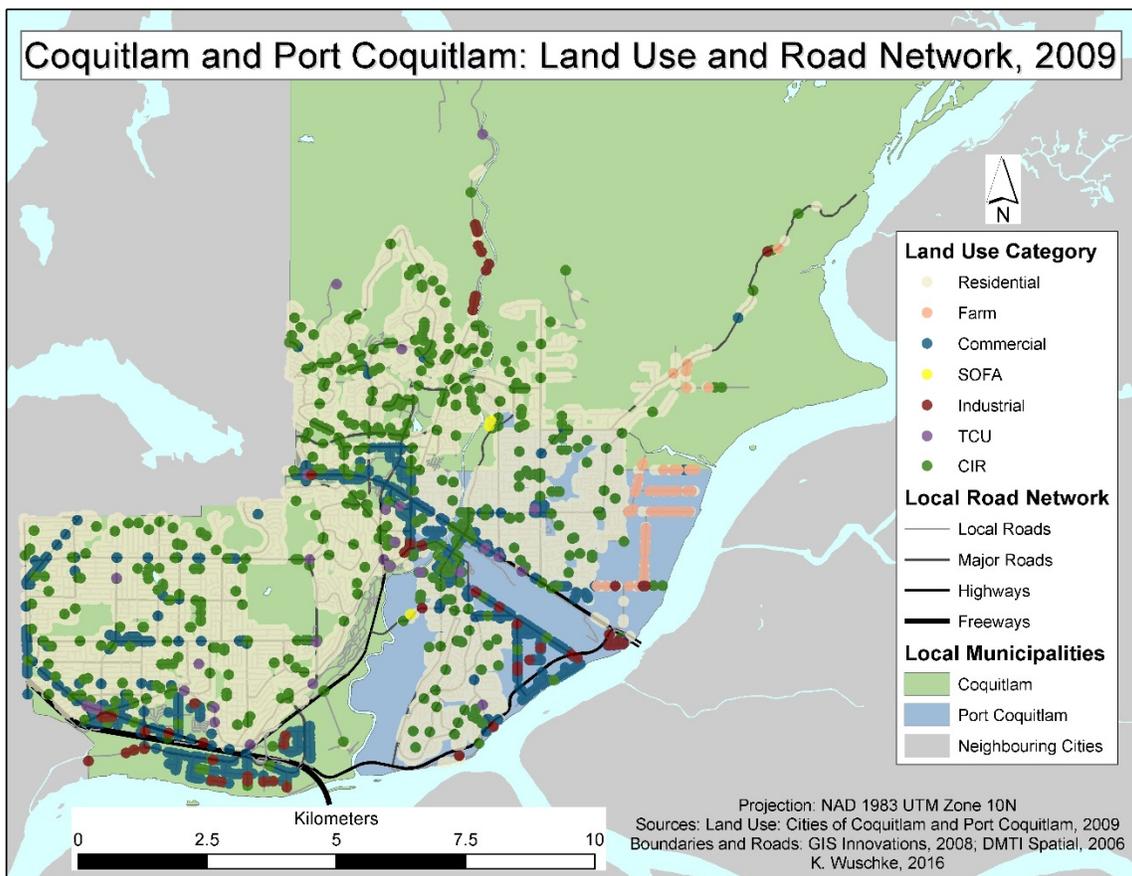


Figure 2: BC Assessment general land use classifications and road networks within Coquitlam and Port Coquitlam.

2.5. Methodology

A sizeable amount of literature has identified and supported the links between built environmental features and the spatial distribution of urban crime. In order to better understand these relationships specific to Coquitlam and Port Coquitlam, the crime event data are considered within the context of the street type and/or land use category on which they occur. In this analysis, an adapted version of the location quotient is used to identify if and how the crime event data vary along with built environmental features within the study site.

2.5.1. Location quotients: Use, adaptations and limitations

The location quotient is a measure that allows for simple comparisons of the proportion of crime between sub-areas within the same larger region (Brantingham and Brantingham, 1993b; McCord and Ratcliffe, 2007; Ratcliffe and Rengert, 2008; Andresen, 2007, 2009; Andresen et al., 2009; Groff, 2011; Carleton et al., 2014). The location quotient is often calculated as a ratio of the proportion of a crime in a given sub-area, in comparison to the proportion of the same crime in the greater region. As such, it provides a locally-based, standardized measure that easily identifies sub-areas with over- or under-representation of the measured crime.

The standard conceptualization of a location quotient is calculated using categorical crime data alone, without standardizing by area or population counts. As such, it traditionally provides a measure of the *specialization* of crime in one sub-region, in comparison to the greater region as a whole (Brantingham and Brantingham, 1993b; Brantingham and Brantingham, 1994; Andresen, 2007; 2009; Andresen et al., 2009; Carleton et al., 2014; Ratcliffe and Rengert, 2008). However, in recent years, location quotients have been adapted as a standardized rate, where the crimes per unit within a given sub-area are standardized by the crimes per unit in the larger region (McCord and Ratcliffe, 2007; Groff, 2011; Groff and McCord, 2012). Both methods allow for relatively simple comparisons across sub-areas within the same region, and both methods result in a metric standardized around the value of 1. Sub-areas with a location quotient value of greater than 1 display over-representation of a specific crime type in comparison to the

wider region; sub-areas with a location quotient value of less than 1 display under-representation. As an example, a sub-area with a calculated location quotient value of 1.5 can be interpreted as having 1.5 times the expected proportion of the measured crime within the sub-area, as compared to the region as a whole.

There are a number of limits associated with the location quotient. The location quotient requires crime data as input, and crime data only accounts for reported crime occurrences. When relying on police-based datasets in particular, there is a known discrepancy between the amount of crime that occurs, and the amount of crime that is reported to police; this results in a considerable under-representation of actual criminal occurrences (Andresen, 2014). This issue is present in essentially any study relying on police recorded crime data to represent criminal occurrences, but must be considered and acknowledged. In addition, location quotients are designed to measure over/under-representation within sub-areas of a greater region. They therefore require the aggregation of crime data to specific sub-areas or units. Any point-based data that is aggregated to units is subject to the modifiable area unit problem (MAUP), whereby the spatial patterns presented at one level of aggregation will change should the data be aggregated to different spatial units (Openshaw, 1984b). In this sense, the units of aggregation require considerable forethought as the spatial units of analysis have the potential to greatly influence results.

An additional challenge associated with the use of the adapted, standardized-rate location quotients is the impact that areas have on the overall calculation (Groff, 2011; McCord and Ratcliffe, 2009). Small areas are greatly impacted by small changes in the number of crime events. This concern is inherent in any area-based crime rate calculation, and is exacerbated when regions include sub-areas where criminal events are unlikely to occur, such as water features, cliffs, or areas that are otherwise difficult to access. With this in mind, careful consideration of the denominators used to calculate crime rates is essential for the development of a meaningful location quotient (Harries, 1991; Andresen et al., 2009; Malleson and Andresen, 2015b).

In response to the latter two concerns, further adaptations of the location quotient are introduced and applied in this chapter, aiming to reduce the impact of area on the

standardized rate. The conceptualization of sub-units within a region is adjusted first. Rather than comparing specific neighbourhoods or geographic sub-areas within a broader region, this adaptation groups crime according to the road type or land use category on which the event occurs. Crime rate denominators, then, are selected based on the most appropriate choice available, given the selected categorization (Harries, 1991; Brantingham and Brantingham, 1994). When exploring crime along the road network, for example, the adapted location quotient, or category quotient (CQ), is calculated as follows:

$$CQ = \frac{C_n}{D_n} \bigg/ \frac{C_N}{D_N}$$

Where

CQ = Category quotient

C_n = Count of crimes occurring along road type *n* (within Region *N*)

D_n = Total distance of road type *n* (within Region *N*)

C_N = Count of crime within the entire Region *N*

D_N = Total distance of all road types within entire Region *N*

The above calculation classifies crime according to the road type on which it occurs, and calculates a category quotient based on the rate of criminal events per distance of one road type. This value is then standardized by the region-wide rate of all criminal events per distance of all roads. This minor adaptation creates classifications that are more meaningful within the local built environment – crime is categorized not according to arbitrary geographic boundaries, for example, but according to the specific environmental feature on which it occurs. Further, in choosing a distance-based denominator, it reduces the impact of larger area-based denominators that include locations where crimes would be unable to be attributed to.

When exploring crime in relation to land use, the units of analysis become the count of properties within land use categories themselves. These categories can be constructed at a variety of levels – from broad land use classifications (for example, crime at residential units) to specific actual use sub-groupings (for example, crime at low-rise multi-family apartments). Crime is classified according to the land use on which it occurs, and a CQ is

calculated based on the rate of crime events per property units of the given land use (and standardized by the rate of crime events per all property units within the study region). This can be represented as follows:

$$CQ = \frac{\frac{C_n}{P_n}}{\frac{C_N}{P_N}}$$

Where

CQ = *Category quotient*

C_n = *Count of crimes occurring on properties with Land Use type n (within Region N)*

P_n = *Total count of properties with Land Use type n (within Region N)*

C_N = *Count of crime within the entire Region N*

P_N = *Total count of all properties within entire Region N*

The CQ can be further adjusted to consider different crime categories. In this case, the equation calculates the count of a given crime *type* per specific road distance (or property units of a given land use land use), standardized by the total count of that crime type per total road distance (or total property units) across the study site. For example, the CQ for property crimes along arterial roads would consider the count of such crimes on arteries per distance of arterial roads, standardized by the total count of property crimes per total road distance. The values of CQs can be compared within region, and within crime category. While the magnitude of the quotient is instructive to indicate over- or under-representation, the value itself should not be used to compare between regions, or between crime categories. To clarify, a CQ calculated for all crimes on arterial roads within a given region can be directly compared to a CQ calculated for all crimes on highways within the same region. However, the CQ value for all crime on arteries should not be directly compared to the CQ value for all *property* crimes on arteries within the same region, because these measures are calculated using different denominators.

There is not a standard test to measure the statistical significance of the over- or under-representation within a given area, as measured by the various interpretations of

the location quotient⁶ (Groff, 2011; Andresen, 2007). Several values have been suggested within previous research as reasonable indicators of very high overrepresentation within sub-areas; these values range from 1.3 (Miller et al., 1991; Andresen, 2007, 2009; Andresen et al., 2009) to 2 (Rengert et al., 2005; Groff, 2011; Groff and McCord, 2012). The latter value has been selected as a guideline for use within this chapter in an effort to capture the environmental features that display considerably higher crime rates than the area-wide norms.

While the CQ addresses some of the concerns associated with previous renditions of the location quotient calculation, it is unable to better account for unreported criminal events. Further, as crime data is still being grouped into classifications, any groupings with few units (such as land use types with small amounts of properties, or road types with short distances within the study region) are impacted by small changes in the crime counts. As with all rate-based calculations, the denominator must be carefully considered during analysis. When calculating the CQ of crimes occurring at single family dwellings, for example, the count of crimes per dwelling is calculated, and standardized by the city-wide rate of crimes per total properties. However, when considering multi-unit housing types, such as apartment buildings, the CQ becomes a calculation of the crimes per apartment building, standardized by the same city-wide rate of crimes per total properties. While both measures calculate rates based on single “properties”, the second measure is likely to be inflated based on the large number of residential units that a single apartment building represents. With this in mind, careful consideration must be taken when comparing CQs across classification types, keeping in mind the typical use of such category. In spite of these limitations, the CQ provides an informative measure with which to consider how crime rates vary across built environmental categories within the study area.

⁶ Recent work by Wang and colleagues has introduced a significance test for application with a further adaptation upon the traditional location quotient – a local colocation quotient (Wang et al., 2016). This statistical method shows promise for application across a wider range of location quotient formats.

2.5.2. Measuring crime concentration by built environmental features

The CQ is applied within this chapter to measure the impact of built environmental features on crime within Coquitlam and Port Coquitlam. This analysis was undertaken in several phases. First, all records within the study area were analyzed by road type to identify the classes of roads associated with disproportionate amounts of crime events. The address-matched subset of the data was further analyzed according to broad land use categorization in order to explore the local relationships between the built environment and crime. This methodology identified the macro-level land use categories associated with high counts and rates of crime events. This organically directed further explorations into the sub-categories of the land-use datasets. Meso-level analysis identified the top five land use sub-categories displaying the highest rates of police records per unit. Micro-level analysis was performed by both address and street segment, and identified the precise land use and street type of the five highest crime blocks and property units within the study area.

Together, the road network and BC Assessment dataset provide a representation of the physical built environment within these mid-sized suburban municipalities. Simultaneously, the selected police records provide insight into the distribution of recorded crime and disorder events within the locale. Linking and analyzing these datasets together allows for a better understanding of the local relationships between the built environment and crime within an urban setting that remains under-studied.

2.6. Results

2.6.1. Macro-level exploration

This analysis begins at the macro-level, exploring the connections between road type and criminal events across the study area. Table 1 presents the initial breakdown of crime events according to the road type associated with each recorded location. Subsequent sections of Table 1 (b through g) further break down the analysis according to crime type to explore how the resulting crime concentrations shift. As emphasized in

Table 1, the study municipalities report an overall average of 16.5 criminal events per kilometer of roadway; however, as shown by the CQ, this rate increases 2.9 times when considering arterial roads. Collector roads display a CQ of 1.2, indicating a slight over-representation of crime in comparison to the remainder of the study area. The CQs of all other road classifications display under-representation of crime. Very few sections of roads are classified as freeways within Coquitlam and Port Coquitlam; no crime events at all are associated with this road type.

Table 1: Criminal events by road type of event location: All crimes, and specific crime types (2009)

a) All Crimes						
Road Type	Road Length (KM)	% Total Road Length	Crime Events	% of All Events	Events/ KM	Category Quotient
Arterial	96.44	12.43%	4541	35.52%	47.08	2.86
Collector	98.88	12.74%	1911	14.95%	19.33	1.17
Freeway	13.31	1.72%	0	0.00%	0.00	0.00
Highway	34.12	4.40%	266	2.08%	7.80	0.47
Local	461.05	59.41%	6011	47.01%	13.04	0.79
Other	72.22	9.31%	57	0.45%	0.79	0.05
Total	776.02	100.00%	12786	100.00%	16.48	1
b) Crimes Against Persons						
Road Type	Road Length (KM)	% Total Road Length	Crime Events	% of Category	Events/ KM	Category Quotient
Arterial	96.44	12.43%	464	31.06%	4.81	2.50
Collector	98.88	12.74%	227	15.19%	2.30	1.19
Freeway	13.31	1.72%	0	0.00%	0.00	0.00
Highway	34.12	4.40%	20	1.34%	0.59	0.30
Local	461.05	59.41%	779	52.14%	1.69	0.88
Other	72.22	9.31%	4	0.27%	0.06	0.03
Total	776.02	100.00%	1494	100.00%	1.93	1
c) Offences Against Property						
Road Type	Road Length (KM)	% Total Road Length	Crime Events	% of Category	Events/ KM	Category Quotient
Arterial	96.44	12.43%	2126	32.76%	22.04	2.64
Collector	98.88	12.74%	972	14.98%	9.83	1.18
Freeway	13.31	1.72%	0	0.00%	0.00	0.00
Highway	34.12	4.40%	154	2.37%	4.51	0.54
Local	461.05	59.41%	3214	49.52%	6.97	0.83
Other	72.22	9.31%	24	0.37%	0.33	0.04
Total	776.02	100.00%	6490	100.00%	8.36	1

d) Other Criminal Code Violations						
Road Type	Road Length (KM)	% Total Road Length	Crime Events	% of Category	Events/ KM	Category Quotient
Arterial	96.44	12.43%	1339	39.71%	13.88	3.20
Collector	98.88	12.74%	452	13.40%	4.57	1.05
Freeway	13.31	1.72%	0	0.00%	0.00	0.00
Highway	34.12	4.40%	47	1.39%	1.38	0.32
Local	461.05	59.41%	1514	44.90%	3.28	0.76
Other	72.22	9.31%	20	0.59%	0.28	0.06
Total	776.02	100.00%	3372	100.00%	4.35	1
e) Controlled Drugs and Substance Act Violation						
Road Type	Road Length (KM)	% Total Road Length	Crime Events	% of Category	Events/ KM	Category Quotient
Arterial	96.44	12.43%	213	37.90%	2.21	3.05
Collector	98.88	12.74%	82	14.59%	0.83	1.15
Freeway	13.31	1.72%	0	0.00%	0.00	0.00
Highway	34.12	4.40%	12	2.14%	0.35	0.49
Local	461.05	59.41%	252	44.84%	0.55	0.75
Other	72.22	9.31%	3	0.53%	0.04	0.06
Total	776.02	100.00%	562	100.00%	0.72	1
f) Other Federal Statute Violations						
Road Type	Road Length (KM)	% Total Road Length	Crime Events	% of Category	Events/ KM	Category Quotient
Arterial	96.44	12.43%	12	18.75%	0.12	1.51
Collector	98.88	12.74%	11	17.19%	0.11	1.35
Freeway	13.31	1.72%	0	0.00%	0.00	0.00
Highway	34.12	4.40%	0	0.00%	0.00	0.00
Local	461.05	59.41%	41	64.06%	0.09	1.08
Other	72.22	9.31%	0	0.00%	0.00	0.00
Total	776.02	100.00%	64	100.00%	0.08	1
g) Traffic Violations						
Road Type	Road Length (KM)	% Total Road Length	Crime Events	% of Category	Events/ KM	Category Quotient
Arterial	96.44	12.43%	387	48.13%	4.01	3.87
Collector	98.88	12.74%	167	20.77%	1.69	1.63
Freeway	13.31	1.72%	0	0.00%	0.00	0.00
Highway	34.12	4.40%	33	4.10%	0.97	0.93
Local	461.05	59.41%	211	26.24%	0.46	0.44
Other	72.22	9.31%	6	0.75%	0.08	0.08
Total	776.02	100.00%	804	100.00%	1.04	1

The relative values of the CQs as displayed in Table 1 remain consistent across crime categories. Regardless of the crime type under consideration, arterial roads consistently display the highest CQ, showing over-representation across all crime categories. The magnitude of the CQ of arterial roads is consistently and considerably higher than the average for the region, surpassing the threshold value of 2 in all categories – with one exception. *Other federal statute violations*, which are federal offences other than drug crimes, display disproportionate crime rates across arterial, collector and local roads, though no road type surpasses the CQ threshold. No offences within this category fall on any other road type within the study area. Collector roads consistently have the second highest CQ, and reliably display a quotient value higher than 1. The magnitude of collector roads is consistently, though not considerably, higher than the regional average, and does not surpass the threshold of 2. All other road classifications display CQ values very near, or below 1, indicating average or under-representation of the crime categories in question.

When considering crime concentrations according to road type, arterial roads consistently display the highest CQs, indicating higher than expected crime rates along these environmental features. Continuing the macro-level analysis, Table 2 explores crime event counts and CQs according to broad land use type, beginning with all events (Table 2a) and following with breakdowns by crime type (b through g). Residential land use displays the highest counts of police records, however, as 93 percent of all properties in Coquitlam and Port Coquitlam are residential, this finding is expected. The study area also contains a number of property units classified within both the commercial, and the civic, institutional and recreational (CIR) land use category; likewise, a considerable percentage of crime events are associated with these categories. A very small number of occurrences fall on the few lots identified as farm; industrial; stratified operational facility areas (SOFA)⁷; or transportation, utility and communication (TCU) land uses.

The CQ for each land use classification is displayed in the final column of Table 2. The CQ minimizes the impact of the residential land use category, while emphasizing the disproportionately high rates of police records associated with both Commercial and CIR

⁷ A very small number of lots are classified as SOFA. These refer to the common buildings within a strata, including condominium lobbies, shared strata buildings and common areas in shopping malls.

land uses. This over-representation remains consistent when considering crime types, with both land use groupings consistently surpassing the CQ threshold. Industrial land use shows a slight over-representation when considering all crime types, as well as when focusing on property crimes (Table 2c) and drug offences (Table 2e); however, regardless of crime type, all industrial CQs are less than 2. Additionally, with a CQ of 3, TCU land use displays a considerable over-representation of drug crimes (Table 2e). When these quotients are considered alongside the overall counts of police records within the study site, it becomes apparent that three broad land use types are of particular interest. The majority of the individual units within the cities (99%), and most of the police records (99%) are captured when considering the residential, commercial, and CIR land use categories.

Table 2: Address-matched crime events by Land Use of event location (2009)

a) All Events						
Land Use Category	Property Units	% of all Units	Crime Events	% of all Events	Events/ Unit	Category Quotient
Residential	35342	95.42%	5267	54.90%	0.15	0.58
Commercial	981	2.65%	3390	35.34%	3.46	13.34
CIR	507	1.37%	897	9.35%	1.77	6.83
Farm	79	0.21%	10	0.10%	0.13	0.49
Industrial	78	0.21%	23	0.24%	0.29	1.14
TCU	49	0.13%	6	0.06%	0.12	0.47
SOFA	3	0.01%	0	0.00%	0.00	0.00
Total	37039	100.00%	9593	100.00%	0.26	1.00
b) Crimes Against Persons						
Land Use Category	Property Units	% of all Units	Crime Events	% of Category	Events/ Unit	Category Quotient
Residential	35342	95.42%	853	68.40%	0.02	0.72
Commercial	981	2.65%	267	21.41%	0.27	8.08
CIR	507	1.37%	124	9.94%	0.24	7.26
Farm	79	0.21%	2	0.16%	0.03	0.75
Industrial	78	0.21%	0	0.00%	0.00	0.00
TCU	49	0.13%	1	0.08%	0.02	0.61
SOFA	3	0.01%	0	0.00%	0.00	0.00
Total	37039	100.00%	1247	100.00%	0.03	1.00
c) Offences Against Property						
Land Use Category	Property Units	% of all Units	Crime Events	% of Category	Events/ Unit	Category Quotient
Residential	35342	95.42%	3026	55.85%	0.09	0.59
Commercial	981	2.65%	2015	37.19%	2.05	14.04
CIR	507	1.37%	350	6.46%	0.69	4.72
Farm	79	0.21%	5	0.09%	0.06	0.43
Industrial	78	0.21%	21	0.39%	0.27	1.84
TCU	49	0.13%	1	0.02%	0.02	0.14
SOFA	3	0.01%	0	0.00%	0.00	0.00
Total	37039	100.00%	5418	100.00%	0.15	1.00

d) Other Criminal Code Violations						
Land Use Category	Property Units	% of all Units	Crime Events	% of Category	Events/ Unit	Category Quotient
Residential	35342	95.42%	1145	47.75%	0.03	0.50
Commercial	981	2.65%	904	37.70%	0.92	14.23
CIR	507	1.37%	342	14.26%	0.67	10.42
Farm	79	0.21%	3	0.13%	0.04	0.59
Industrial	78	0.21%	1	0.04%	0.01	0.20
TCU	49	0.13%	3	0.13%	0.06	0.95
SOFA	3	0.01%	0	0.00%	0.00	0.00
Total	37039	100.00%	2398	100.00%	0.06	1.00
e) Controlled Drugs and Substances Act Violations						
Land Use Category	Property Units	% of all Units	Crime Events	% of Category	Events/ Unit	Category Quotient
Residential	35342	95.42%	98	39.68%	0.00	0.42
Commercial	981	2.65%	79	31.98%	0.08	12.08
CIR	507	1.37%	68	27.53%	0.13	20.11
Farm	79	0.21%	0	0.00%	0.00	0.00
Industrial	78	0.21%	1	0.40%	0.01	1.92
TCU	49	0.13%	1	0.40%	0.02	3.06
SOFA	3	0.01%	0	0.00%	0.00	0.00
Total	37039	100.00%	247	100.00%	0.01	1.00
f) Other Federal Statute Violations						
Land Use Category	Property Units	% of all Units	Crime Events	% of Category	Events/ Unit	Category Quotient
Residential	35342	95.42%	33	67.35%	0.00	0.71
Commercial	981	2.65%	12	24.49%	0.01	9.25
CIR	507	1.37%	4	8.16%	0.01	5.96
Farm	79	0.21%	0	0.00%	0.00	0.00
Industrial	78	0.21%	0	0.00%	0.00	0.00
TCU	49	0.13%	0	0.00%	0.00	0.00
SOFA	3	0.01%	0	0.00%	0.00	0.00
Total	37039	100.00%	49	100.00%	0.00	1.00
g) Traffic Offences						
Land Use Category	Property Units	% of all Units	Crime Events	% of Category	Events/ Unit	Category Quotient
Residential	35342	95.42%	112	47.86%	0.00	0.50
Commercial	981	2.65%	113	48.29%	0.12	18.23
CIR	507	1.37%	9	3.85%	0.02	2.81
Farm	79	0.21%	0	0.00%	0.00	0.00
Industrial	78	0.21%	0	0.00%	0.00	0.00
TCU	49	0.13%	0	0.00%	0.00	0.00
SOFA	3	0.01%	0	0.00%	0.00	0.00
Total	37039	100.00%	234	100.00%	0.01	1.00

At the macro level, crime clusters considerably according to physical elements within the urban landscape. The CQs displayed in Table 1 emphasize the concentration of crime along arterial roads. Table 2 reveals that criminal events within the cities of Coquitlam and Port Coquitlam are largely captured within land uses classified as residential, commercial and CIR. A disproportionate rate of these events are associated with the latter two classifications. These concentrations are largely consistent across crime types. While this provides some insight into the general environmental features associated with local distributions of crime, further information can be gained by exploring the concentrations of crime by land use sub-categories.

2.6.2. Meso-level exploration

Crime events within Coquitlam and Port Coquitlam appear to concentrate along arterial roadways and within several broad land use categories. This uneven distribution of police records is further evident when considering sub-categories of land use. The large variation in CQs within each land use category emphasizes the considerable clustering at the meso-level. Not all residential land use sub-types display low rates of crime per units; likewise, not all commercial and CIR land use sub-types display great over-representation.

Table 3 (below) emphasizes these differences by displaying the top five detailed actual use types⁸ with the highest CQs within the Residential, Commercial and CIR land use categories. Actual use CQs are standardized according to their broad land use type: for example, the number of crime events per shopping centre is standardized by the overall rate of crimes per commercial unit. With this in mind, the displayed category quotients are useful to compare rates within sub-groups, but not between land use classifications. The calculated results further stress the non-uniformity of crime within urban settings.

When considering the CQs within residential units (Table 3), multi-family dwellings dominate the land use. The top sub-categories must be interpreted with care, taking note

⁸ Actual use is different than land use in that the actual use sub-type refers to how a given property is being used, regardless of overall intention. As an example, while a property may fall into the broad Residential land use category, the actual use of the property may reveal that it is currently a vacant lot. This is an important distinction when considering the potential implications for crime and disorder.

of the relatively low proportion of both units, and crime events. Shopping centres display the highest rates of records per unit when exploring properties classified as commercial (Table 3). The concentration of crime at these sites is worth noting: nearly one-quarter of all crimes that occur on commercial land uses are recorded at a regional or community shopping centre. This amounts to about 6 percent of the total crime within the study site. Likewise, within the CIR land use classification, hospitals, recreation centres and schools are notable sub-categories associated with a disproportionate rate of records per unit. The large variation in CQs within each land use category emphasizes the considerable clustering at the meso-level. Not all residential land use sub-types display low rates of crime per units; likewise, not all commercial and CIR land use sub-types display great over-representation.

Table 3: Crime events by actual use sub-category of event address: Top categories within Residential, Commercial, and CIR land use categories (2009)

a) Top Residential Property Sub-Categories	Property Units	% of All Residential Units	Crime Events	% of All Residential Events	Events /Unit	Category Quotient
Manufactured Home Within Park	4	0.01%	32	0.61%	8.00	53.68
Stratified Rental Apartment, One Owner	8	0.02%	38	0.72%	4.75	31.87
Multi-Family (Minimal Commercial)	4	0.01%	19	0.36%	4.75	31.87
Multi-Family Garden Apartment and Row Housing	28	0.08%	120	2.28%	4.29	28.76
Multi-Family Apartment Block	100	0.28%	413	7.84%	4.13	27.71
Top 5 Residential	144	0.41%	622	11.81%	4.32	28.98
b) Top Commercial Property Sub-Categories	Property Units	% of All Commercial Units	Crime Events	% of All Commercial Events	Events /Unit	Category Quotient
Regional Shopping Centre	1	0.10%	396	11.68%	396.00	114.59
Community Shopping Centre	7	0.71%	424	12.51%	60.57	17.53
Hotel	5	0.51%	167	4.93%	33.40	9.67
Theatre Building	2	0.20%	66	1.95%	33.00	9.55
Neighbourhood Store	4	0.41%	122	3.60%	30.50	8.83
Top 5 Commercial	19	1.95%	1175	34.66%	61.84	17.90
c) Top CIR Property Sub-Categories	Property Units	% of All CIR Units	Crime Events	% of All CIR Events	Events /Unit	Category Quotient
Hospital	2	0.39%	85	9.48%	42.50	24.02
Recreational and Cultural Building	16	3.16%	114	12.71%	7.13	4.03
School/University	65	12.82%	439	48.94%	6.75	3.82
Government Building	13	2.56%	40	4.46%	3.08	1.74
Recreational/Ski Club	1	0.20%	3	0.33%	3.00	1.70
Top 5 CIR	97	19.13%	681	75.92%	7.02	3.97

2.6.3. Micro-level exploration

Looking at the municipalities of Coquitlam and Port Coquitlam as a whole, arterial roads and the property units classified as commercial and CIR have higher rates of crime

than other environmental features. When narrowing the focus *within* land use categories, great variations in CQs emphasize further clustering at the meso-level. Moving one step further, this concentration becomes ever more apparent as we focus on the specific street blocks and specific addresses associated with the highest counts of records. Table 4 and Table 5 (below) provide a closer look at the hottest micro-level crime concentrations within Coquitlam and Port Coquitlam: first, at the block-level, and second, at the property unit level.

In each case, these micro-scale explorations reveal considerable concentrations of crime. The five single blocks listed in Table 4 together account for nearly 8% of all crime events within Coquitlam and Port Coquitlam. Likewise, the five single addresses with the highest crime counts together account for over 9% of all address-matched records across both municipalities; the single top address, representing the area's regional shopping mall, accounts for 4% of these events. The CQs for each of these top locations reveals both the extreme concentration of criminal events per unit (distance or property) in comparison to the overall average for the study site as a whole.

Further insight into the local relationships between the built environment and crime emerge when exploring the details about these micro-scale hotspots. All five highest-crime blocks are classified as arterial roads, once again emphasizing the local relevance of this environmental feature when considering crime distributions. Further, the top three highest crime property units within Coquitlam and Port Coquitlam are shopping centres, echoing the meso-level analysis. The remaining two highest-crime properties listed in Table 5 include a single hotel, re-affirming the local importance of this use of land in relation to the distribution of crime, as well as a bank. This land use sub-category did not emerge within the meso-level analysis, yet this single property address is recorded as the location of 101 crime events within 2009, and as such, is clearly a locally-relevant facility.

Table 4: Top 5 blocks (out of 776 total Kilometers of road) with highest counts of crime events (2009)

Road Type	Road Length (Meters)	Crime Events	% of Total Events (n = 12,786)	Category Quotient
Arterial	100.87	396	3.10%	238.12
Arterial	310.89	206	1.61%	40.19
Arterial	233.44	165	1.29%	42.87
Arterial	417.20	133	1.04%	19.34
Arterial	412.27	115	0.90%	16.92
Total - Top 5 Segments	1474.66	1015	7.94%	41.75

Table 5: Top 5 property units (out of 37,039 total properties) with highest counts of address-matched crime events (2009)

Actual Land Use Description	Broad Land Use Type	Crime Events	% of Total Events (n=9,903)	Category Quotient
Regional Shopping Centre (A)	Commercial	396	4.13%	1528.97
Community Shopping Centre (A)	Commercial	147	1.53%	567.57
Community Shopping Centre (B)	Commercial	133	1.39%	513.52
Bank (A)	Commercial	101	1.05%	389.97
Hotel (A)	Commercial	97	1.01%	374.52
Total - Top 5 Properties		874	9.11%	674.91

2.7. Discussion

The varying concentrations of crime across the cities of Coquitlam and Port Coquitlam support the finding that crime is not uniformly distributed across the urban landscape. Past academic literature has identified specific features within the built environment that are frequently associated with disproportionate rates of urban crime; these include major roads, liquor-related establishments, commercial areas, schools and parks. This multi-scale analysis has identified the physical features that are associated with an over-representation of crime within the local context of two mid-sized suburban municipalities.

2.7.1. Crime and the built environment: a macro-level assessment

Existing research has emphasized the importance of major roads in shaping the spatial distribution of crime and disorder events (Brantingham and Brantingham, 1993c;

Beavon et al., 1994; Rengert et al., 2000; Weisburd et al., 2004, 2009, 2012; Johnson and Bowers, 2010; Groff and Lockwood, 2014). However, several challenges emerge while considering such road-based analysis. The first concerns crime at intersections: when exploring crime in relation to the road network, how can events with uncertain locations be incorporated into the analysis? When considering crime according to road type, each event typically needs to be linked to a road segment to access the associated attribute data. Intersections present a challenge, as these locations are in contact with not one, but often four (and potentially more) separate segments. Due to the complexity associated with appropriately linking intersection data to street segments, these events are often excluded from segment-based analysis (Weisburd et al., 2004, 2009, 2012; Groff, 2011; Curman et al., 2015). However, decisions to exclude this data must consider the impact of such data loss (Braga et al., 2010; Weisburd, 2015; Andresen and Curman, 2016).

Within Coquitlam and Port Coquitlam, events recorded at intersections account for approximately 15% of overall crimes. Rather than excluding this considerable subset of the dataset from the entire study, these locations have been incorporated within all road-based analysis by using the spatial join technique within ArcGIS. When a point falls at a specific address or is recorded at a 100-block, the spatial join makes a direct link between the event and the attributes of the appropriate segment. However, when dealing with events at intersections, ArcGIS randomly selects one of the segments in contact with the point and makes a link based on this selection. While this process introduces uncertainty into the analysis, events recorded at intersections are inherently uncertain. Events may have occurred at the intersecting point of the streets, or may have occurred along one of the segments adjacent to the intersection. By randomly assigning each point to one of the contacting streets, this process links the event to one of the relevant road types; it does not double-count the data point, and does not make assumptions about what segment the event occurred on. For example, a crime recorded at the intersection of an arterial road and a local road is not automatically assumed to be associated with the artery, but instead is randomly assigned to one of the segments. As such, the calculated crime according to road type provided within this analysis includes all available data; while some uncertainty is inherent in this inclusion, the results err on the conservative side and are more likely to under-represent the relevance of arterial roads. Further research must explore alternative

methods of incorporating events at intersections (see for examples, Braga et al., 2010; Andresen and Curman, 2016).

A second challenge emerging when researching crime along roadways is the definition of 'major roads' themselves. What constitutes a 'major' road is open to interpretation and is likely to be dependent on the local environmental design. There is little consistency across existing research regarding which road classifications are to be considered as major: some studies explore highways as the unit of analysis, others incorporate a combination of several high-volume road types (see for examples, Rengert et al., 2000; Brantingham et al., 2009; Groff and Lockwood, 2014). Within Coquitlam and Port Coquitlam, not a single crime event location is recorded along the freeway, and relatively few are associated with local highways. These two categories make up a comparably small proportion of the total road distances within the study municipalities; while typically well-used, these routes include fewer intersections and exits than other road categories. This translates into fewer opportunities to stop and access any targets that may be identified along the route (Brantingham and Brantingham, 1993c). While these road classifications can certainly be thought of as *major*, based on road distance and associated criminal events alone, these higher-level major roads appear unlikely to be directly spatially related to key concentrations of crime within the study site.

In contrast, collector and arterial roads are also well-travelled, but in comparison to freeways and highways they provide ample opportunities to stop, start, identify and access potential targets. Collectors make up nearly 13% of the road network within the study site, and are associated with 15% of recorded crime events. Likewise, over 12% of the local road network is classified as arterial, and 36% of all criminal events fall on these streets. When focusing on the counts and percentages of crime events, as well as the rate of events per kilometer, it is clear that a considerable proportion of events occur on both collector and arterial roads. However, based on these metrics alone, the relative importance of these built environmental features is not immediately clear.

The CQ acts as a standard metric with which to compare rates of crimes, and provides a clear and concise method to quantify the relative importance of different road types within the study site. The CQs measuring overall crime counts per distance of

freeways and highways within the study site are 0 and 0.5 respectively, indicating considerable under-representation of crime along these road types. The CQ for all events along collector roads is 1.17 – a slight, but not considerable over-representation of crime rates on these road types. Arterial roadways, however, display consistent and considerable over-represented CQ values, exceeding the threshold value of 2 when considering all crime events. These patterns are echoed when breaking down crime according to event type, with a minor reduction in magnitude (and a dip below the threshold value) when considering the few federal violations (other than drug crimes) recorded within the study site. In contrast, the CQs of local and other roads within the area remain at or below the local area average, regardless of event type. These findings reiterate the results found in past research, and support the relevance of major roads in determining the concentration of urban crime (Weisburd et al., 2012; Curman et al., 2015). Further, these results indicate that a working definition of major roads should include arteries, but can exclude collectors, highways and freeways within this locale.

At the macro-level, three broad land use categories dominate the local landscape, and are associated with the vast majority of all address-matched crime events. Over one-half of all crimes occur at residential properties – this is no surprise, given the dominance of residential land use within these suburban areas. The residential CQ adds context to the proportion of crime captured within this land use zone, indicating consistent under-representation of events per unit of residential land use across all crime categories. There are comparably fewer crime events associated with property units classified as commercial and CIR; however, such properties display much higher rates of police records per unit. The commercial CQ indicates that the rate of all crime events per property is over thirteen times greater than the study area average; the CIR quotient value of nearly 7 is also indicative of a considerably over-represented crime rate (see Table 2a). These findings are consistent across crime type, and are also consistent with the findings of Kinney and colleagues in their study of a larger neighbouring municipality (2008).

2.7.2. Exploring within categories: meso-level analysis

Just as there is notable variation within the rates of crime according to broad land use classifications, there is also significant variation in crime rates within the actual use

sub-categories. When considering residential land use, multi-family units display far higher rates of crimes per unit than their broader parent category as a whole, as emphasized by the magnitude of the CQs in Table 3a. These inflated rates are due in part to the nature of the land use dataset used in this analysis, which provides one record for each land use at a given address. High-density developments with multiple housing units at the same street address are represented as one property unit. With this caveat in mind, noting the counts of property units and crime events becomes vital when interpreting CQs. The five residential actual use types with the highest CQs combined, account for less than 12% of all crime events occurring on residential addresses (Table 3a). The CQs must be interpreted with care, particularly within multi-unit complexes, due to this rate-based inflation.⁹ In the absence of higher-quality data that can provide insight into the number of users, occupants or sub-units within a given building, the associated rate of crime events per unit must be understood as a rate per complex. In spite of this, the crime rate per complex and CQ can, together, provide insight regarding the specific facility types that are associated with higher counts of crimes within the generally under-represented residential land use category.

The broad commercial land use classification reveals further concentration in crime rates across a number of key sub-categories. Shopping centres are particularly relevant within the study site, displaying both high counts and rates of crimes. The CQ corresponding to the study area's regional mall is nearly 115; the rates of crime per community-level shopping centre is nearly eighteen times that of the average rate of crime per commercial unit within the region. This is consistent with an array of research that has identified such locations as crime attractors and generators (Brantingham and Brantingham, 1993b; 2000; Kinney et al., 2008; Bichler et al., 2011; Frank et al., 2013). In addition to these top categories, hotels, theatre buildings and neighbourhood stores appear as detailed land use categories with disproportionately high rates of crime. While there are very few lots relating to these sub-categories, there are a considerable number of crime events associated with each, indicating that these may be important facilities

⁹ In some cases, the unit-based denominator used to calculate rates per unit provides a resulting rate and CQ measure that is less meaningful than in others. When very few property units within a single sub-category are present, rates may be better understood in conjunction with count information. A table displaying the meso-level land use sub-categories with the highest counts, rather than the highest rates, has also been created, and is available in the Appendix.

within the locale. These findings emphasize that within the highly over-represented commercial land use category, there are several actual use sub-categories where crime events concentrate even more intensely: 35% of all crime events within commercial land use can be accounted for by these five actual use sub-categories.

Within the broad CIR land use classification, hospitals, recreational and cultural buildings, and schools are of particular interest. The CQs associated with these actual use types exceed the threshold value of 2, indicating that crime rates are considerably higher at these actual use sub-types than across the broad CIR land use category as a whole. Government buildings (other than the municipal police station and local courthouse, which were removed from the analysis due to inconsistent reporting practices) and recreational clubs round out the top five actual use sub-categories within the CIR categories – however the CQs associated with these facility types do not surpass the threshold of 2, indicating that the values are not substantially higher than the average rate for all CIR units within the study area. This emphasizes the significant clustering within the broad CIR category as a whole: roughly 71% of all police records associated with CIR land use fall into one of the top three sub-categories (hospitals, recreational and cultural buildings, and schools).

2.7.3. Local-level hot spots: a micro-level analysis

Moving to the micro-level, the exceptionally clustered nature of local crime is further emphasized, as 8% of all crimes are associated with five single blocks across both municipalities (Table 4). Likewise, 9% of all address-matched crimes occur at five single addresses (Table 5). The local importance of arterial roads is once again underscored at the micro-level, as each of the blocks with the highest counts of crime fall within this category. The CQs, calculated for each block, well exceeds the threshold value of 2 in each case– though this is certainly expected, it continues to emphasize the within-category clustering along arteries.

When considering the five top addresses, the local importance of the broad commercial land use type is again emphasized: each of the highest crime addresses is associated with commercial property. Shopping centres emerge as a key facility within this local micro-scale analysis: the regional mall dominates the overall count of crimes at a

single address (as well as its associated CQ), and is followed by two community-level shopping malls. A bank and a hotel round out the top 5 crime addresses. While hotels emerged as a key actual use type within the meso-level analysis, nearly 60% of all crime events at hotels are associated with just one of the five local facilities. Not all local hotels, then, are equally criminogenic, but rather, a single hotel appears to be of local concern. These findings emphasize the within-category clustering present in crime distributions, and underscore the importance of exploring the environmental context through locally-based analysis at multiple scales (Brantingham et al., 1976; Eck et al., 2007; Bowers, 2013).

The emergence of a bank at the micro-scale is of particular interest: this single facility exhibits a high count of events and a CQ with an exceptionally high magnitude, yet banks as a land use sub-category did not emerge within the meso-level analysis. Further exploration of this facility indicates that it shares an address with a community shopping mall. Given the current data availability, it is not clear whether the crimes linked to the address are associated with the bank itself, or with the shopping mall. This could mean that the associated shopping mall, already identified as a local criminogenic feature of interest within the meso- and micro- analyses, is associated with an even larger proportion of local crime – however, exploring such assumptions would require more detail within the crime event dataset than is currently available. The multi-scale methodology implemented within this chapter has allowed for the identification of this anomaly; further research will explore potential methods to address this micro-level uncertainty.

Perhaps most apparent at the micro-scale analysis is the overlap between different environmental features. It is no coincidence that the top block and the top address both contain 396 crime events; they represent the same micro-spatial location. The block with the highest counts of crime also happens to house the regional shopping centre within the study area, adding dual emphasis to this location. This overlap opens the door to a research question warranting further analysis in future studies. Does the spatial overlap between key environmental features result in increased crime concentration?

When considered alongside the results from the macro- and meso-level analyses, the micro-level clustering highlights that not all similar features are equally associated with local crime distributions (Eck et al., 2007; Weisburd et al., 2009, 2012; Bowers, 2013; Groff

and Lockwood, 2014). While arterial roads appear at both the macro and micro-levels as being related to a disproportionate amount of criminal events, these findings certainly do not apply to all arterial blocks: in fact, there are no reported crime events along 30% of the local arterial road distance. Likewise, the micro-scale analysis further reveals that not all local shopping centres and hotels (and certainly not all commercial or CIR properties) are equally associated with crime events. 51% of all commercial properties have no reported crimes, and 73% of all CIR properties are void of recorded criminal activity. Further, while the CIR land use category displays high crime concentrations at the macro-level, the meso-level analysis emphasizes considerable within-category clustering, and none of the top five micro-level addresses are associated with this land use.

The highly clustered nature of crime events is further evident at the city-wide level. 41% of the total road distance across Coquitlam and Port Coquitlam have no reported crime events in 2009, and 58% of all blocks within the two municipalities had one or fewer crime events. These concentrations are even stronger when considering the subset of events linked to an address. 89% of all local addresses have no reported crime events, and a further 7.5% of addresses are associated with just one event. This translates to 11% of local addresses containing 100% of the address-linked criminal events; and just 3.5% of all local addresses containing 73% of all local crime events falling on an address.

2.7.4. Contributions and future research directions

This study has made a number of contributions to the existing body of research exploring crime within the context of the urban built environment. Proposing several adaptations to the location quotient, this research has introduced the category quotient. The CQ is a metric that addresses some existing limitations associated with rate-based measures, while continuing to provide easy identification of crime concentrations. It provides a standardized metric to measure relative concentrations of crime along road networks, allowing for a clear, locally-informed definition of criminogenic major roads. In addition, in applying the CQ across crime categories, land use categories, and spatial scales of analysis, this metric has emphasized the clustered nature of crime within two mid-sized suburban municipalities.

This study has revealed that, in many ways, Coquitlam and Port Coquitlam are consistent with their larger urban counterparts and neighbouring municipalities. Arterial roads, commercial areas and civic, institutional and recreational (CIR) land use categories are the sites of considerable counts and rates of crime. Within these high-crime categories, events concentrate on specific land use sub-types: most notably, commercial crime clusters at shopping centres, while CIR crime clusters at local hospitals, recreation centres and schools. Further concentration at the micro-scale emphasizes the impact of single high-crime blocks and addresses, revealing further within-category crime concentration, and stressing the need for analysis at multiple spatial scales (Brantingham et al., 1976; Brantingham and Brantingham, 1994; Kinney et al., 2008).

While supporting existing research, this chapter has also emphasized the need for further investigation within this field of study. While this research considers crime both in aggregate, as well as by broad crime type, in fitting with the multi-level analytical approach presented herein, it is likely that new patterns and concentrations will emerge with the inclusion of more nuanced crime categories (Andresen and Linning, 2012). Further, in including crime at intersections within the road-based analysis, this research has incorporated some uncertainty along with the expanded dataset. Further research is needed to identify appropriate methods to account for crime in uncertain locations. In addition, findings from this study identify key environmental features based on the location of the crime event itself, matching a single event with its associated road type and/or land use. Subsequent research must look beyond the precise location of these high crime features to explore the wider local impact that such built environmental elements have on crime and disorder within their wider urban region. By exploring the specific association of key environmental features and crime both at the local level and in the immediate surrounding areas, a more complete understanding of the relationship between the local built environment and crime can emerge.

2.8. Conclusion

Crime is not uniformly distributed across urban spaces. Key features within the urban landscape are frequently found to be related to higher counts and rates of disorder and crime events. These locations are typically common activity nodes and major travel

routes which attract high volumes of both motivated offenders and suitable targets. While there has been a wide breadth of research identifying the types of facilities associated with high volumes of crime, there has been a call for further locally-based analyses to determine the applicability of such findings across wider urban settings (see Groff, 2011; Ratcliffe, 2012; Groff and Lockwood, 2014). This chapter serves to add to the relatively small body of research focusing on mid-sized, suburban settings (Seasons, 2003). Findings from this analysis emphasize major roads as the site of a considerable proportion of crime, and further define major roads within the local context as arterial routes. Commercial, and civic, institutional and recreational land use categories house high concentrations of local crimes, but also exhibit considerable within-category clustering at both the meso- and micro-levels. This research emphasizes the need for analysis at multiple scales of aggregation, as nuanced patterns and concentrations emerge with each level of analysis.

Chapter 3.

Beyond the Hotspot: Exploring the Wider Spatial Impact of Crime Attractors, Generators and Major Roads

3.1. Abstract

Crime and disorder events are inherently tied to the built environment within which they occur. Research has emphasized that such events often cluster along arterial roadways and at key crime attracting and generating activity nodes. While methods for the identification and analysis of spatial concentrations of crime continue to advance, a smaller sub-set of research is exploring the context around the high-crime features themselves. While this focused research area is growing, there is a need for continued studies within a variety of urban settings; in particular, there is a shortage of research focusing on smaller locales, which may exhibit different relationships between the built environment and crime than the larger urban settings where existing research is primarily focused. This chapter measures the impact of criminogenic features within two mid-sized suburban municipalities by analysing crime events based on their spatial relationship to locally-identified criminogenic features. The areas immediately surrounding the key local features are the focus of this study. By applying an adapted version of the location quotient, the concentrations of crime surrounding key environmental features are analyzed to identify and measure changes in crime rates as distance increases. Results indicate that different environmental features have vastly different spatial impacts on crime and disorder events within their immediate surroundings.

Keywords: land use, road networks, built environment, crime attractors and generators, proximity, distance

3.2. Introduction

The built environment shapes the way urban residents live and move. Road networks are designed to channel the flow of traffic along specific, predictable routes.

Shopping centres and gas stations are located along these major corridors, and are easily accessible to customers. Schools, hospitals, ambulance stations and fire halls are located in places that are designed to efficiently and safely serve their surrounding catchment areas. The locations of such features are often chosen to streamline the flow and movement of urban residents – and in doing so, these facilities alter the spatial patterns of crime and disorder events. Criminal occurrences are tied to the structure of urban areas, concentrating in some locations while leaving others essentially untouched.

Academic research has identified a variety of urban structural features that are associated with predictably greater amounts of crime and disorder events. These features vary by urban environment, but are often key activity nodes that attract large volumes of people for routine, non-criminal activities (Cohen and Felson, 1979; Brantingham and Brantingham, 1993b; Frank et al., 2013), as well as the major transportation corridors that connect these locations (Brantingham et al., 2009; Curman et al., 2015). These key crime attractors and generators have also been found to impact crime and disorder events within their surrounding neighbourhoods (Brantingham and Brantingham, 1982; Johnson and Bowers, 2010; Groff, 2011; Groff and McCord, 2012; Ratcliffe, 2012; Bowers, 2013; Haberman et al., 2013; Groff, 2013; Groff and Lockwood, 2014). Understanding the impact of such environmental features on the local distribution of crime and disorder is essential for both planning for and responding to these crime hotspots. Existing research, while instructive, has further stressed the importance of understanding these relationships on a local scale, noting that the impacts of potentially criminogenic features and areas may differ according to environmental situation (Haberman et al., 2013) and facility type (Groff and Lockwood, 2014; Groff, 2011; Ratcliffe, 2012).

Focusing on two mid-sized suburban communities within the Metro Vancouver area, this study provides a unique contribution by considering an important, but under-researched urban environment (Seasons, 2003). The proportion of Canadians living in urban areas continues to grow (Statistics Canada, 2012b), with the majority of this growth centred in suburban or peripheral cities (Statistics Canada, 2012a; Gordon and Janzen, 2013; Turcotte, 2001). With the growing importance of suburban regions in mind, understanding the dynamic connections between crime and urban features within such locales is increasingly relevant. This research further contributes to existing studies by

exploring the micro-level spatial impact of a range of locally-relevant environmental features within the same study site, therefore allowing for a comparison of the varying connections between different facility types and local crime.

3.3. Background: Crime and the Built Environment

Crime and disorder events tend to concentrate in specific areas within the urban environment, while leaving other locations unaffected. The built environment plays a key role in determining where such events cluster. Several theoretical approaches within environmental criminology help to explain this relationship. The routine activities approach emphasizes the importance of normal, mundane human activities in shaping the distributions of crime events (Cohen and Felson, 1979). Within this approach, a motivated offender and a suitable target must intersect at the same time and place, in the absence of a capable guardian, in order for a crime to occur. The physical urban structure influences the movement of people, and in doing so, influences where and when such opportunities for criminal occurrences arise. More offences may occur, then, at common activity nodes where there are more potential offenders and targets alike. The type of activities that routinely occur at specific locations will shape the type of criminal opportunities that are available at these sites, and in turn, the type and amount of crime that occurs (Felson, 1987).

The Brantinghams have investigated the relationship between the built environment and crime in detail. Their theoretical works further understanding about the geometry of crime, recognizing that there are patterns to individual movement within the urban environment (Brantingham and Brantingham, 1981, 1991, 1993a). Offenders and non-offenders alike move through the city in non-random and predictable ways. Individuals travel from home, to work, to shopping and entertainment areas – their key activity nodes – using pathways defined by the built physical environment. This combination of nodes and pathways forms an individual's activity space; the broader space beyond these frequented areas forms an awareness space. Offenders typically select targets from specific areas that are within their awareness space. This is done for a variety of reasons, including local familiarity and comfort with the area, as well as ease of both access and escape (Brantingham and Brantingham, 1991). The majority of the nodes and pathways

within one's awareness space are shared amongst many people – for example, the grocery store, the school, and the major roads connecting these areas are all part of a common awareness space (Brantingham and Brantingham, 1991, 1993c). With this in mind, these common spaces have a higher likelihood of criminal occurrences, as they are part of the awareness space of more offenders and are rich in potential targets (Brantingham and Brantingham, 2000).

Recognizing that not all common activity spaces are equally as prone to criminal occurrences, the Brantinghams introduced the concepts of crime generators and attractors (Brantingham and Brantingham, 1995). Generators are locations or areas that draw a large number of individuals for non-criminal activities. With these crowds come greater numbers of potential offenders and potential targets, as well as a higher likelihood that seemingly good opportunities for criminal activity may arise. These include facilities such as malls, mass transit nodes and parking lots (Brantingham and Brantingham, 1995). The most common criminal occurrences at generators are crimes of opportunities. Attractors are destinations that offenders travel to with the specific intention to commit crimes. These are areas that have a reputation of being a good location for specific criminal activities. Offenders may travel long distances to reach these destinations, and come to these areas planning to carry out a particular offence (Brantingham and Brantingham, 1995).

3.3.1. Crime at and around the attractor/generator

The concept of the crime generator and attractor has been well-researched in recent years. Findings frequently identify specific nodes that tend to draw criminal activity across a variety of locales, including shopping centres, liquor serving establishments, parks, transit nodes, and schools (Roncek and LoBosco, 1983; Brantingham and Brantingham, 1994, 1995; Kinney, 1999; Kinney et al., 2008; Groff, 2011, 2014; Groff and McCord, 2012; Frank et al., 2013; Groff and Lockwood, 2014). In addition, the major roads connecting these locations act as a linear attractor, with criminal events also clustering along specific road types (Brantingham and Brantingham, 1993a, 1993b, 1995; Brantingham et al., 2009; Johnson and Bowers, 2010) and on specific blocks (Weisburd et al., 2004, 2009, 2012; Groff et al., 2010; Groff, 2013; Curman et al., 2015). Establishing a wide knowledge base regarding the urban features at which criminal events tend to

cluster is important at number of levels. Such local knowledge can highlight current micro-level hotspots of crime, aiding in the allocation of police resources to address existing concerns. In addition, understanding the local connections between the built environment and crime can identify areas where hotspots may develop based on the presence or planned development of identified environmental features. With such knowledge, preventative measures at the policing or planning levels may be able to mitigate potential crime hot-spots prior to development.

In addition to the range of research identifying the specific facilities and environmental features where crime events tend to concentrate, a focused body of literature explores the wider context *beyond* the criminogenic feature itself. Brantingham and Brantingham's geometry of crime emphasizes the importance of distance by theorizing that offenders search for targets near the locations where they spend their time: home, work, shopping and entertainment districts, and around the pathways that link these features (Brantingham and Brantingham, 1981, 1991). This search area follows the principles of distance decay in that as distance from key features within an offender's awareness space increases, the search intensity decreases. The authors illustrate this principle by measuring the rates of commercial burglary within two blocks of common, locally-identified activity nodes. Findings indicate that such crimes occur at far higher rates within these micro spaces than compared to the city-wide rates as a whole (Brantingham and Brantingham, 1982; 1993b).

A growing number of scholars have further researched the impact of key nodes and pathways on crime within their surrounding environment. Roncek and colleagues explore the distribution of crime events around public high schools, finding concentrations along blocks adjacent to these facilities (Roncek and LoBosco, 1983; Roncek and Faggiani, 1985). In a further exploration of environment-based concentrations, Kinney's thorough analysis of crime distributions in the micro-spaces around bars in Downtown Vancouver emphasizes the impact that these facilities have on the distribution of police calls for service (Kinney, 1999). Incivility-related calls and violent offences increase within the range of 10% when considering the spaces located within 50 meters of the facilities; correspondingly, property crimes decrease by the same magnitude within these areas.

These findings are further concentrated when limiting the analysis to the timeframe more closely associated with bar-time activities (Kinney, 1999).

Several studies centring on Philadelphia and the surrounding metropolitan area explore the spatial impact of crime attractors and generators within the large metropolitan centre. Notably, Rengert and colleagues consider the connections between crime and the built environment within a number of detailed studies centred on Wilmington, Delaware, which is a smaller, automobile-based suburb within the greater Philadelphia metropolitan area (Rengert et al., 2000; 2005). Findings reveal that drug crimes cluster within two kilometers of the interstate route running through the city (Rengert et al., 2000), as well as within 400 feet of local taverns (Rengert et al., 2005). Adapting the methodology introduced in Rengert's 2005 collaboration, McCord and Ratcliffe (2007) explore drug arrests in proximity to a number of local crime attractors. While drug crimes are significantly clustered around each feature, these effects are reduced upon accounting for local measures of social disorganization (McCord and Ratcliffe, 2007). In contrast, Groff and Lockwood (2014) explore the impact of a number of local criminogenic facilities (bars, transit nodes, schools, halfway houses and drug treatment centres) on crimes at the street segment level. Results indicate a strong level of spatial influence surrounding the facilities, which varies by both facility and crime type, and remains after accounting for sociodemographic variables. Further explorations of key activity nodes within Philadelphia have identified that crime events cluster in and around parks in a non-linear fashion (Groff and McCord, 2012), and that violent crimes concentrate within 85 feet of the city's liquor serving establishments (Ratcliffe, 2012). Street robberies in Philadelphia, in contrast, spatially cluster around subway stations (McCord and Ratcliffe, 2009) and around some (but not all) public housing facilities (Haberman et al., 2013).

The proximity research centering on and around Philadelphia has been instrumental in furthering an understanding of how crime events cluster around local crime attractors, generators and pathways. Overall, results have emphasized the differing spatial effects of different environmental features. The variation in results within Philadelphia's metropolitan area emphasize the need for further research, exploring a wider variety of crimes, facilities, and locales. Recognizing this need, several studies within the UK have expanded understanding about the spatial influence that key environmental features have

on crime rates. Johnson and Bowers (2010) identify the importance of access and street connectivity, finding that street segments with more connections, particularly to major roads, have higher crime than blocks with fewer access points. Bowers (2013) further explores the spatial impact of risky facilities, or specific crime attractors and generators. Results indicate that high crime facilities are positively associated with external crimes located nearby these places (Bowers, 2013).

A growing number of studies focusing on the Pacific Northwest region have sought to further measure the spatial impact of environmental features on surrounding crime events. Research undertaken in Seattle provides an additional perspective on the impact of drinking establishments on crime events within the surrounding area (Groff, 2011). Results indicate that crime clusters within three street blocks of alcohol-related facilities. Further work centred within Canada's metropolitan Vancouver area has explored the spatial impact that the edges – conceptualized as the divides between two different land use types – have on the concentration of crime (Song et al., 2013; 2016). These studies have highlighted the considerable increase in the volume of crime within close proximities to edges. The crime rate and spatial effect of an edge is impacted by the type of land use present (Song et al., 2013), as well as by the presence of additional crime attractors within the vicinity (Song et al., 2016). Further, while the general patterns of clustering near edges appears to be consistent across a number of local study sites, the crime rates and spatial impact of the edges varies by municipality (Song et al., 2016).

Decades of research within environmental criminology and beyond have emphasized the non-random nature of criminal activity. In recent years, such research has increasingly focused on identifying the urban features in and around which crimes tend to concentrate. A relatively small, but growing area of research aims to quantify the spatial impact that key facilities and pathways have on crime concentrations within their surrounding environments. Several general findings and recommendations have emerged from within this body of research. First, the type of facility or environmental feature matters. Crime patterns concentrate differently around different environmental features; additional research is needed to further detail these varying influences (Groff and Lockwood, 2014; Song et al., 2016). Second, not all similar facilities are equal. Crimes may concentrate in spatial proximity to some types of bars, for example, while showing no significant clustering

around others (see for example, Kinney, 1999; Eck et al., 2007; Bowers, 2013; Haberman et al., 2013). Third, the location matters: patterns within one urban environment are not necessarily generalizable to other environments, making local-level analysis increasingly important (Rengert et al., 2000; McCord and Ratcliffe, 2007; Charron et al., 2008; Song et al., 2016). Lastly, the methods used to identify and quantify proximal clusters of crime have a significant influence on results (Groff, 2011, 2013; Ratcliffe, 2012; Song et al., 2016). This body of research has emphasized the need for continued explorations of the wider spatial impact of high-crime facilities and features across a variety of urban environments, while providing best-practice methodological guidance to be considered within such research. The following section reviews the key methodological approaches and recommendations garnered from existing research within the field.

3.3.2. Measuring proximity – a review of standard methods:

A number of methods have been developed and adapted to quantify the spatial impact of environmental features. Methods often involve capturing and counting all crime events occurring within a buffer distance from a feature of interest, in order to calculate a rate of events per buffer area. This measure can be compared to the region-wide crime rate, or to the rate within other buffers, in order to determine where the density of crime events is highest (Kinney, 1999; Rengert et al., 2000; Rengert et al. 2005; McCord and Ratcliffe, 2007, 2009; Groff, 2011; Groff and McCord, 2012; Ratcliffe, 2012; Song et al., 2013, 2016). Two key methodological challenges emerge when following this approach: determining how to construct the buffers to best capture proximal events, and determining the most appropriate bandwidth for the buffer distances (Groff, 2011; Ratcliffe, 2012).

The buffer debate: Euclidean or network-based?

Buffers are most conveniently constructed using Euclidean distance measures. Euclidean buffers capture all areas located within a given distance from a selected feature, as measured in a straight line distance moving in all directions. The resulting area is a circular form surrounding the feature of interest (or, when a series of Euclidean buffers are used, a set of circular rings radiating outward from the feature). This method is easy to understand and visualize, and has the advantage of being computationally simple as well. As such, it has been used within a number of studies exploring crime concentrations in

proximity to key environmental features (see for examples, Kinney, 1999; Rengert et al., 2000; Rengert et al., 2005; Ratcliffe, 2012). An example of a simple Euclidean buffer is illustrated in Figure 3, below, represented by the yellow circular polygon surrounding a point representing a school.

While this method has advantages, in simplifying proximity to straight-line measures, it also has several limitations. Euclidean-based buffers are unable to account for both the network-based connectivity, as well as the geographical barriers that exists within the environment (Schuurman et al., 2006a; Oliver et al., 2007). For example, properties may be located near one another when considering Euclidean distance measures, but disconnects within the street network, or geographic barriers such as rivers, ravines or mountains may prevent direct access between these locations. Euclidean buffers do not account for actual travel distance or accessibility, but rather, identify an area that includes every feature within a given straight-line distance. This is illustrated in Figure 3: there are 348 property units located within 0.5 kilometers of the school (represented by a red triangle in the centre of the image, and measured using Euclidean distance). Not all of these properties, however, are located within 0.5 kilometers of travel distance from the school, nor do all of the properties display direct access to the school via the street network. The Euclidean buffer, as illustrated, has an area of 0.79 square kilometers.

As an alternative to the Euclidean-based buffer, distance measures are increasingly being captured using network-based analyses (see for example, Schuurman et al., 2006a; Oliver et al., 2007; Groff, 2011). While this method is more computationally intensive, it selects all features or areas within a set distance, as measured along a road network. As such, the network-based distance measures better account for the actual connectivity within the landscape, because urban movement is often constrained to the road network itself (Martin et al., 2002; Schuurman et al., 2006a, Groff, 2011). Road network based buffers are typically more restrictive than Euclidean, capturing fewer points within a more condensed area. Figure 3 portrays a 0.5 kilometer network-based buffer, displayed as an irregular blue polygon. This buffer, generated in ArcGIS using the Network Analyst extension, has been trimmed to 25 meters on either side of the road network, and captures 185 neighboring property units within 0.20 square kilometers.

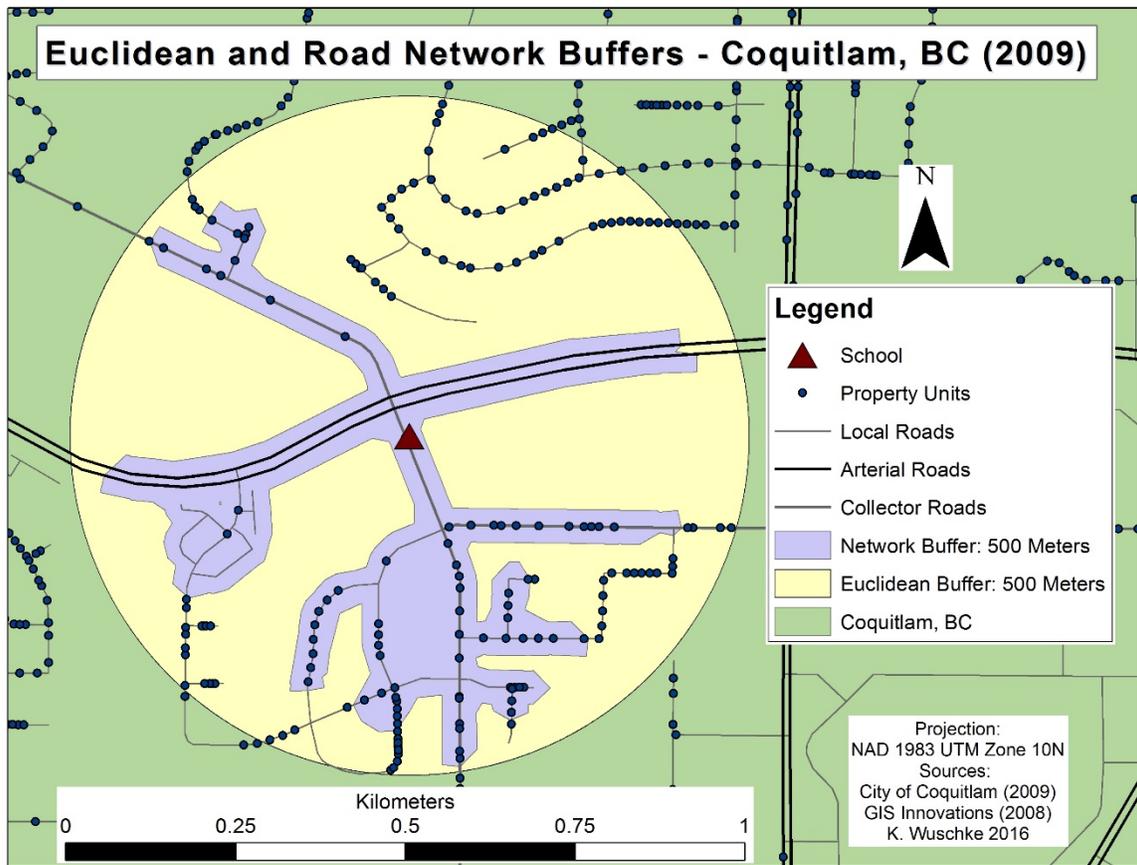


Figure 3: A comparison of 0.5 kilometer Euclidean and network-based buffers. Coquitlam, 2009.

The impact of the choice in buffers is clearly illustrated within Figure 3. The Euclidean buffer identifies more property units as being within 0.5 kilometers of the selected school than does the network-based buffer. Further, the Euclidean buffer covers an area that is considerably larger than the network-based alternative. This results in a Euclidean-based rate of 443 properties per square kilometer. In contrast, the network-based buffer selects far fewer properties, but also captures a far narrower area. The resulting rate using the network-based measure is 909 properties per square kilometer, indicating a far greater density of properties within the same bandwidth. Which measure, then, is more accurate?

A number of researchers have highlighted the shortcomings of Euclidean-based measures. The over-representation in the number of properties (or events) captured within a given bandwidth is concerning, particularly to researchers and practitioners exploring

questions regarding service accessibility and delivery. Incorrectly identifying a given location as accessible within a set distance or timeframe can result in inconvenience when considering school zone catchment areas, for example; however, the same misrepresentation can have significant consequences when considering emergency response times (Martin et al., 2002; Schuurman et al., 2006a). In addition, over-estimating the area that can be accessed within a given buffer zone impacts the resulting density rates. Density measures, including crime rates, are often calculated as a count of events, standardized by a given area. When the area measure is inflated, the corresponding rates are reduced (Groff, 2011; Ratcliffe, 2012). In studies seeking to identify and measure concentrations of crime, this inflated area and associated reduced crime rate has the potential to greatly impact results.

Several researchers have recognized these concerns and have responded by proposing adjustments to standard Euclidean-based crime rate calculations. Ratcliffe (2012) emphasizes that the most commonly used geocoding process generalizes the locations where crime occurrences (or any address point, for that matter) can be represented on a map. Crime events may occur in a park, inside a building, or on a street, for example, but regardless of the precise location of the occurrence, it is typically recorded within police records management systems as a street address, a 100-block, or an intersection. When these locations are geocoded, the point representing the event is placed on the street network itself, or can be mapped at a standard offset on the appropriate side of the street. This generalization process means that if an area does not have network access, crime events will not be geocoded onto this location. With this in mind, Ratcliffe (2012) proposes that the area measures can be reduced by removing, or “clipping” out parks and waterways, which are some of the urban spaces where crime events are unable to be represented. By reducing the buffer areas by large expanses of land where crime events cannot be mapped to, this method reduces the impact of an inflated area measure on the resulting crime rate (Ratcliffe, 2012).

While Ratcliffe’s measures to reduce area inflation results an improvement to traditional crime rate calculations, it does not fully address the concerns across all urban environments. In highly urbanised locations where the road network is a consistent density throughout the study site, the adjusted area may serve as an appropriate crime rate

denominator. However, in areas with less consistency in network density, as is typically found in suburban environments (and as displayed in Figure 3, above), the removal of park space and waterways does not sufficiently or consistently account for all areas without road access (see for example, Johnson and Bowers, 2010). As such, the resulting area measures not only over-estimate the locations where events may be geocoded to, this over-estimation is unlikely to be consistent across the study site.

Song and colleagues (2013; 2016) respond to the challenge associated with area over-representation by selecting an entirely different denominator with which to calculate crime rates. Instead of standardizing crime counts by the areas captured within set buffer distances, the authors standardize crimes according to the number of property units captured within the same Euclidean buffer. By using a point-based denominator, Song and colleagues are removing area from the equation; as such, they inherently exclude the locations where crime events are unable to be represented. However, when calculating a crime rate, careful consideration must be given to ensure that the denominator is an appropriate match for the crime events included in the analysis (Harries, 1991; Johnson and Bowers, 2010; Andresen, 2014; Malleson and Andresen, 2015b). Careful consideration must therefore be given to crimes occurring on the street network and recorded at the block or intersection: these events are not linked to an address, therefore they cannot be directly tied to a specific property unit location. Without accounting for this mismatch between such crime events and property units, this method may result in the use of a denominator value that is too restrictive, leading to an inflated crime rate.

Both Ratcliffe (2012) and Song and co-authors (2013; 2016) have recognized the challenges associated with calculating area-based crime rates, specifically while using Euclidean buffers. While both of these studies propose methods to improve upon traditional rate-based calculations, some limitations have not been fully addressed within the adapted methodologies. Further, while both methods propose adjustments to the crime rate denominator, neither adaptation is able to account for the over-estimation of the numerator: the count of events within a given bandwidth range. As displayed in Figure 3, there are considerably more properties identified as being within 0.5 kilometers from the school when measured using a Euclidean buffer, than when measured along the road network. While Euclidean-based measurement continues to be frequently used within

academic literature, these combined inaccuracies suggest that access-based measurements are preferable where computationally possible.

Best-practice research based out of both geography and criminology have emphasized that improved measures of access can be acquired by using network-based connections rather than Euclidean distances (Martin et al., 2002; Schuurman et al., 2006a; Oliver et al., 2007; Groff, 2011, 2013). Findings further indicate that these improvements are consistent over a variety of landscapes – from dense metropolitan settings (Groff, 2011) to smaller urban environments (Oliver et al., 2007) to rural and remote locales (Schuurman et al., 2006a). As network-based measures have been found to arrive at a more accurate representation of accessibility and connectivity, such measures provide a more suitable measurement of proximity.

Network-based approaches allow for a more accurate measurement of the functional proximity between locations. However, the count of proximal features (for example, the count of properties within 0.5 kilometers of a school, as illustrated in Figure 3) typically requires standardization prior to comparison between groups. In this vein, network-based rate calculations present similar challenges to their Euclidean counterparts, and these challenges have been addressed in a variety of ways. In a 1982 study, the Brantinghams measure commercial burglary rates according to street block face, comparing the rates of burglary on blocks contiguous to key crime attractors within the urban landscape, to those located more than two blocks away from features of interest. In this study, the authors calculate rates of burglaries per 10 stores (Brantingham and Brantingham, 1982). Given that the crime under investigation can be tied precisely to a store location, this standardization method proves to be an effective measure; however, this denominator isn't widely applicable. In contrast, in Groff's network based analysis of crime concentrations in proximity to liquor serving establishments, she standardizes crime counts according to the network-based buffer area (Groff, 2011). This denominator can be applied more broadly than can a unit-specific standardization; however, it also has the potential to include areas where crime events cannot occur (or where they cannot be geocoded to) (Groff, 2011; Ratcliffe, 2012). However, when network-based buffers are trimmed to a uniform distance beyond the road network itself (as displayed in Figure 3),

the impact of over-representation within the area-based denominator is mitigated, as this over-representation is consistent across the study area.

A breadth of existing research has compared and contrasted the use of both Euclidean and network based buffers within a range of environments. Findings consistently support the use of network-based measures, indicating that by taking into account the true connectivity of the landscape, more accurate assessments of both access and proximity can be calculated (Martin et al., 2002; Schuurman et al., 2006a; Oliver et al., 2007; Groff, 2011). While a number of adjustments have been implemented to address existing concerns with Euclidean, rate-based measurements (see for example, Ratcliffe, 2012, and Song et al., 2013, 2016), these adapted methodologies are primarily aimed at improving the accuracy of the rate denominator, and do not address the concerns associated with over-estimating connectivity and accessibility. Network-based measures, like all crime measures, still require careful consideration of the most appropriate standardization method; however, the increased accuracy of this measure indicates that it is a clear preference when computational ability is present.

Identifying an Appropriate Bandwidth:

Upon selecting a buffer method, the next key challenge involves identifying the most appropriate bandwidth with which to classify events. The bandwidths represent the search distance, as measured away from the feature of interest. All events located within the chosen bandwidth distances are grouped and frequently measured as a rate, with each event typically given an equal weighting (McCord and Ratcliffe, 2009; Groff, 2011). This practice highlights the importance of careful bandwidth selection – when aggregating point data, groupings will generalize event locations and therefore may mask within-group clustering (McCord and Ratcliffe, 2009). Such within-group clustering is most likely to be masked when larger bandwidth sizes are selected. Conversely, when smaller bandwidths are selected, there are likely to be fewer events per grouping, thus having potentially significant impacts on rate comparisons between groups (Johnson and Bowers, 2010).

There have been a range of best practices identified throughout research in this area. When exploring crime concentrations in proximity to bars, Kinney (1999) tests three buffer bandwidths: 160 meters, 100 meters and 50 meters. While all buffers reveal

evidence of clustering around the alcohol establishments, the greatest clustering is isolated within the smallest, 50 meter buffer (Kinney, 1999). Groff's comprehensive review on the topic echoes these sentiments. She compares results from a series of bandwidths based on average street length (122 meters) to those based on a standard measure used within planning research to represent an average walkable distance (402 meters) (Groff, 2011). Her findings further recommend the use of smaller buffer bandwidths, emphasizing that micro-spatial details emerge at smaller units which are masked by larger distance groupings (Groff, 2011). The move towards small bandwidth distances receives continued support from both Song and colleagues (2013, 2016) and Ratcliffe (2012), both of whom employ minute buffer distances in an effort to capture the nuanced changes at the micro-scale (using 10 meter, and 15-meter buffers, respectively). Results from both studies identify clusters of crime located at small distances from features of interest, emphasizing the importance of selecting small buffer bandwidths to reduce the likelihood of generalizing such micro-scale crime patterns (Ratcliffe, 2012; Song et al., 2013, 2016).

Two key methodological recommendations emerge through the evolving body of research exploring crime clusters in proximity to key urban features. First, when measuring the proximity between features, methods that account for accessibility provide results that most accurately represent micro-scale clustering. Such analyses based on connectivity via the road network allow for greater recognition of actual travel distances, while also accounting for environmental barriers to access (Groff, 2011; Groff and Lockwood, 2014). Second, when considering the bandwidth distances to classify nearness, smaller measures better reveal nuances in the spatial patterns which are hidden at larger geographic units (Kinney, 1999; Groff et al., 2010; Groff, 2011). This chapter builds upon such previous research by measuring how crime events cluster near five types of locally-identified criminogenic environmental features within two suburban municipalities. It seeks to contribute to existing literature by merging the best practices identified across previous research, measuring proximity based on network connectivity, and grouping data at micro-scale distances. It further extends the methodological discussion by proposing an alternative measure to the area-based and unit-based crime rates that are frequently used within the field.

3.4. The Study Area: Coquitlam and Port Coquitlam, BC

The Metro Vancouver area has been the site of considerable urban growth and development within recent years. With over 2.3 million residents, Vancouver is the third largest census metropolitan area in Canada, and is growing at a rate that exceeds the national average (2011 figures, as reported by Statistics Canada, 2012a). However, for over a decade, much of this population growth has been focused not in the city's dense urban core, but in the peripheral suburban municipalities (Turcotte, 2001; Statistics Canada, 2012a, Gordon and Janzen, 2013). The metropolitan region's growth strategy has fostered such peripheral development by designing a number of localized town centres throughout the area. These clusters contain high-density land use developments and access points to the region-wide mass transportation system, acting as local commercial hubs for surrounding communities (Metro Vancouver, 2011).

Coquitlam, British Columbia, contains one of these regional centres. With a population of just over 125,000, Coquitlam is the fifth largest city within the Metropolitan Vancouver area (Statistics Canada, 2012a). Coquitlam's city centre has been the site of significant redevelopment in recent years as the area transforms from a primarily low-density residential suburb, into a local downtown core with a dense mix of urban land uses. Local developments include significant expansions in and around the regional shopping centre, a redeveloped city hall and community facilities, a large college campus, and a network of pedestrian-oriented pathways connecting the developments (City of Coquitlam, 2008). In addition, the city centre area will be connected to downtown Vancouver, as well as to other regional hubs via the Evergreen rapid transit line, slated to become operational in 2017. In light of this continued redevelopment, the city continues to expand, growing at a higher rate than the metropolitan region as a whole (Statistics Canada, 2012a).

One of the local municipalities served by the redeveloped Coquitlam City Centre area is neighbouring Port Coquitlam. With a population of just over 50,000 residents, Port Coquitlam is predominantly residential in nature. It is experiencing population growth as well, though it is growing at a rate just below the region-wide average (Statistics Canada, 2012a). In the midst of the growth and redevelopment occurring within these cities, there is a pressing need to understand the interplay between the changing built environment and

local concentrations of crime. This study builds upon the findings presented in a previous study of the same location by exploring crime in the areas surrounding locally-identified crime attractors and generators.

3.5. Data Sources and Data Preparation:

Crime data were provided for this analysis by the Coquitlam Detachment of the Royal Canadian Mounted Police; the municipal police force serving both Coquitlam and Port Coquitlam. All recorded crime records from 2009, as stored in the detachment's police records management system, were provided (n = 39,387). Data were cleaned and geocoded at a high success rate (94%), then were clipped to remove all records associated with events that occurred outside of the municipal boundaries of either Coquitlam, or Port Coquitlam (424 events). The police records data were further reduced by removing all records pertaining to unfounded events (7,215 records), as well as all records associated with police statistics codes (16,683 records). Lastly, all records occurring at either the police department or the provincial courthouse were excluded from the analysis (82 events). The final dataset includes 12,786 geocoded crime events.

The local built environment was represented in this analysis by two additional datasets – a detailed local road network, and a detailed land use dataset. The road network was provided by the Coquitlam RCMP Detachment, and was developed by a private local geospatial company. It includes 776 kilometers of roads, categorized according to road type. The data used in this analysis were updated in 2008. The land use data incorporated into this study were collected from the municipal planning departments of Coquitlam and Port Coquitlam. These address-level datasets were developed by the British Columbia Assessment Authority, a local independent crown corporation that collects detailed valuation and actual use data about each property within the province for taxation purposes. Information is updated each year to ensure consistency. The 2009 actual use data for both Coquitlam and Port Coquitlam were combined for incorporation into this analysis (n = 59,711). After cleaning, geocoding, and merging records to ensure that one record was listed for every address within the study area, the final land use dataset contained 37,039 records.

Each of these datasets were systematically merged for use within this study. First, the road network data was spatially joined onto the crime event data to provide information about the road type on which each event occurred¹⁰. Second, the land use data were joined to the subset of crime event data that had a precise address location (9,593 events) in order to provide detailed use of land information for every possible crime event. These datasets form the foundation for the proximity analysis within this study.

3.6. Methodology

3.6.1. Local area analysis: Reviewing previous findings

Previous research within this study area identifies a number of local environmental features that are associated with a disproportionate volume of crime (Chapter 2). A number of features associated with local concentrations of crime are consistent with existing literature within the field. At the macro level, arterial roadways, and both commercial, and civic, institutional and recreational (CIR) land use types reveal higher than expected volumes of crimes than compared to other road types and land use categories. These findings are consistent with existing literature emphasizing the importance of these features within other study locales (see for examples Weisburd et al., 2004, 2012; Kinney et al., 2008; Song et al., 2013; Curman et al., 2015). However, when exploring within these high-crime features, further patterns emerge at both the meso- and micro- levels of analysis.

When exploring within the broad commercial land use category, several specific sub-categories emerge as being associated with high volumes of crime within Coquitlam and Port Coquitlam. The area's regional shopping mall, as well as the 7 community shopping malls, consistently appear as important local features. In addition, the few properties within the locale identified as hotels, theatres, and neighbourhood stores are

¹⁰ While the process of spatially joining road type data to point-based crime event data is straightforward for most events, this process presents challenges for the 1,883 crime events recorded at intersections. As these events are typically geocoded at the intersection of four street segments, ArcGIS randomly chooses one of the connecting segments and assigns the road attribute data from this segment to the intersection event. Limitations associated with this process are discussed below.

each associated with a rate of crime per address that is considerably higher than the crime across the commercial land use category as a whole. When exploring within the broad CIR category, hospitals, recreational buildings and educational facilities emerge as the land use sub-types with disproportionate rates of crime (Chapter 2).

A micro-scale analysis of local built environmental features reinforces several meso-level findings, while revealing additional connections as well. The top five single blocks with the highest crime rates are arterial; the top 5 single addresses with the highest crime counts are each commercial. Shopping malls – both regional and community – continue to drive local crime patterns at the micro-scale. A single bank and a single hotel also emerge at the micro-scale, emphasizing the importance of multi-scale analyses to identify and explore crime concentrations within land use categories (Eck et al., 2007; Bowers, 2013). With this in mind – categories emerging at one scale of analysis must be carefully explored at other scales in order to best understand the environmental features most associated with local crime (Chapter 2).

Through a review of the results from a local analysis of this study site, it becomes clear that a number of environmental features are of key importance when considering the distributions of crime within Coquitlam and Port Coquitlam. Arterial roads are associated with more crime than are other road classifications. Some commercial and CIR properties are also the sites of a disproportionate amount of local crimes. Shopping centres – both regional and community – are relevant across multiple scales of analysis. Hotels, theatres, neighbourhood stores and a bank also appear to be relevant sites of crime concentrations – though these findings are not consistent across multiple scales of analysis. Hospitals, recreation centres and schools are driving a very large proportion of the crime events occurring within the CIR land use category. Each of these categories of built environmental features are associated with a considerable amount of local crimes on site – but what happens in the urban spaces near these features? Does crime concentrate around these locations as well – and if so, how far around these features?

3.6.2. Exploring the wider spatial impact of local criminogenic features

A number of authors have explored and measured the impact of spatial proximity to key criminogenic features on crime patterns within nearby urban areas. Building off of best practices as identified in the work of Kinney (1999), Groff (2011), Groff and Lockwood (2014), Ratcliffe (2012) and Song and colleagues (2013, 2016), this study adapts and expands upon existing techniques to both identify and measure the clustering of crime around local features of interest. To begin, high-crime environmental features from within the locale are identified and selected for further analysis. A variety of facilities and features were chosen for further exploration, and include arterial roads, as well as shopping centres (combining both regional and community categories), hospitals, recreational centres and schools. These locations were selected to include a range of locally-relevant feature types, with each category having high counts and rates of local crime. The top road type, as well as the highest crime features from both the commercial and CIR land use categories were identified for initial comparison, though this selection could be expanded to include any additional feature of interest.

Using ESRI's ArcGIS (version 10.2), a separate point-based shapefile was created for each feature. This was a straightforward process for each of the address-based land use features, including the shopping centres, hospitals, recreational centres, and schools: each set of land use types were selected and exported individually, forming four separate point files. As line files, the arterial roads needed to be converted to a point-based feature – this was done by creating a new point shapefile, and using ArcGIS's Editor Tool, adding a series of points at 10 meter intervals along the centerline of all arterial roads. Additional points were added at the vertices of each arterial line segment, resulting in a single point file representing this linear road category.

ArcGIS's Network Analyst extension was then used to create a series of micro-scale, network-based buffers surrounding each local feature of interest. Point features were input as facilities, one at a time, ensuring that all points were snapped to the road centerline. A series of buffers were then developed using the *create service area* function, selecting 15 meter buffer intervals and extending for 600 meters outward from the facilities of interest. The 15 meter buffer distance was selected to recognize past research that has

emphasized the importance of micro-scale analysis (see for examples, Song et al., 2013, 2016; Ratcliffe, 2012; Kinney, 1999). Both larger and smaller buffer sizes were tested as well. 50 meter buffers appeared to mask some micro-level clustering within categories, while 10 meter buffers produced a large number of distance measures capturing few or no crime events at all. Based on these explorations, 15 meter distances were identified as a suitable balance between capturing micro-scale clusters, while reducing the negative impact of small crime counts within buffers. All buffers were merged by their break value to ensure that if the service areas surrounding two facilities touched, they would be joined together to eliminate double-counting of events. Upon creation of the service area buffers, the resulting area files were clipped to 0.5 meters on either side of the road network. The final shapefiles essentially delineate 15 meter intervals along the road network, radiating away from each feature of interest.

All crime data were then spatially joined to the network-based buffers in order to capture a count of events per distance interval. As the focus of this analysis is to study the concentration of crime occurring in the spaces *beyond* each feature of interest, any event occurring at the study site itself was excluded from the spatial join. To clarify, all crime records that were linked to arterial roads during the initial spatial join (n = 4541) were excluded from the analysis of events occurring nearby arteries; likewise, all events occurring at shopping centres (n = 820) were excluded from the analysis of crime concentrations near malls. The result of this step was a series of five shapefiles (one for each identified criminogenic feature), each containing 40 segments representing 15 meter distance intervals as measured away from the feature. Attributes for each buffer segment include a count of the total number of crime events, as well as the corresponding road length contained within the buffer.

In order to quantify and compare the density of crime within each buffer, an adapted version of the location quotient is applied. The location quotient is a standardized measure that enables comparison of the proportion of crime between sub-areas of the same larger region (Brantingham and Brantingham, 1993b; McCord and Ratcliffe, 2007; Andresen, 2007, 2009; Ratcliffe and Rengert, 2008; Andresen et al., 2009; Groff, 2011; Carleton et al., 2014). While traditionally used within criminology as a measure of crime specialization, the location quotient has been adapted in some recent studies to act as a standardized

crime rate. One such adaptation is the category quotient (CQ) (as described in Chapter 2). The CQ reconceptualises the sub-areas used in traditional location quotient analysis. Rather than requiring contiguous geographic sub-areas such as census boundaries, the CQ groups events according to a similar attribute – for example, road type or land use – or in this case, distance from a given road type or land use. The rate of events per road distance is calculated for a given sub-area, then is standardized by the total count of crime per road distance across the larger study site. When used to measure changes in crime density between buffer distances, the CQ is calculated as follows:

$$CQ = \frac{C_n}{D_n} \bigg/ \frac{C_N}{D_N}$$

Where

CQ = Category quotient

C_n = Count of crimes occurring within buffer n (within Region N)

D_n = Total distance of road within buffer n (within Region N)

C_N = Count of crime within the entire Region N

D_N = Total distance of all roads within entire Region N

The resulting calculation is a positive value ranging around 1. If the value is less than 1, the sub-area in question has less crime per road distance than the wider region; if the value is greater than 1, the crime concentration in the sub-area is higher than the regional average. The value itself can be understood as a multiple of the region-wide crime rate. For example, a CQ value of 2 indicates that the sub-area in question has twice the crime rate of the region as a whole. While there is not a standard test with which to determine the statistical significance of the CQ value, past research has chosen a threshold of 2 as a value of interest¹¹. Sub-areas with CQ values exceeding this threshold reveal considerable over-representation of crime given the overall trends found within the region as a whole (Groff, 2011; Groff and McCord, 2012). CQs were calculated for every 15 meter buffer distance from each feature of interest, and all results were graphed to provide a visual representation of the crime concentrations as distance from the feature

¹¹ Recent research undertaken by Wang and colleagues has facilitated the development of a statistical technique designed for use with an adaptation of the location quotient (2016). This approach shows promise for potential application with other variations on the measure.

increases. This approach allowed for ease of comparison between patterns of crime concentration around different features. Results from these studies are presented below.

3.7. Results

A large and growing amount of research has indicated that certain locations within the urban environment are associated with higher numbers of crime and disorder events than others. This non-uniformity is apparent within the cities of Coquitlam and Port Coquitlam, where crime records are found to be unevenly distributed across road types and land use categories at the macro level, meso-level and micro-level (Chapter 2). Building upon this finding, this study explores the areas immediately surrounding these known higher-crime urban features. If a specific feature of the built environment is associated with a higher proportion of overall crime records on site, then how does this location impact the crime patterns of neighbouring areas? By grouping events according to their distance from key features within the built environment, this broader spatial impact becomes clearer. This section presents the findings regarding the local spatial impact of a number of features identified within previous research as having a considerable concentration of crime within the Coquitlam/Port Coquitlam area.

Figures 4 through 8, below, illustrate the changing CQs for all crime events in areas surrounding each of the features of interest. Each bar represents the category quotient value for one 15 meter buffer distance. The metric along the x-axis of each chart represents distance as moving away from any of the features of interest within the study site: for example, when considering arterial roads, the metric indicates distance away from any of the arteries within Coquitlam or Port Coquitlam. In this study, distance is measured in 15-meter intervals, with intervals labelled by the furthest distance break point. The y-axis displays the value of the CQs, and the metric along each y-axis changes depending on the feature of investigation. In order to provide a point of comparison between each graph, the selected CQ threshold value of 2 is displayed as a dashed line. Values above this line indicate considerable over-representation of crime events within the given buffer range. Values above 1, but not exceeding the dashed line, indicate crime rates that are higher than the rate for the region as a whole, though not high enough to surpass the selected threshold. Values less than 1 indicate crime rates lower than the region-wide rate.

Figure 4, below, displays the changing CQs as distance from arterial roads increase. The first 15-meter interval includes all events that occurred between 0 and 15 meters from arteries, excluding those that were spatially joined to the arterial road segments themselves. The CQ value of 4 indicates that the rate of events per road distance is four times higher than the overall rate for the study region as a whole. This indicates a considerable concentration of crime events located within 15 meters of arteries. This concentration drops off within the next 15 meter interval, then hovers around the crime rate for the wider region (as indicated by a CQ value of 1). While there is some fluctuation in the CQ value after the first 15 meter distance, the CQ values do not meet the threshold of 2 after the first buffer distance. After the 345 meter distance, the CQ values dip and remain below 1, indicating that crime rates after this distance fall below the region-wide rate.

Just as crime events cluster in the micro-scale distances beyond arterial roads, so too do they appear to cluster in areas beyond shopping centres. This is illustrated in Figure 5, which shows a dramatic over-representation in crime rates within 15 meters of malls within the study region. Crime rates are nearly thirty times the overall rate of the study site within this distance. Though the concentration of crime events drops considerably within the next buffer (15-30 meters away from shopping centres), CQ values remain above the threshold value of 2, and continue to indicate a considerable concentration within this bandwidth. Values fall below this threshold after 30 meters beyond the facilities, and remain below the threshold until the 90 to 105 meter interval, when crime rates once again increase to 6.4 times the rate of the wider study region. CQs continue to fluctuate as distance from malls increases, with several peaks surpassing the threshold value of 2 at irregular intervals throughout the 600 meter exploration.

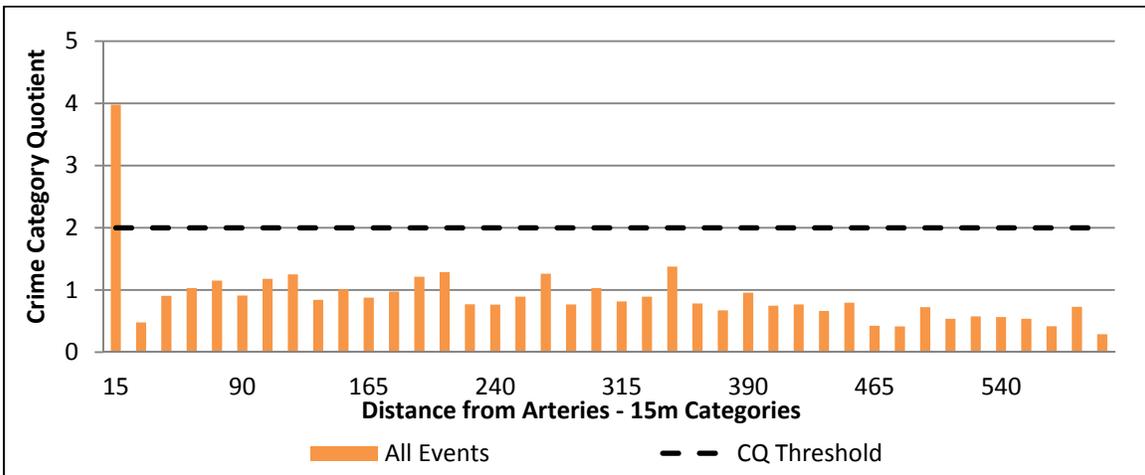


Figure 4: Crime event density by distance from arterial roads, 15 meter intervals

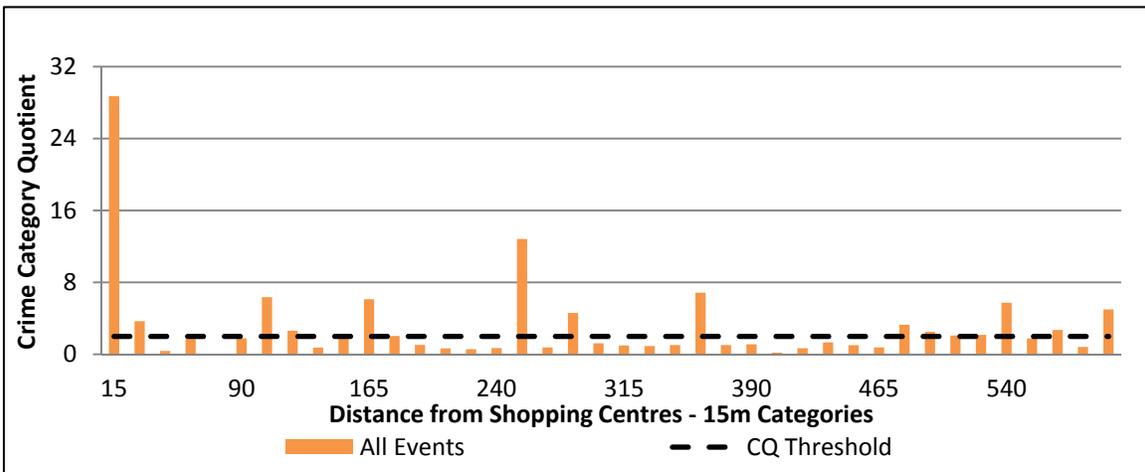


Figure 5: Crime event density by distance from shopping centres, 15 meter intervals

Both arterial roadways and shopping centres exhibit considerable micro-scale clustering of crime events within 15 meters from the location of the features. When shifting to sub-categories of the civic, institutional and recreational land use category, the spatial patterns of clustering around facilities change markedly.

Figure 6, below, illustrates the CQ values as distance from local hospitals increase. There are virtually no events recorded within 15 meters of these facilities, after excluding all events occurring at the facilities themselves. However, crime rates surge to 10.7 times the rate of the study area within the 15 to 30 meter interval. Another peak emerges at a distance of 45 to 60 meters away from the hospital facilities, once again surrounded by buffer distances containing no events. Crime events surrounding hospital facilities, then,

display considerable clustering focused in specific surrounding micro-spaces, and these clusters are surrounded by pockets of road distances that are completely free of crime events.

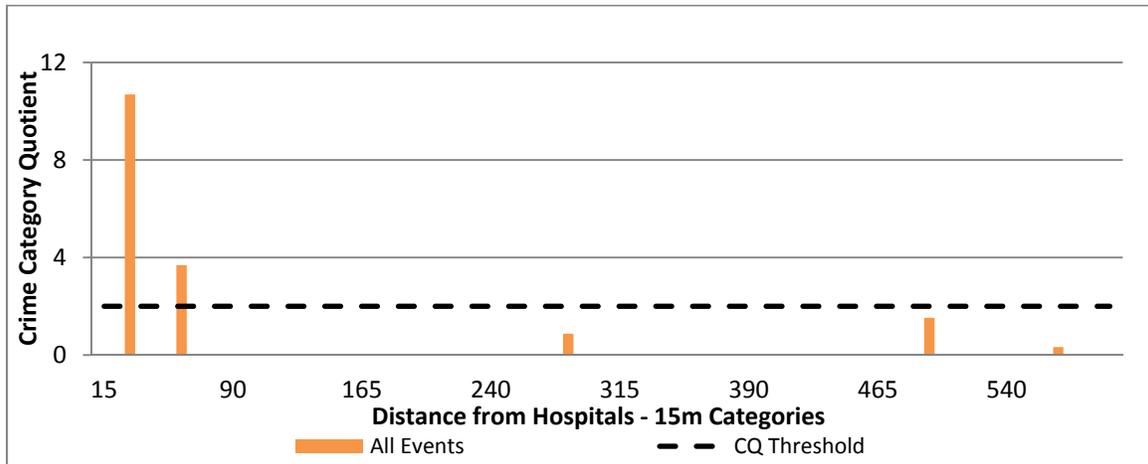


Figure 6: Crime event density by distance from hospitals, 15 meter intervals

The spatial patterns of crime surrounding hospitals reveals dramatically different trends than the comparable patterns surrounding both shopping facilities, and arterial roadways. This differing concentration continues when exploring the micro-spaces surrounding recreation centres in Coquitlam and Port Coquitlam. As illustrated in Figure 7, the crime rate surrounding these facilities surpasses the area-wide rate within 15 meters of the address location – however, the magnitude of the CQ value does not meet the threshold of 2. This threshold is exceeded across the next three buffer distances – from 15 to 30 meters, through to 45 to 60 meters. The CQ increases across these micro-distances, reaching an initial peak value of 6.5 between 45 and 60 meters from the facility. This initial cluster of high crime is followed by a 45-meter stretch where CQ values fluctuate around 1. However, values once again exceed the threshold of 2 at distances ranging from 105 to 150 meters. Crime rates peak within this cluster, between 135 and 150 meters from recreation centres. Beyond this point, CQ values fluctuate near the threshold value of 2 – notably, these values typically remain higher than the region-wide CQ average value of 1. Several additional peaks occur between 300 and 330 meters, as well as between 450 and 465 meters.

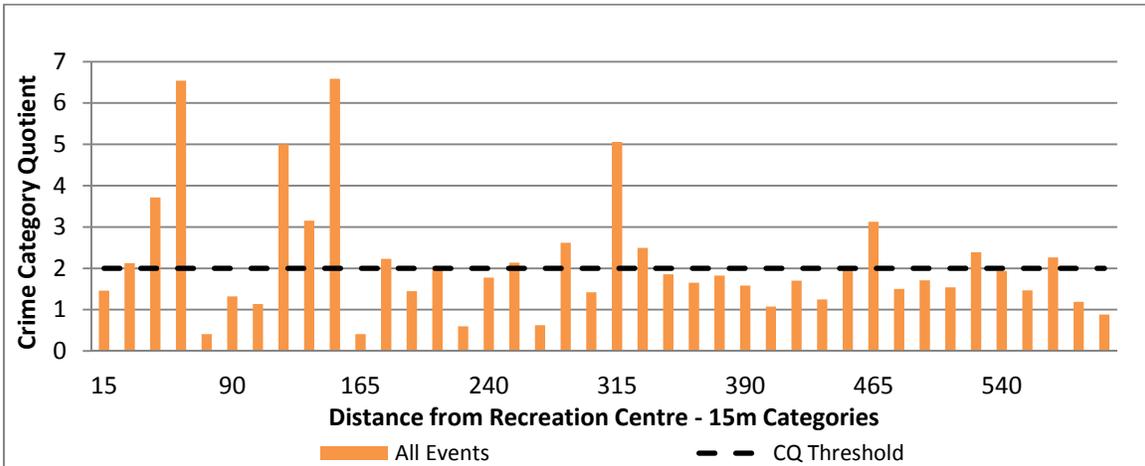


Figure 7: Crime event density by distance from recreation centres, 15 meter intervals

The crime concentrations surrounding recreation centres within Coquitlam and Port Coquitlam display a notably different pattern than the concentrations revealed around other local criminogenic facilities. When exploring the changes in crime rates around local schools, new trends emerge once again. Figure 8 illustrates the change in crime concentrations at increasing distance intervals from schools. Again, crime does not notably concentrate within 15 meters from schools. The crime rate increases within the next distance interval, though not surpassing the CQ threshold value. As the distance from schools increase, however, a concentration of crime is identified between 30 and 45 meters. The crime rate within this micro-distance is double the rate of the city as a whole, indicating a considerable over-representation of crime within this buffer. Following this distance interval, the crime rate drops once again, and generally fluctuate around the area-wide rate for the remainder of the distance under investigation.

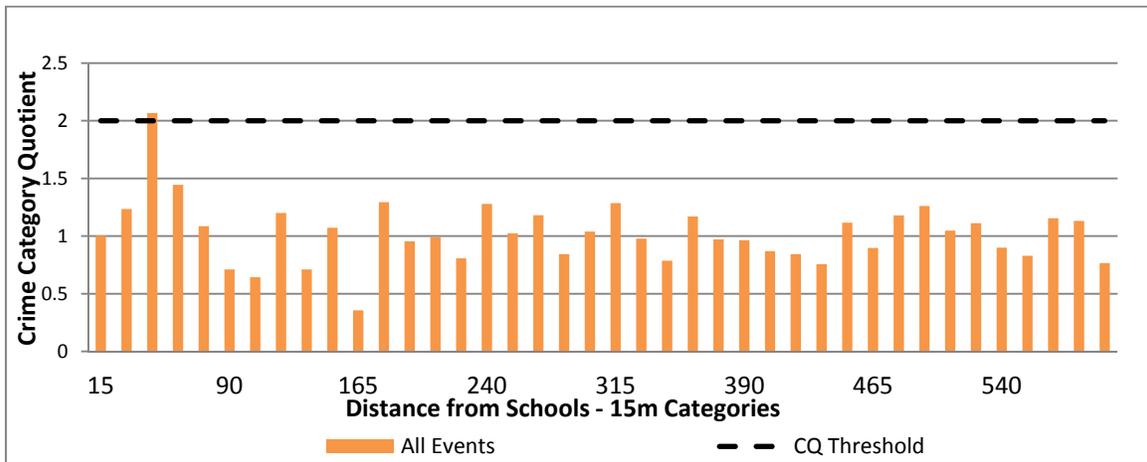


Figure 8: Crime event density by distance from schools, 15 meter intervals

3.8. Discussion

Five local, high-crime features were selected within this analysis in order to explore if and how crime concentrates in the urban spaces immediately surrounding them. The category quotient enables easy identification of the micro-spaces with crime rates that considerably exceed the area average. When exploring the variation in this measure, concentrations of crime are visible within the first 60 meters of each built environmental feature. However, in spite of this general similarity, the micro-level analysis reveals that there are vast differences in the overall patterns of crime concentrations surrounding built environmental features.

3.8.1. Crime concentrations in proximity to arterial roads

When exploring crime concentrations nearby arterial roads, considerable clustering is identified within 15 meters from the features. This finding corresponds to research by both Beavon and colleagues (1994) as well as by Johnson and Bowers (2010), highlighting roads with greater access to major roads have higher risks of property crimes. Perhaps most interesting about the micro-level concentration in Coquitlam and Port Coquitlam, however, is that the CQ value for these partial road segments, at 4.0, exceeds the CQ value for all crime events on the arteries themselves (2.9, as highlighted in Table 1 in Chapter 2).

That crime concentrates on arteries is no surprise – but that the concentrations further increase within the micro-spaces immediately beyond such segment types raises additional questions. This measured increase is likely due to the process of linking the street type data to crime events using a spatial join. When events are recorded at intersections, the point is in contact with several street segments, potentially with a number of different street types. When a point is equidistant to more than one segment, the spatial join process in ArcGIS randomly assigns the point to one of the contacting street segments. A number of points occurring at intersections of arterial roads, then, will be randomly assigned to the intersecting streets. If these intersecting streets are not arteries themselves, then these events would be captured within the first 15 meter buffer from arterial roads, but would not be attributed to the arterial roads themselves. The consequences of this random process include potential under-representation of events on arteries, and potential over-representation of events within the first buffer-distance. Indeed, when accounting for this discrepancy, reductions in crime density within this micro space results. The CQ value for crime events on arteries increases slightly, while the CQ measuring crime clustering within 15 meters of arteries drops¹²; all other values corresponding to different distance intervals remain unchanged. While the recalculated value within the first 15 meter buffers remain above 1, indicating crime rates that are higher than the area-wide measures, the value does not exceed the CQ threshold of 2.

The above-mentioned adjustment is straightforward and easy to implement, but raises a question as to whether this adds accuracy to the analysis. Crime event data recorded at intersections may represent an uncertain location. The event may have occurred directly at the centroid of two street crossings, but it is more likely to have occurred on one specific segment located near the listed cross-street. By assuming that all events linked to intersections containing an arterial road should be attributed to the artery, rather than to one of the intersecting streets, this decision may shift the results to over-emphasize the crime rate of intersections in ways that the data is not able to verify. The recorded location does not provide sufficient information to determine which segment the event should be attributed to (Groff et al., 2010; Weisburd et al., 2004; Weisburd et al., 2009; Curman et al., 2015). Because of this, events occurring at intersections are often

¹² The CQ value for all events within 15 meters of arterial roads drops from 4.0 to 1.6 when attributing all events occurring at arterial intersections to the arteries themselves.

excluded from this type of analysis. However, decisions regarding the exclusion (or inclusion) intersections should consider the relative importance of events that occur on these locations (Braga et al., 2010; Weisburd, 2015).

Given that nearly 15% of all crime events within Coquitlam and Port Coquitlam are recorded at intersections (n = 1883), this study has chosen to retain this data rather than exclude it. By including this information, additional uncertainty is incorporated into the results of the micro-spatial analysis, and is largely identifiable as an increased concentration of crime within the first 15 meters surrounding arterial roads. However, including events at intersections throughout the remainder of the analysis may allow for a more complete measurement of crime concentrations in proximity to all features of interest. Recognizing this uncertainty, further research is needed to identify appropriate methods to capture and account for events at intersections (see for examples, Braga et al., 2010; Hibdon and Groff, 2014; Andresen and Curman, 2016).

Based on the findings of the micro-scale analysis surrounding major roads, crime events appear to cluster within very close proximity to these features. The magnitude of this clustering is uncertain, with crime rates for all events occurring within 15 meters of arteries fluctuating between 4 and 1.6 times the region-wide average. In spite of the micro-level discrepancy impacting clear results within 15 meters of arteries, crime rates do appear to cluster within these micro-spaces, then drop considerably within the adjacent 15 to 30 meter distance. Beyond this distance, crime rates fluctuate around the region-wide average, with a downward trend that remains below the rate of the study area after 345 meters from arteries. Given that the highest crime rates occur within 15 meters of arterial roads, it appears that the roads have little discernable impact on nearby crime patterns after this distance.

3.8.2. Crime concentrations in proximity to shopping centres:

While crime events concentrate within 15 meters of arterial roads, the magnitude of these findings remains unclear due to uncertainty associated with coding events located on intersections. The inclusion of intersections presents challenges when investigating crime within micro-spaces around road features; however, these locations do not present the same uncertainty when non-road features become the focus of analysis. Shopping

centres are particularly important features within the local landscape of Coquitlam and Port Coquitlam (Chapter 2; Frank et al., 2013). One regional shopping centre and seven community shopping centres together account for over 6 percent of all crime events within the study municipalities. In addition, the three highest crime addresses across the study sites are shopping centres. As these facilities are associated with a considerable amount of crime on site, understanding the wider spatial impact of shopping centres is particularly relevant within this locale.

When exploring the crime rates of the spaces beyond shopping malls, further concentration is immediately apparent. Crime rates are 28.7 times greater within 15 meters of shopping centres than across the study region as a whole. This concentrated crime rate drops rapidly as distance from the shopping centres increase: the CQ for all events located between 15 and 30 meters from malls drops to 3.7. The crime rate drops below the area average after 30 meters, but remains quite volatile throughout the 600 meter distance beyond the facilities, with several peaks surging well beyond the threshold value of 2 occurring at irregular distance intervals.

The irregularity of the crime rates when moving away from shopping malls may be associated with the small buffer distances used in this analysis. This is a limitation of metrics that rely on crime rates, as increased variability is introduced with decreased counts of events (Johnson and Bowers, 2010). However, the small distances capture the micro-level clustering at more detail than larger distances. The dramatic clustering in close proximity to malls is visible, but is muted considerably when repeating the analysis using 50 meter buffer bandwidths. In using smaller distance classifications, the magnitude of the crime concentration in areas immediately adjacent to the shopping facilities is clearly visible. These results indicate that crime events cluster within 30 meters of shopping malls, with events declining sharply within this distance.

These findings provide support to the work of Song and colleagues, who have identified that crime rates concentrate within 30 meters from the edges of commercial areas (Song et al., 2013). It is unclear whether the rate fluctuations identified after the 30 meter mark can be attributed to the presence of the shopping malls, or whether other factors further influence local crime rates at these distances. Given both the local spatial

concentration of commercial land uses, as well as the regional goals to shift towards dense mixes of land use, future research is required to adequately explore the joint impact of multiple criminogenic land uses on the micro-level spatial concentrations of crime (Groff, 2013, 2014; Groff and Lockwood, 2014; Song et al, 2016;).

3.8.3. Crime concentrations in proximity to hospitals:

The road distances in immediate proximity to shopping centres reveal a dramatic concentration of crime within Coquitlam and Port Coquitlam. As indicated within past research, this type of facility attracts a large portion of the local population and is the site of a considerable portion of local crime (Chapter 2; Kinney et al., 2008; Frank et al., 2013). However, a number of other local facility types have also been identified as being associated with high counts and rates of crime. Coquitlam and Port Coquitlam are home to two facilities classified within the land use dataset as hospitals. These locations are not traditional medical facilities providing public access to health care – there is not a public hospital within either municipality. Rather, they are forensic and psychiatric hospitals, located in relatively remote areas within the study site, and as such they have few immediate neighbours. Unlike the local shopping centres that are the site of considerable growth and densification in recent years (City of Coquitlam, 2011), these facilities have seen budget cuts and closures; in spite of these patterns, however, they continue to report relatively high crime, making these locations interesting contrasts to the high activity shopping centres.

It is no surprise, then, that the crime rates surrounding the local hospitals clusters in different ways than the rates around shopping centres. To begin, while shopping malls exhibit dramatic clustering within 15 meters of the facilities, hospitals, in contrast, have no events at all located within this distance. A considerable concentration, however, is located within the next bandwidth distance, between 15 and 30 meters from the facilities. The crime rate within this micro-space is 10.7 times the corresponding rate across the study area as a whole. While no crime is recorded within the next distance buffer, another concentration is present between 45 and 60 meters, with a CQ value of 3.7. This variation within the first 60 meters from hospitals could be associated with guardianship at the facilities, as the local forensic and psychiatric hospitals are likely to have well-established place managers

and security guards on site (Eck, 1995). As emphasized by the routine activities approach, such guardians increase the risks associated with criminal activities, and as such, result in the reduction (or in this case, the absence) of events within immediate proximity to the facilities (Cohen and Felson, 1979). The risk associated with the presence of such guardians may reduce with increased distance from facilities, leading to crimes concentrating at distances slightly removed from the hospitals.

Moving beyond the 60 meter buffer distance away from the hospitals, crime events are almost entirely absent. The routine activities approach continues to be instructive in explaining this trend (Cohen and Felson, 1979). While the address of one facility geocodes onto a busy highway within the study site, very few properties off of the hospital grounds can be accessed within 600 meters via the road network. The second facility is accessible via one road only, and virtually no other properties or addresses can be accessed within 600 meters. This remoteness is likely to account for the absence of crime within many buffer distances away from the hospitals, as fewer targets, and therefore few opportunities are present in these areas (Cohen and Felson, 1979).

While the patterns surrounding the local hospital facilities can be understood based on the likely presence of guardians and absence of targets, these trends are unlikely to be mirrored by hospital facilities within other locales. Typically, hospitals are located in highly accessible places, and are accessed by large volumes of people. The facilities within Coquitlam and Port Coquitlam, however, are located in distinctly remote areas, with limited access points, thus creating a unique concentration of crime rates within surrounding spaces, and emphasizing the need for local context when analyzing spatial patterns of crime.

3.8.4. Crime concentrations in proximity to recreation centres:

The cities of Coquitlam and Port Coquitlam are home to 16 recreation centres, including public and privately owned sporting facilities, as well as local cultural complexes. When considered as a land use category, these locations are associated with high crime counts and rates. Unlike the local hospitals, the recreation centres are designed to be in accessible locations, and as such, the crime concentrations in areas surrounding these

locales are unique to the facility type. Crime concentrations do not peak in the micro-spaces immediately adjacent to the recreation centres themselves; rather, they form two notable clusters between 15 and 60 meters away from facilities, and again, between 105 and 150 meters away. The presence of these dual clusters could be associated with the structure of the facilities. Large buildings, located nearby large parking lots and perhaps outdoor fields, may naturally shape the locations where criminal events concentrate – or at least where such events are likely to be recorded and geocoded. An additional, facility-based spatial analysis is needed in order to better understand the specific relationship between these dual clusters of crime and each facility. Such an approach can determine whether these trends are consistent across all facilities, or are the result of a number of different spatial concentrations being viewed in aggregate.

Local facility-based guardians may be associated with crime rates peaking in spaces beyond the facilities themselves (Eck, 1995; Groff and McCord, 2012). While recreation centres are likely to have local staff and security on site, such individuals have less control as distance from the facility increases. This could result in the illustrated initial reduction in crime events immediately adjacent to facilities, and the corresponding increase in rates beyond this distance. Groff and McCord's research on crime in proximity to parks is helpful in contextualizing these results (Groff and McCord, 2012). The authors found that areas surrounding parks in Philadelphia exhibit increased rates of disorder, violent and property crimes. Spaces with a recreation centre on site, however, have significantly lower rates of disorder in surrounding areas, but do not have lower rates of violent or property crime (Groff and McCord, 2012). Groff and McCord follow a different methodology in that they consider parks as the key focus of study, rather than the address of the recreation centre itself. Further, their study extends the park by a 50 foot (roughly 15 meter) buffer to create a larger park environ, and they explore the areas within and beyond the park using 400 foot bandwidths (roughly 122 meters) (Groff and McCord, 2012). As such, the micro-spatial clustering and variation revealed within the Coquitlam and Port Coquitlam study is likely to be masked by the broader focus and larger bandwidths used in the Philadelphia study. However, the pattern of high crime rates in close proximity to recreation facilities persists within both locations. Further crime-specific and site-specific research is needed in order to explore the connections between recreation centres and

nearby crime patterns, specifically in relation to the potential impact of place managers (Eck, 1995; Groff and McCord, 2012).

3.8.5. Crime concentrations in proximity to schools:

The concentrations of crime surrounding recreation facilities reveal a different and unique spatial pattern, distinct from the patterns surrounding hospitals, shopping centres and arterial roads. When considering the areas beyond local schools, distinct patterns emerge once again. Schools present an interesting study focus, as their location is relatively evenly distributed throughout the study area. They exhibit high levels of accessibility and attract both a high number of individuals, and a high count of local crime. As was the case in both hospitals and recreation centres, this land use type does not show a concentration of crime within the first 15 meter buffer. Crime events rise as distance from schools increases, peaking between 30 and 45 meters from the educational facilities. The crime rate reaches twice the average of the study area at this point, then declines within the next buffer bandwidth.

The spatial patterns occurring beyond schools illustrate another likely example of the impact of place managers (Eck, 1995). Such facilities may have policies in place to prevent crime events on site, but as emphasized in related work, this can result in increases in crime rates on adjacent blocks and in surrounding areas (Roncek et al., 1985; Groff and Lockwood, 2014). Previous research has identified different impacts depending on school type, distinguishing between primary, and middle or secondary schools (Groff and Lockwood), as well as between public and private facilities (Roncek et al., 1985). While micro-level clustering is apparent when considering local schools as an aggregate category, further research is needed to explore how these trends shift when considering specific types of schools, as well as specific times of day when key place managers may be absent from the facility (Groff and Lockwood, 2014).

3.8.6. Key contributions and further research:

This analysis makes a number of contributions to the growing research field exploring crime in proximity to existing criminogenic features. It begins by selecting urban

features to analyse based on the results from a local area exploration. Five local features were chosen based on high rates and counts of crime events on site, illustrating an existing local need for further exploration of these key locations. This approach is particularly important when exploring under-studied urban locales, such as mid-sized suburban environments: as emphasized both within past research, as well as in the current study, the spatial patterns of crime identified in one urban setting are not always consistent with patterns found in other environments (Seasons, 2003; Song et al., 2016). Few existing studies explore multiple features; however, this approach is beneficial in that it allows for local comparisons of the wider spatial impact of different urban environmental elements (Rengert et al., 2005; McCord and Ratcliffe, 2007; Groff and Lockwood, 2014; Song et al., 2016). In addition, this study contributes to existing micro-level spatial analysis methodologies by employing a network-based approach to identify the accessible sites beyond each feature of interest (Schuurman et al., 2006a; Oliver et al., 2007; Groff, 2011). It combines this approach with micro-level bandwidth distances to capture changes in crime patterns at 15 meter intervals from each urban feature (Kinney, 1999; Ratcliffe, 2012; Song et al., 2013, 2016).

Crime concentrations within these micro-spaces are identified and measured through the use of an adapted version of the location quotient: the category quotient (CQ). This adjusted metric addresses a number of shortcomings associated with existing standardized rate-based quotient calculations by creating micro-level catchments based on proximity to existing urban features, rather than using arbitrary census or political boundaries (Brantingham and Brantingham, 1978; Schuurman et al., 2007; Brantingham et al., 2009). In addition, within this study, the CQ measures crime per road distance rather than area, therefore excluding the vast majority of urban spaces where crime events either cannot occur, or cannot be spatially represented due to the geocoding process (McCord et al., 2007; Ratcliffe, 2011; Groff and McCord, 2012). The CQ continues to provide the ease of calculation and interpretation found in the location quotient, making it a useful tool to identify concentrations within micro-spaces across the urban landscape (Brantingham and Brantingham, 1993b; Groff, 2011; Carleton et al., 2015).

Findings from this study emphasize the unique spatial impact of different criminogenic features within urban environments (Groff and Lockwood, 2014). While

concentrations of crime are present in the micro-distances beyond each feature within this analysis, the nature of this clustering vary greatly according to the study focus. Arterial roads display an increase in crime events within the first 15 meters of the feature; however this increase is likely to be attributed to the uncertainty associated with crime events recorded at arterial intersections. Crime continues to cluster when accounting for these events, though the clustering is present at a magnitude below the selected threshold value. Local shopping centres exhibit a dramatic concentration of events within 15 meters from the facility, with these rates declining in the next bandwidth, and dropping below the threshold after 30 meters. Local hospitals report no events at all within the first 15 meter bandwidth, but reveal a cluster from 15 to 30 meters, and from 45 to 60 meters. Recreation centres exhibit a bi-modal concentration of crime, with two notable clusters within 150 meters of the facilities. Lastly, schools reveal an increase in crime events within the first several bandwidth distances, peaking between 30 and 45 meters from the facilities. These unique patterns, identifiable when investigating at a large spatial scale, are muted when repeating the analysis using 50 meter bandwidths: all features simply show clustering within the first measured distance beyond the facility itself.

Throughout this analysis, several limitations have been identified, as well as a number of key areas for future research. Most prominently, additional research is needed to identify appropriate methods to account for crime events occurring at intersections, particularly when exploring the spatial impact of road features on surrounding crime. This study would further benefit from an empirical test to quantify the significance of the crime concentrations identified through the use of the CQ (Groff and McCord, 2012; see also Wang et al., 2016 for potential application). While this metric is easy to calculate and interpret, further research is needed to determine whether the commonly selected threshold value of 2 is appropriate for use across a variety of urban settings, and across a range of environmental features.

This study has explored crime events at an aggregate level. Existing research has emphasized the further variation in crime-specific spatial patterns (McCord and Ratcliffe, 2007; Groff and Lockwood, 2014). With this in mind, future studies within Coquitlam and Port Coquitlam must include a breakdown of crime events according to type. Additional variation in the spatial clustering of crime also emphasizes a further need for facility-

specific analysis to determine if individual, high-risk facilities are driving the identified patterns (Eck et al., 2007; Bowers, 2013).

3.9. Conclusion

This research has explored the concentrations of crime events in the micro-spaces surrounding five local criminogenic features: arterial roads, shopping centres, hospitals, recreation centres and schools. These key features were selected based on their identified relevance when considering local distributions of crime – each of these location types were identified as having high counts and rates of crime on site (Chapter 2). While knowledge of existing criminogenic features within the local urban landscape is important and can inform both planning and policing policy alike, gaining further understanding of how these locales influence crime rates in nearby areas adds further insight to policy decisions and is particularly important to consider at the planning stage (Brantingham and Brantingham, 1993c; Groff and Lockwood, 2014). Findings from this research emphasize the unique spatial patterns of crime concentrating within micro-level distance buffers surrounding each feature of interest. These results emphasize the importance of local analysis, guided by local concerns, and undertaken at the micro-level to capture the nuanced spatial patterns of crime emerging at small distances surrounding environmental features.

Chapter 4.

Planning for Crime: Towards the Development of a Crime and Resourcing Planning Tool

4.1. Abstract

Spatial patterns of urban crime are shaped and influenced by the built environment within which they occur. Key local nodes such as commercial, institutional and recreational facilities attract large portions of the urban population for legitimate, non-criminal activities; in doing so, these locations are often the site of disproportionate amounts of crime and disorder. Likewise, the arterial roads that connect such facilities, and that large portions of the urban population use for daily travel, are also associated with higher proportions of crime than other road types. Crime is often concentrated at the site of these features, as well as in close proximity. While the relationship between crime and urban form has clear policy implications within both municipal planning and police resource allocation realms, there is a considerable shortfall in research that connects such academic findings with applications that can be used to shape policy and planning decisions. This study provides the initial framework for such an approach by introducing a prototype planning tool that models urban growth and crime, allows for consideration of multiple scenarios, and provides estimates for the policing resources needed to maintain or improve service levels.

Keywords: crime analysis, land use, planning, built environment, police resourcing

4.2. Introduction

The built urban environment is a dynamic network of land use and transportation systems, organized and developed in accordance with a detailed planning process. Plans guide development goals across a variety of spatial levels, from national to provincial, regional to municipal, neighbourhood to individual property. At the municipal level, zoning bylaws and community plans influence the development and revitalization of neighbourhoods by regulating the location of urban land use categories (Maantay, 2001). Such regulations further determine the mix of land use within specific areas, the density of

development, and the placement of key facilities in proximity to one another (Ashe et al., 2003). Recognizing the wider public health and service implications, such municipal-level regulations determine the location of fire halls, ambulance stations, schools and parks, for example, and provide further rules that restrict the locations of potentially harmful or risky uses of land, such as industrial areas, alcohol serving establishments, and fast food restaurants (Maantay, 2001; Ashe et al., 2003). Land use planning shapes the built environment; as such, it has been recognized as an effective tool for shaping the behaviour of residents by promoting walkability, enabling community interaction, and encouraging healthy and sustainable lifestyle choices (Jacobs, 1961; Ewing and Cervero, 2001; Handy et al., 2002; Frank et al., 2004; Oliver et al., 2011).

The built urban environment, designed and structured according to urban planning decisions, shapes the way that people travel and move within it by determining the location of their origins, destinations, and routes. Just as the urban structure has implications for the health and wellbeing of urban residents, so too does it affect other complex social interactions, including criminal occurrences. Decades of research within environmental criminology have emphasized the important connections between the physical urban structure and patterns of criminal activity (Jacobs, 1961; Felson, 1987; Brantingham and Brantingham, 1978a, 1993c, 1995; Kinney et al., 2008; Groff and Lockwood, 2014). Within this research and beyond, the links between urban form and patterns of crime are repeatedly identified, emphasizing the potential planning, policy and resourcing implications of such connections. However, in spite of this identified application, the connections between urban structure and crime are inadequately considered at the planning stage (Jacobs, 1961; Brantingham and Brantingham, 1984; Cozens, 2007, 2011; Paulsen, 2012). There also remains a shortage of models and tools developed with a criminology perspective, identifying how such information may be applied to inform urban planning and public safety resource decisions (Brantingham and Brantingham, 1995).

This chapter moves towards the development of a planning tool that incorporates the identified local connections between crime, disorder and the built environment. Developed based on the needs of one suburban police detachment and two associated municipalities within the metropolitan Vancouver area, this prototype tool models potential shifts in crime and disorder associated with projected urban growth. It provides estimates

of the changing police resource needs associated with urban development, allowing for multiple user inputs to explore alternative levels of service as well as alternative development scenarios. The chapter closes by revisiting past calls for integrating crime and place literature within urban planning, and explores future priorities for expansion, development and testing.

4.3. A brief review of the built environment and crime

Crime occurrences cluster across the urban landscape, concentrating in some locations and avoiding other areas. Following decades of empirical support from within the field of environmental criminology and beyond, it is generally accepted that crime is shaped by the physical environment (Johnson and Bowers, 2010; Cozens, 2011). Several key theories emphasize that crime is a bi-product of normal human activities, often occurring in higher volumes in the same locations where urban populations themselves concentrate (Cohen and Felson, 1979; Brantingham and Brantingham, 1993a, 1993c). Cohen and Felson's routine activities approach indicates that criminal opportunities emerge when a motivated offender and a suitable target intersect in space and time, in the absence of a capable guardian (Cohen and Felson, 1979). Both Felson, and the Brantinghams further emphasize that these intersections occur in predictable locations, shaped by the daily routines of individuals, as well as the structure of the physical environment (Felson, 1998; Brantingham and Brantingham, 1991).

The urban landscape contains a structured pattern of nodes, including home locations, workplaces, schools, entertainment and shopping areas (Brantingham and Brantingham, 1991, 1993c). These primary locations, as well as the pathways that connect them, form an individual's activity space; the wider areas of familiarity extending beyond these nodes and pathways form one's awareness space. Individuals spend the majority of their time within their awareness space; offenders typically identify or seek out opportunities to offend within these personally familiar areas. The majority of the nodes and pathways are common destinations for many individuals, resulting in an overlapping public awareness space. Some of the locations that attract a large volume of people will have higher volumes of crime, simply due to the increased likelihood of a present offender identifying an appropriate opportunity. These locations are known as crime generators,

and often include shopping centres, schools and transit exchanges (Brantingham and Brantingham, 1995; Kinney et al., 2008). Other urban sites become crime destinations – locations that offenders seek out and travel to for the explicit purpose of committing an offense. These nodes are called crime attractors, and may include specific drinking establishments or large parking lots containing little security (Brantingham and Brantingham, 1995; Reid and Andresen, 2014).

Crime attractors and generators have been the subject of a considerable amount of research, as scholars seek to understand the key urban sites where crime events concentrate. While these key locations vary according to urban locale, a number of nodes are repeatedly identified within academic literature as local crime hotspots. Such sites include liquor serving establishments, shopping centres, schools (typically public high schools), park spaces, public housing and key transit stops, to name just a few (Roncek and LoBosco, 1983; Felson, 1987; Brantingham and Brantingham, 1994, 1995; McCord and Ratcliffe, 2007; Kinney et al., 2008; Groff and McCord, 2012; Haberman et al., 2013; Groff and Lockwood, 2014; Haberman and Ratcliffe, 2015). In addition to the site itself, research continues to identify the wider spatial impact of such crime attractors and generators (Brantingham and Brantingham, 1982; Kinney, 1999; Groff, 2011, 2014; Ratcliffe, 2012; Bowers, 2013). While findings are dependent on both city and scale of analysis, and vary according to crime type, facility, and time of day, research consistently emphasizes the important role that such nodes play in shaping the urban distribution of crime.

Urban nodes are connected by pathways – the streets, transit lines and routes that individuals take when traveling through cities. The types of pathways available for travel vary according to urban design: dense metropolitan cores may have a latticed grid network of arterial and collector streets, while sprawling suburban areas may include more complex road networks with winding pathways and cul-de-sacs (Axhausen, 2005; Johnson and Bowers, 2010). Road networks are designed with a hierarchy of street types, funneling residents from local roads, towards main arteries, highways and freeways. As certain pathways draw a large proportion of urban travellers, higher-volume routes are often associated with higher crime rates as well (Beavon et al., 1994; Brantingham and Brantingham, 1995; Johnson and Bowers, 2010; Curman et al., 2015). Higher volume

routes that provide more opportunities to stop and interact with the surrounding environment, such as arterial roads, are frequently found to be more criminogenic than highways and freeways, with limited access and exit points (Brantingham and Brantingham, 1993c; Curman et al., 2015).

A considerable portion of the urban environment is shared by many people. These legitimately shared spaces result in increased anonymity, and a reduced ability to identify insiders and outsiders. Key nodes often cluster in spatial proximity, and are often on or near major routes, creating dynamic urban zones with multiple land uses converging along one pathway (Song et al., 2013). Such urban locations are known as edges – locations that mark the transition from one zone to another (Brantingham and Brantingham, 1993c; Song et al., 2013, 2016). Edges can be sharp, noticeable barriers between locations, caused by dramatic shifts in land use, built structures such as freeways or walls, or natural environmental features such as rivers; alternatively, they can be gradual perceptual changes, such as shifts in land use that occur over a series of blocks (Brantingham and Brantingham, 1978; Robinson, 2008; Clare et al., 2009; Brantingham et al., 2009). Crime tends to concentrate in and along the edges within urban environments (Brantingham et al., 2009; Song et al., 2013, 2016).

The physical urban landscape shapes the way that residents move within it. The connections between urban structure and complex human behaviour has been well researched across a variety of disciplines, perhaps most notably within public health and planning literature (Maantay, 2001; Handy et al., 2002; Ashe et al., 2003; Frank et al., 2004; Oliver et al., 2011). Related to these connections are the complex relationships between the built environment and patterns of criminal activity. Decades of research have established and explored the links between physical urban environments and patterns of crime, with repeated emphasis on the important implications that such relationships have on planning and policy (Groff and McCord, 2007; Lockwood, 2007; Ratcliffe, 2012; Song et al., 2013; Groff and Lockwood, 2014). In 1995, Brantingham and Brantingham went one step further, identifying the need for the development of a model of crime and the built environment. They call for the development of “a planning tool that will allow us to estimate the criminogenic and fear-generating potentials of different planning and development decisions in context in the way that traffic engineers can presently predict the potential of

different land uses in generating car journeys” Brantingham and Brantingham, 1995, 5-6). In spite of the important planning implications of such a model, there remains a shortage of applied research, designed to connect planners with the tools to explore how development decisions may impact local crime (Paulsen, 2012). This chapter moves towards the development of a preliminary model of urban crime, designed as a prototype tool to aid in urban planning decision making and public safety resourcing.

4.4. Considerations and challenges in modelling spatial data:

A wide range of academic research has supported the strong connection between the built environment and the spatial distribution of disorder, fear of crime, and criminal events. As computing power advances alongside mapping and database management systems, researchers are better situated to further explore and model these complex relationships (Walker, 2007). Models are representations of real world phenomena or processes created for the purpose of analysis, projection or to better understand how the world works (Goodchild, 2005). The increasing availability of high-quality, large-scale spatial data sources (including detailed land use and transportation data), coupled with the improvement in police records management and data collection accuracy has provided a solid foundation from which to construct integrated crime models that can estimate future crime patterns and inform policing and planning policy alike (Brantingham and Brantingham, 1995; Ratcliffe and McCullagh, 1999, 2001; Groff and La Vigne, 2002; Groff and Lockwood, 2014).

The call for and shift towards higher resolution urban modelling and analysis has crossed disciplinary boundaries and has spanned several decades (Brantingham et al., 1976; Brantingham and Brantingham, 1995; Longley and Harris, 1999; Longley, 2003; Schuurman et al., 2006b; Groff, 2007; Brantingham et al., 2009; Malleson et al., 2009, 2010; Jjumba and Dragičević, 2012). The challenges associated with merging a variety of spatial and non-spatial data have been discussed and are well-documented in several recent geographic and criminological works. These cautions and considerations are well worthy of review prior to undertaking data integration and modeling involving spatial sources.

4.4.1. Data scale

Scale is a vital consideration when analyzing spatial data. Census geography has frequently formed the basis for exploring patterns of crime, with census areas (such as the census tract, dissemination/enumeration area or census block) often selected as a spatial unit of analysis (Ackerman and Murray, 2004; Andresen, 2006a, 2006b; Schuurman et al., 2007; Wuschke, 2007; McCord et al., 2007; Brantingham et al., 2009; Andresen and Linning, 2012; Haberman and Ratcliffe, 2015). This spatial unit is often identified as the most suitable level of aggregation, as it allows for seamless integration with a wide variety of socio-economic census variables. Such aggregate data is challenging and problematic to integrate into investigations performed at different units of analysis. When attempted, integration is typically done at the expense of data quality, often with an added footnote or limitation acknowledging the challenges of the ecological fallacy – in name, or in definition (Brantingham et al., 1976; McCord and Ratcliffe, 2007; Stucky and Ottensmann, 2009). The ecological fallacy becomes a concern when inferences are made regarding individuals or a sub-population of an area, based on information presented at the area-level itself (Openshaw, 1984a). Research from within the field of environmental criminology continues to emphasize the variations in crime patterns *within* areas; this simultaneously highlights the dangers of making such ecological assumptions, while emphasizing the importance of micro-level analysis (Brantingham et al., 1976; Sheppard and McMaster, 2004; Harries, 2005; Ackerman and Murray, 2006; Kinney et al., 2008; Groff et al., 2010; Curman et al., 2015).

Applying census-level data to smaller, disaggregate sub-areas can prove to be a challenge. However, census data itself, like all data sources, has a number of inherent limitations. All individual data aggregated to an area are subject to the modifiable area unit problem (MAUP). The MAUP occurs when trends and results appearing at one spatial scale change when calculated at a different scale (Openshaw, 1984b). Furthermore, census boundaries are typically drawn to conform to population limits and street networks, rather than to reflect zones of similar socio-economic status (Schuurman et al., 2007). Such administrative boundaries tend to imply sharp contrasts between, and uniformity within areas. However, one cannot assume that all individuals within a given census area experience the same socio-economic conditions or have an equal risk of victimization; the

census boundaries may not represent accurate borders distinguishing the discrete patterns measured within them (Brantingham and Brantingham, 1978b).

The advancement in technology and data availability has increasingly resulted in a movement towards larger spatial scale analysis, providing higher resolution, disaggregate data (Longley and Harris, 1999; Schuurman et al., 2006b; Brantingham et al., 2009; Jjumba and Dragičević, 2012). Cadastral level data holds the potential to avoid aggregation problems by working from the ground-up. By beginning data collection at the individual parcel, and aggregating and grouping data, either spatially or categorically as needed, users are better able to understand the composition, and as such, better able to make informed decisions about if, and how, to best group the data (Longley and Harris, 1999; Schuurman et al., 2006b; Brantingham et al., 2009). However, this inherently presents a new challenge – accessing such high-resolution spatial data.

4.4.2. Data availability and data quality

Technological advances in recent decades, including increases in the efficiency, storage capacity and affordability of computing systems, have markedly improved the quantity and availability of a wide variety of spatial and demographic data sources (Ratcliffe and McCullagh, 1999; Groff and La Vigne, 2002; O’Sullivan, 2004; Andresen, 2011; Malleson and Andresen, 2015a, 2015b; Tompson et al., 2015). However, the *existence* of large, micro-scale data sources does not necessarily guarantee easy *access* to such datasets; and when available, *access* does not guarantee *quality*. Though individual-level data are collected by a number of sources, access to such data can be expensive, and often requires essential ethical review processes and extensive security updates to ensure individual privacy is maintained (Nghie and Kammeier, 2001; Ratcliffe, 2004a; Kamel Boulos et al., 2005; see also Kounadi and Leitner, 2014). Furthermore, large-scale data sources can be limited in scope, therefore requiring access from and integration with multiple sources in order to capture a more complete representation of a given study subject. With nationally collected census data, municipal-level planning and zoning, police departmental-level crime databases and other datasets compiled by private businesses, corporations, and even individuals, there is no uniform data entry or quality control

standard – such data verification, if possible at all, becomes the responsibility of the researcher (O’Sullivan, 2004; Tompson et al., 2015).

In this respect, a preliminary step in micro-scale geographic analysis and modelling must critically consider the types of data available, the reliability of the data sources, and their dates of collection. Further, caution must be exercised when using past snapshots as inputs into a predictive model. Social phenomena are unpredictable and complex in nature, and acquiring accurate future results with limited past datasets is unlikely (O’Sullivan, 2004). Rather, such data inputs, once verified for accuracy and understood in scope, are better served in models designed to help understand current relationships, which, when used as a guide, may help to inform policy through scenario-testing and projecting ranges of potential outcomes.

4.4.3. Data integration

Along with the challenges associated with identifying and acquiring micro-scale spatial data, come the potential difficulties associated with merging multiple discrete data sources. Accepting that single data sources will seldom provide the depth and focus needed for specific analyses, researchers may be faced with integrating multiple micro-scale datasets (as with Kinney et al., 2008), or merging datasets of varying spatial scales (see Schuurman and Leszczynski, 2006; Stucky and Ottensmann, 2009). Challenges arise when different agencies record comparable attributes in different manners (for example, when one municipality provides separated fields for house number, street name, and street type, versus another providing address as a single field). Further complications emerge when different data collection agencies record entirely different attributes (as when one municipality records cadastral-level zoning, while another provides cadastral-level land use) (Schuurman and Leszczynski, 2006). The former challenge can be solved with a relatively simple fix, by creating comparable fields in both datasets; however, the latter challenge is harder to pinpoint, and may require the acquisition of additional data sources. Further complicating data joining is the issue of semantic standardization – when two or more data sources name the same field differently, or when multiple data sources label different fields using the same name (Schuurman, 2005). While such links and corrections can sometimes be made with careful exploration of data and metadata, this becomes

onerous and time-consuming when faced with extensive datasets requiring verification and integration. Schuurman and others have worked extensively to develop methodologies to integrate various cadastral level datasets, providing best practices and additional cautions when merging disparate data sources (see for example, Nghi and Kammeier, 2001; Schuurman, 2005; Schuurman et al., 2006b; Schuurman and Leszczynski, 2006). Such data interoperability challenges and semantic roadblocks must be addressed during data integration in order to maintain data quality and reliability.

4.5. Modelling social systems

The process of modeling dynamic urban systems is wrought with challenges. In spite of these challenges, various modelling methodologies have been developed, applied and tested to aid in the analysis and understanding of urban systems. Many different types of models have been used to represent and plan for dynamic urban phenomenon, several of which are currently being employed and adapted for urban crime analysis. The following sub-sections provide a brief overview of a variety of methods and best practices found within a subset of existing urban modeling literature, focusing on land use models, transportation models, and crime models. Findings from these studies shape and inform the development of an integrated model with aims to explore the potential impact that urban growth and development may have on levels of crime and police resourcing needs.

4.5.1. Land use, planning and urban growth models

For years, urban planners have been employing models of various forms to aid in the design and redevelopment of cities and surrounding areas. Many planning models take the shape of physical plans and layouts for urban designs, integrating themes and concepts identified by planners to be most suitable or desirable for urban living (see for example, Howard, 1946). A particularly well-known urban design, dating from the turn of the twentieth century, is that of Howard's Garden City (1946/2007). The design principles focus on walk-ability and easy access to work, shopping, school and parks for all urban residents, while providing markets at which the surrounding farmers can offer their produce. While created over 100 years ago, principles of the design are still apparent in current compact community plans of today (see for a local example, City of Coquitlam,

2008; Metro Vancouver, 2011). However, in spite of continued interest in similar areas, no true garden city has been designed according to Howard's specifications, and the most common adaptation of garden cities – sprawling suburban landscapes with ample greenspace – certainly miss a number of key principles inherent in Howard's original design (Hardy, 2005). However, even with the original designs marked as idealistic and unrealistic, the ideas of compact, complete and accessible community living remain key components found in design principles being implemented today.

In 1969, Kilbridge and colleagues published a thorough review of existing urban planning models to date, providing an overview of common characteristics and methodologies used at that time. While the state of the art methods listed in the article are considerably dated, the themes and advice found within this piece remain sage and practical for consideration prior to model development today. The authors offer a conceptual framework for model development, beginning with the identification of the model subject, followed by a description of the model function, an overview of the theories and principles on which the model is based, and finally requiring an explanation of the methods used to implement the theories (Kilbridge et al., 1969). Kilbridge and co-authors note that while nearly all urban planning models involve some sort of projection of a future status based on present day inputs and functional relationships, the strongest models do not perform this projection in one step. Rather, through the use of multiple-interval projection, such models allow for dynamic changes to be input into the model at various stages, either through manual input or programmatically, to account for changes in policy, economics or other shifts which may impact model output (Kilbridge et al., 1969, 252).

In his influential book, *Urban Modelling*, Michael Batty reviews several classic mathematical and economic modelling methodologies which have continued to be applied and expanded upon today (Batty, 1976). He classifies urban models as either generation models, or allocation models (or, in more complex cases, both). Generation-based models include basic population forecasting models, where the population at time $t+1$ is forecasted based on the population at time t , using a given growth factor (Batty, 1976, 24). Allocation models, however, involve the movement or placement of model features across the model space. The archetypal allocation model within the geographic realm is the gravity model, which assumes that the interaction between two urban centres varies directly according to

the populations of the urban centres, and inversely to the distance separating the locales (Batty, 1974, 35). Batty further elaborates on both classes of models, expanding base equations to increase complexity and broaden their scope; redefining the basic generative model to depict economic growth, and adjusting the allocative model to measure the draw of shopping centres within urban areas. These fundamental features can be further joined and expanded upon to increase complexity and better explain urban dynamics (Batty, 1974).

Key planning and urban modelling concepts, including those described above, continue to be applied and expanded upon in the twenty-first century. Models of urban growth and dynamics are increasingly incorporating complex systems approaches such as cellular automata (CA) and agent-based modeling (ABM) to measure dynamic urban environments. Several examples from within this active urban field help to contextualize how complex interactions can be explored. Continuing his research in the area of urban modelling, Batty and Xie propose an expansion on the basic gravity model to take on a dynamic form. The authors transform the model into a CA environment, where each cell within the model can represent a single land use or household. Densification, diffusion and urban growth can be modelled within this environment, through the mathematical implementation of specific rules defining cell states and transition thresholds (Batty and Xie, 2005).

Such CA modeling approaches have been increasingly applied within urban development research in recent years, producing a number of relevant complex spatial models. Such models are being adapted and expanded upon to further broaden their potential within the planning field. Paul Torrens has contributed to the complex modelling literature, arguing for a Geographic Automata approach to understanding residential movement patterns (2007). Torrens sees Geographic Automata as an extension of CA, whereby the inherent spatiality of the datasets is maintained through all stages of model design (Torrens, 2007). He applies his integrated technique to simulate residential mobility within an urban environment, testing multiple scenarios and finding that the Geographic Automata environment is able to produce appropriate results that allow the researcher to incorporate spatial dynamics and interactions into the model.

Further expanding on the capabilities and flexibilities of traditional CA, Stevens and colleagues present the *iCity* model: a vector-based program that moves away from traditional raster-based CA grid cells (Stevens et al., 2007). Incorporating cadastral-level spatial datasets within an ArcGIS environment, the researchers were able to provide a realistic visualization of complex urban growth patterns and project future growth within an expanding Canadian city. Building on this concept, Jjumba and Dragičević extend the approach within an ABM framework called *Agent iCity*, introducing complex behaviours and actors into the dynamic urban system (Jjumba and Dragičević, 2012). Such methodologies allow for realistic, non-uniform urban areas and non-grid-based topologies to be represented. The resulting model proves to be both spatially and visually accurate, providing output in vector-based mapped form which can be easily integrated into a variety of publicly-available mapping software (Stevens et al., 2007; Jjumba and Dragičević, 2012).

CA and ABM approaches such as the *iCity* suite are receiving considerable attention within urban development literature, with a growing number of integrated modeling approaches emerging within the last decade. A number of approaches build upon a CA framework to model landscape change and development, but incorporate agents within the approach to factor in the impact of complex human decision-making (Xie et al., 2007; Vancheri et al., 2008a, 2008b). Further approaches link the bottom-up development of ABM with decision-making frameworks to capture the multi-level complexities of land use growth and development (Bone et al., 2011; Zhang et al., 2015). The results of these models show significant promise, providing large-scale spatial output that identifies growth patterns at the micro-level.

Advances in modeling complex systems have led to the development of a series of approaches that simulate urban growth and land use change. Such integrated approaches continue to emerge, and provide compelling visualizations of projected development patterns at a very fine spatial resolution (Stevens et al., 2007; Vancheri et al., 2008b; Bone et al., 2011; Jjumba and Dragičević, 2012; Zhang et al., 2015). The authors frequently emphasize the importance of considering such projected modeling approaches at the planning stage, using results from scenario-testing as decision-making tools (Stevens et al., 2007; Bone et al., 2011; Jjumba and Dragičević, 2012; Zhang et al., 2015). However,

there is a need for increased consideration of the logistics behind actual model implementation within the urban planning realm, including access to required software, integration with existing data sources, and training for use (Stevens et al., 2007).

4.5.2. Travel, movement and transportation modelling

The urban landscape has been influenced by many planning styles and designs over the decades, but perhaps the strongest catalyst for urban structural change has been the introduction and accessibility of the automobile. With the rise in automobile use and availability, urban living has shifted to an increasingly decentralized model, with home, work and shopping frequently located in separate areas (Axhausen, 2005; Shiftan et al., 2007; Wegener, 2014). This shift has been accompanied with additional social and economic changes, including an increase of females in the workforce, increases in flexible working schedules, and even increases in personal leisure and vacation time (Cohen and Felson, 1979; Shiftan et al., 2007). Such fundamental (and continuing) changes to travel patterns have created a need to understand and model transportation systems, allowing for more appropriate planning and greater efficiency in travel. As urban travel patterns continue to shift alongside urban development, the need for a clearer understanding of the dynamic patterns of human movement continues to grow.

Research within the transportation planning area often explores methods for projecting expected traffic volumes. In 1974, Daniel McFadden contributed a model of urban travel behaviour within the San Francisco Bay Area. The model employs binary and conditional logit modelling to forecast future patronage of the San Francisco Bay Area Rapid Transit (BART) (McFadden, 1974, 316). It considers the impact that home location, access to BART stations, cost, additional transportation alternatives and length of travel time (among other variables) have on the likelihood that a household would choose to use the rapid transit option. His results provide a good, if preliminary match to early BART patronage, emphasizing that while 69% of people expected that they could use the BART to meet their transportation needs, just 16% intended to do so (McFadden, 1974). McFadden's work increases understanding of which factors may increase BART ridership, as well as the factors that inhibit or prevent individuals from selecting this mode of transportation.

McFadden's exploration of travel decision-making incorporates a variety of socio-economic and demographic variables in order to garner an understanding of the features that impact an individual's decision to travel in a specific way. Exploring a similar study topic, Ferguson and Patterson forecast transit ridership demand through the development of an integrated time series and cross-sectional model (Ferguson and Patterson, 1993). This statistical model forecasts future usage of the transportation system, while accounting for temporally related fluctuations to usage. While findings indicate that the application of such a modelling method shows promise within transport planning settings, the authors caution that all users must be well-versed in the user commands, and must pay keen attention to the methods and order of data analysis (Ferguson and Patterson, 1993).

The impact of built urban form on human movement and decision-making has been the focus of research spanning disciplinary boundaries (Kwan, 1999, 2004; Lee-Gosselin and Doherty, 2005). Echoing work from within environmental criminology, there has been a renewed push within the transportation planning field to incorporate an understanding of individual activity spaces into travel decision-making models (Brantingham and Brantingham, 1991; Axhausen, 2005; Miller, 2005; McCray et al., 2005). By approximating activity nodes and pathways, alongside constraint measures including time and distance, such information can provide researchers with the data input needed to model likely travel behaviour across different population groups (Hägerstrand, 1970; Kwan, 2000a, 2000b; McCray et al., 2005). With a movement towards large scale analysis, gaining access to high-resolution, detailed data sources, and integrating multiple data sources continues to present a significant barrier to research within the field (Roorda et al., 2005; Ramadier et al., 2005). In addition, when access to large scale data permits micro-simulation modelling approaches, such methods often introduce a significant amount of error (Wegener, 2014). With this in mind, Wegener cautions that "the optimum level of disaggregation may not be the most disaggregate one" (2014, 753).

When considering urban growth and transportation modelling, approaches and methodologies have developed alongside technological advances. Researchers exploring land use and transportation development have benefitted from increased access to some large-scale data sources, as well as from greater access to affordable and efficient computing power with which to analyze and model these sources (Wegener, 2014). In

spite of the increases in data availability, finding and integrating high resolution sources of uniform quality continues to present challenges within the field. In addition, while such models are often designed with a goal of informing the planning profession, there are a shortage of models that provide a clear framework for integration into an existing planning toolkit (Stevens et al., 2007).

4.5.3. Modeling urban crime patterns

From land use growth and development, to use of transportation systems, cross-disciplinary research has repeatedly stressed the importance of human behaviour in shaping the use of land and modes of transport (Miller, 2005; McCray et al., 2005; Jjumba and Dragičević, 2012). When shifting the focus to models of crime, the emphasis often reverses, focusing instead on the importance of land use and transportation systems in shaping human behaviour (Ackerman and Murray, 2004; Savoie, 2008; Kinney et al., 2008; Robinson, 2008). The growing body of literature surrounding the impact of urban structures on crime contributes to the development of a more nuanced understanding of the complex relationship between these features, and has clear implications within the planning and police resourcing realms (Brantingham and Brantingham, 1995; Ratcliffe and McCullagh, 2001; Groff and Lockwood, 2014).

The relationship between the built environment and crime is frequently investigated through spatial analysis and statistical models, either used independently, or in conjunction with one another. The interactions between the social and physical environmental characteristics, as described in the routine activities approach, crime pattern theory and social disorganization theory have been the focus of a considerable amount of research, as reviewed earlier in this chapter. As computing technologies advance and data collection and storage increases, new data sources are becoming available, leading to new challenges in data integration, as well as new methods to harness information from such sources (Gerber, 2014; Malleson and Andresen, 2015a, 2015b; Thompson et al., 2015). Such large-scale datasets allow for a more detailed focus on the spatial connections between crime and the built environment, with research emphasizing the importance of micro-scale analysis (Harries, 2005; Kinney et al., 2008; Groff et al., 2010; Andresen and Malleson, 2011; Curman et al., 2015).

In 2004, Brantingham and Brantingham emphasized that while existing research within the field of environmental criminology was able to identify a number of connections between the environment and human behaviour, the statistical and spatial modeling methods currently applied within the field lacked the ability to account for the true complexity of such interactions (Brantingham and Brantingham, 2004). They encourage the application of simulation modeling as a method with the potential to represent both micro-level interactions, and macro-level impacts, while accounting for the complex feedback loops imbedded into key environmental theories such as crime pattern theory (Brantingham and Brantingham, 1993a, 2004; Brantingham et al., 2012). The value of capturing such recursive feedback is echoed by Walker in his 2007 work, in which he proposes a complex systems approach to criminological modeling. In much of criminological research, he points out, crime has been viewed “as the outcome of neighborhood characteristics and disorder, and also the cause of it” (Walker, 2007, p.575): complex systems science can incorporate this complication into the modelling process.

A number of researchers within criminology have contributed to the complex modeling field, typically by applying simulation methods such as ABM and/or CA to explore how offenders and targets interact within the built urban environment (Liu et al., 2005; Brantingham et al., 2005, 2008; Groff, 2007a; Liu and Eck, 2008; Malleson et al., 2009, 2010; Dabbaghian et al., 2010; Brantingham et al., 2012). Such models have provided important research tools, permitting hypothesis testing and scenario exploration, while acknowledging the complexities of the dynamic interactions between the many actors within the urban environment. Importantly, such approaches allow for recognition of individual-level, site-specific differences in the environmental backcloth at the crime location itself – something that aggregate, statistical models are unable to account for (Brantingham and Brantingham, 1991, 2004; Groff, 2007a, 2007b; Malleson et al., 2010; Brantingham et al., 2012).

Simulation modeling approaches offer the potential for advancements in understanding the multi-scale complexities of human behaviour and crime patterns- even in the absence of individual-level travel patterns and decision-making data (Brantingham and Brantingham, 2004; Groff, 2007a). In spite of this potential, there are some challenges associated with their use. Such programs have the potential to be computationally

intensive, often require programming experience, and modelled abstractions of reality may be difficult for unfamiliar users to contextualize (Groff, 2007a; Brantingham et al., 2008). Such limits are increasingly being addressed as user-friendly toolkits allow modeling programs as add-ons to existing software, thus lessening the learning curve for model developers, while providing output in a format that is more familiar to consumers (Groff, 2007a). Regardless of the modeling approach, Brantingham and colleagues emphasize that the process of model development is in itself an important method to advance theory:

“The goal [of model building] is clarity and consistency with theoretical or operational validity. The process of model building forces the model builder to be clear about assumptions and about relationships of model parts, and to identify what is and is not included within the model. Models are supportable when past research is included in the construction of the rules, but are found to be of high value when they explore new areas of thought. Theory development and modeling are closely tied.” (Brantingham et al., 2012, 199).

4.5.4. Moving forward: Recommendations for model development

In light of the wide range of past and current research exploring the connections between land use, transportation networks, and human activity, there exists a great potential for continued modelling applications within the realm of criminology. Based on the wide range of methodologies and approaches, there is no single ‘best practice’ to follow. Rather, heeding the advice of Kilbridge and colleagues, model development must begin with an understanding of the subject to be modelled, and the goal or purpose of the model (Kilbridge et al., 1969). Further, models must be soundly grounded in theoretical basis, and must clearly define how the appropriate theory will be translated, mathematically or otherwise, within the model. All other features, from model subject to model type, will depend on the features identified within the conceptual framework (Kilbridge et al., 1969; Brantingham et al., 2008).

In spite of the broad range in potential methodologies and directions, there are several key themes and suggestions found throughout previous approaches to help guide and direct future approaches. While models may aim to develop projected output for future years, in the absence of additional contextual information, it is the most recent information that best informs future modeling steps (Chainey et al., 2008; Gerber, 2014). Future

projection models may have most success by including multiple phases into the model, where researchers may see interim output and adjust the *new* inputs according to policy guidelines or to test theories (Kilbridge et al., 1969). Further, human/environmental dynamics are complex and challenging phenomena to represent. When using static snapshots of data as input, models are best used as a guide to develop an understanding of potential behaviours and a range of outcomes, rather than relying on the output for predictive purposes (O’Sullivan, 2004). Lastly, models can act as tools with which to test and develop theory and policy – however, if the tool itself and/or the output results are not easily understandable by the intended model consumers, the model utility is limited (Brantingham et al., 2008; 2012).

A variety of existing models help to illustrate dynamic urban processes such as land use growth and development, transportation system growth and usage, and the interrelationships between these built environmental features and complex human interactions, such as crime. While a considerable amount of research spanning these topics emphasizes the utility of these models in informing urban planning and resource development, few existing examples go beyond mention of this important application and move towards facilitating such model use (Brantingham and Brantingham, 1995; Stevens et al., 2007; Paulsen, 2012). This chapter proposes a prototype model that addresses three existing shortfalls within this vast interdisciplinary field:

- a) This model aims to explore the connections between urban development and potential crime and disorder by building on locally-identified connections between crime and the built environment.
- b) It goes further in aiming to identify potential resource needs that change alongside such concentrated urban development.
- c) It develops this model in partnership with both municipal planning stakeholders, and policing stakeholders alike, aiming to reduce barriers to implementation and use of the tool within both settings.

Best practices as identified within existing research are incorporated to inform the development of this model. While it is preliminary in nature, the modeling process and initial output identify a number of potential areas for future development.

4.6. Case Study: Suburban development and crime

It is widely accepted that there is an important relationship between the spatial distribution of land use, transportation networks and the patterns of criminal activity within urban environments. The urban structure and layout determines the location of common activity nodes and the available routes to access such nodes; as such, it plays an important role in determining how urban spaces are used. Understanding this relationship is particularly important within the metropolitan Vancouver area. As the region continues to expand, a disproportionate amount of local population growth and development is focused on the suburban communities (Turcotte, 2001; Statistics Canada, 2012a, 2012b; Gordon and Janzen, 2013). In response, Metro Vancouver has implemented a regional plan to foster the development of a number of town centres throughout the metropolitan area (Metro Vancouver, 2011). These town centres are sites of high-density growth, providing a mix of residential and commercial land uses, and are intended to act as local downtown cores for their surrounding suburban communities. Coquitlam, British Columbia, is home to one of these redeveloping regional town centres.

Coquitlam's city centre area has undergone considerable development in recent years. The area has been designed to be a complete and walkable community, hosting an expanded shopping mall and commercial hub, a large post-secondary campus, access points to the regional rapid transit system, and a number of community and cultural facilities developed into the core area. A growing number of high-density residential lots are under development within the area, marking a considerable shift from the community's former low-density residential suburban style (City of Coquitlam, 2008).

4.6.1. The local context: Case study background

Policing within British Columbia: Coquitlam Detachment

Policing services across British Columbia are administered by four different organizations - the Royal Canadian Mounted Police (RCMP) provincial force, independent municipal forces, RCMP municipal forces, and First Nations Administered Police Services. Each force provides yearly reports to the provincial government, which include crime rates, police strength, and total operational costs. This information is collected and compiled to

provide an overview of the operations of each police force, and allows for documentation of intra-force changes over years. However, there is considerable variation in the organizational structures and operational costs among police forces that must be considered when making comparisons between forces based on police strength, costs and population (Ministry of Public Safety and Solicitor General, 2015). This is particularly important when comparing different types of forces – while similarly sized RCMP municipal forces may have similar (though not identical) organizational structures, RCMP and independent forces – even those serving similar sized areas – operate under significantly different frameworks.

The ratio of population per officer is a commonly used statistic that can help provide a proxy measure of the police service levels within each municipality. This ratio is calculated by dividing the reported population for each municipality by the reported police strength for a given year. Police strength generally includes both sworn regular and civilian members, but for the purposes of this study, does not include non-sworn civilian support staff or special integrated task force members. Populations for each municipality are adapted and projected from the Canadian Census, which is taken every 5 years – most recently in 2011 (Ministry of Public Safety and Solicitor General, 2015).

Table 6 displays the municipal populations and police strength for Coquitlam and Port Coquitlam for the first year of this study (2008), as well as for the most recently available year (2014)¹³. This table provides an overall population per officer ratio for general comparative purposes. In addition, it includes the total and average reported figures for municipalities served by RCMP municipal forces (above and below 15,000) and independent police forces. Note that both Coquitlam and Port Coquitlam fall into the sub-category of RCMP Municipal Forces serving communities over 15,000.

¹³ In 2014, police strength was reported as both authorized and adjusted strength, which increases the resource counts for municipalities such as Coquitlam and Port Coquitlam based on their contribution to and access to integrated regional policing teams. While the Ministry of Public Safety and Solicitor General calculates population per officer measures based on adjusted strength, Table 6 adjusts this calculation to omit the integrated team contributions to be more consistent with the methods of reporting 2008 resourcing statistics. When considering adjusted police strength, all 2014 population per officer ratios drop; however, Coquitlam and Port Coquitlam's measure remains considerably higher than the provincial averages.

Table 6: Police strength by municipality and detachment type, 2008 and 2014. Adapted from Ministry of Public Safety and Solicitor General, 2009, 2015.

Municipality	2008 Population	2008 Police Strength	2008 Population per Officer	2014 Population	2014 Police Strength	2014 Population per Officer
Coquitlam	121,479	142	855	141,179	152	929
Port Coquitlam	55,589	64	869	59,819	67	893
Combined: Coquitlam and Port Coquitlam	177,067	206	860	200,998	219	918
Total/Average: RCMP Forces over 15,000	2,126,968	2,745	775	2,390,133	3,036	787
Total/Average: RCMP Forces 5,000 - 15,000	294,073	429	685	295,564	432	684
Total/Average: Independent Municipal Police Forces	1,247,344	2,294	544	1,286,838	2,413	533

The population per officer ratios are provided at the municipal level. Municipal boundaries do not always match with the police jurisdictional boundaries. Indeed, this is the case with the Coquitlam Detachment, made up of Coquitlam, Port Coquitlam, and two additional smaller communities. The combined population per officer ratio for Coquitlam Detachment was 860 in 2008, and has risen to 918 in 2014. The comparable ratio for other similarly-sized urban centres served by municipal RCMP forces is significantly lower, at 775 in 2008, and 787 in 2014. While there are certainly a number of additional factors that warrant consideration, such as variations in human resources and support services, this indicates that in 2008 the Coquitlam RCMP Detachment had proportionally fewer officers available to meet the policing needs of the community, and that this shortage continued in 2014.

While the population per officer ratio provides information about the police service levels within a given municipality, additional information can provide a more complete understanding of community safety and policing needs. Further complicating the comparisons, population measures alone are not able to account for how land within the municipalities is actually used. This concept is particularly relevant in areas where

downtown centres and activity hubs attract visitors and out-of-city residents for employment and entertainment purposes (Andresen and Jenion, 2010; Andresen, 2011; Malleson and Andresen, 2015a). From a local perspective, research focusing on Coquitlam and surrounding areas has found that the city's town centre area acts as an important directional attractor for offenders in a number of neighbouring communities and policing jurisdictions (Frank et al., 2013). Additional research on home locations of police contacts within Coquitlam Detachment illustrates the considerable number of interactions associated with individuals residing out of the jurisdictional boundaries (Wuschke, 2011). When considered in conjunction with the comparably high population per officer ratio of Coquitlam and Port Coquitlam, these findings further illustrate a detachment-level need to explore alternative police resourcing metrics. As emphasized within existing research, the known connections between the built environment, crime and disorder may provide an alternative framework for measuring the local need for police resources.

Crime trends in Coquitlam Detachment: Crimes by environmental feature

A wide body of academic literature emphasizes the important links between land use, urban design and criminal events. As illustrated within the geometry of crime theory, physical structures within the urban environment have long been found to impact the location, type and volume of local crime and disorder events. The specific relationship between urban features and crime vary from location to location, and while a number of generalizations can be recognized in many urban communities, this relationship is best understood at a local level.

Previous research focusing on Coquitlam and Port Coquitlam has identified several key local features that are associated with higher proportions of crime (Chapter 2, Chapter 3). At the macro level, arterial roads, properties designated as commercial, and those labelled as civic, institutional and recreational (CIR) have higher concentrations of crime events on site. When moving to a meso resolution, the regional and community shopping malls dominate the commercial land use category, while recreation and cultural centres, hospitals and schools drive the crime concentrations within CIR land uses. Moving to a still finer resolution, the importance of arterial roads and shopping malls is again emphasized, as the top blocks and single addresses with highest counts of crime fall into these classifications (Chapter 2). Crime events continue to concentrate in the micro-spaces

immediately beyond each of these local features of interest as well, with these large spatial scale patterns varying according to feature type (Chapter 3). This local context emphasizes the importance of built environmental features in shaping the distribution of crime and disorder events within Coquitlam and Port Coquitlam. The existing relationships between crime and such local features may be useful measures to inform potential crime patterns and resource needs as the cities continue to develop and densify.

4.6.2. Modeling overview: Data sources and preparation

The local context within Coquitlam and Port Coquitlam presents a unique opportunity to explore how urban growth and development may impact crime concentrations, as well as the need for police resources. The resident population of the wider Coquitlam area has been expanding in recent years, and this trend is expected to continue as the cities undergo increased development and densification (City of Coquitlam, 2008; Metro Vancouver, 2011; Statistics Canada, 2012a, 2012b). With this in mind, the local public safety and policing needs must evolve along with the urban area.

Simplified representations of the complex relationships between these elements are used as input in a preliminary mathematical model, developed as a tool for exploring the potential impacts of anticipated urban growth. Designed for use within both municipal planning settings and policing environments, this prototype model was developed in a standard spreadsheet format to reduce implementation barriers. While this limited the scope of available modeling approaches, this choice built on existing software infrastructure, thus eliminating additional software approvals, installations, and costs for the target users (City of Coquitlam, City of Port Coquitlam, and Coquitlam RCMP detachment). The model addresses the complex nature of urban crime and disorder through a multi-step framework that takes land use, transportation networks, growth, and policing costs into account when exploring potential future resourcing needs. The resulting framework provides local decision makers with a tool that can be edited and adjusted to encompass different urban growth scenarios and changes in police resourcing needs.

The model relies on local data inputs, and as such, was developed in partnership with the City of Coquitlam, the City of Port Coquitlam, and the Coquitlam RCMP

detachment. Table 7, below, lists the primary data sources included in the modeling process.

Table 7: Data Sources included in model

Data Type	Description	Source
Police Records	Detailed RCMP records for Coquitlam Detachment - 2008 and 2009 inclusive	PRIME –police records management system data, provided by Coquitlam RCMP Detachment
Police Costing	Record of cost, as measured in time, of calls for service according to the location of the event.	Computer Aided Dispatch (CAD) Data - provided by Coquitlam RCMP Detachment
Land Use	Micro-level details of actual use of each property for 2008 and 2009	British Columbia Assessment Authority (BCAA) Data - provided by City of Coquitlam and City of Port Coquitlam
Road Network	Detailed road network dataset for study area, 2008 and 2014	GIS Innovations - provided by RCMP E-Division
Police Resourcing	Authorized police strength allocated to Coquitlam and Port Coquitlam – 2008 to 2014 inclusive	Ministry of Public Safety and the Solicitor General, 2009 to 2015

The police records datasets (PRIME), police costing data (as measured in time on scene, found in Computer Aided Dispatch (CAD) records), and land use data (BCAA) required additional data preparation. Addresses for each of these files were geocoded along the road network centreline using ESRI’s ArcGIS 10.2, with each file well surpassing Ratcliffe’s minimum acceptable match rate (Ratcliffe, 2004a). Police records (PRIME and CAD) were clipped to exclude all events occurring outside of the municipal boundaries of Coquitlam and Port Coquitlam in order to match with the land use data available for this study. Records without listed street numbers, and records reported at either the provincial courthouse or the police detachment were omitted from this analysis. However, unlike earlier research on crime and the built environment within the study area, all other police records found within the PRIME dataset were retained in this analysis, including non-chargeable events. These non-crime records were deemed to be important for police resource estimations, as they account for a portion of the police activities that are not represented by traditional crime rates. Further data cleaning led to the removal of a number of CAD records with missing timing details. Lastly, all BCAA land use data was dissolved

based on address and detailed use of land, resulting in a simplification of the dataset and a reduction in the number of records¹⁴. Details of this data preparation are presented in Table 8.

Table 8: Breakdown of data inputs throughout preparation process

Data Source and Year	Initial Count	Geocoded Records: Count	Geocoded Records: %	Within Municipal Boundaries	Final Records
PRIME: 2008	41881	39967	95	39675	36628
PRIME: 2009	39387	37190	94	36766	33467
CAD: 2009	41284	38344	93	38300	23491
BCAA: 2008	51947	51200	99	51200	36314
BCAA: 2009	59711	59286	99	59286	37034

In order to represent the interaction between the built environment and crime, the PRIME and CAD records were first matched by address with the BCAA dataset to provide a record of the use of land associated with each police-associated event. The BCAA data contain a detailed breakdown of specific land uses associated with each property within the cities of Coquitlam and Port Coquitlam. Data are collected for tax assessment purposes, are groundtruthed by the company and landowners alike, and is updated on a yearly basis. 69% of records from each police data file (PRIME 2008, PRIME 2009 and CAD 2009) were able to be linked to the BCAA data, enriching the data with detailed use of land information. The remaining 31% of records could not be directly matched with a detailed land use. This is largely due to police-recorded events either occurring, or being logged at an intersection or the 100-block, though a small portion of recorded addresses did not have a land use match within the BCAA data. These records were analysed according to the road network.

¹⁴ The British Columbia Assessment Authority (BCAA) collects data for taxation purposes, and includes a unique record for every individually- or company-owned property within the province. This results in a large number of records for privately-owned condominiums, for example, but just one record for both single family homes, and high-density rental properties such as apartment buildings. By dissolving the records according to address and land use, this simplifies the data to provide one record for each unique land use at a given address. This process results in a loss of data detail, but addresses the existing inconsistency in the way that similar land uses are recorded by providing one record for each address, rather than each property sub-unit. Crime rates calculated according counts of properties should be mindful of this dataset limitation: one privately owned single family residence is represented by the same number of records as one high-density apartment building, so the rates must be understood accordingly.

The non-address matched records were spatially joined to the local road network for analysis based on both road classification, and location. The records were separated into two classifications – records at intersections, and records on blocks (including all events recorded at a 100-block, as well as all addresses for which no matched land use could be identified). Each of these road-based subsets were further divided into two sub-groups: records on or near arterial roads, and other records. Near, for the purposes on this study, includes all locations within 15 meters of an artery, as measured via road connectivity. This distance was selected based on local findings that crime events disproportionally cluster along, and within 15 meters from arterial routes (Chapter 3). The final datasets were exported out of ArcGIS and imported into spreadsheet workbooks for further analysis and adaptation into the modelling process.

4.6.3. Methods and frameworks: The model process

Using the prepared data sources as inputs, the model provides a projected estimation of the potential authorized police strength needed to accommodate the dynamic growth occurring within Coquitlam and Port Coquitlam. This estimation is measured as a number of full-time equivalent (FTE) sworn RCMP member positions, and is developed following a series of analytical steps.

Authorized strength: Full-time equivalent allocation

The initial phase of this model considers the current allocation of RCMP resourcing for the area in question. Each year, the British Columbia provincial government publishes a report on police strength, reporting the authorized strength for each municipality and provincial jurisdiction in the province. The authorized strength is measured in FTE positions, and represents the total number of both sworn members and sworn civilians designated for Coquitlam and Port Coquitlam, but does not include other municipal support staff (Ministry of Public Safety and Solicitor General, 2009, 2015). The initial model input totals the 2008 authorized strength for Coquitlam (142) and Port Coquitlam (64), and maintains the total proportion of members as divided by municipality throughout the model. The model builds upon the current relationship between police resources, land use development, and police records, requiring the initial authorized strength (as measured at the model start point – in this case, 2008) as data input. Recognizing that the current

resourcing counts may not represent an appropriate or ideal starting figures, these numbers may be adjusted to view the potential impact that more or fewer initial resources may have on policing requirements in later years. This feature is specifically relevant within Coquitlam and Port Coquitlam: if the detachment is underserved by officers at the model start, this shortage in FTEs is maintained throughout the model. By adjusting the initial police strength, output may depict alternative scenarios with higher levels of police resources maintained throughout. This modeling stage also provides the opportunity to input any actual or expected increases in police resources throughout the modeling timeframe, allowing for a comparison of potential anticipated needs versus actual anticipated resources. Police strength per year, measured in FTEs, is represented within the model as:

$$(FTE_t)$$

Where

FTE = the total authorized or projected police strength

t = 1, ..., 7 (representing 7 projected years within the current model
– 2009 to 2015)

Workload by environmental feature

The next step in the modelling process recognizes that it takes different amounts of policing resources to respond to calls for service at different locations. This can be due to the physical features of the land use - for example, high-rise condominiums often have increased security measures, locked stairwells, and elevators that do not permit access to floors without passes. These additional measures may offer increased security to residents, but may also increase the amount of time required for a police officer to access a particular unit. Other facilities, such as parks or recreation sites, may offer ease of access and clear line of sight, reducing the barriers to on-scene access and work. With this in mind, the second phase of the modeling process introduces categories of land use and environmental features, and weighs each category according to the amount of time resources required to respond to calls for service at these locations.

First, all built environmental data for Coquitlam and Port Coquitlam is compiled and grouped according to feature type. Grouping decisions are informed from the results of a local area analysis of crime within the built environment, and include four broad categories

of land use (residential, commercial, CIR and other¹⁵), as well as two broad road-based categories (intersections and blocks). Broad land use categories are broken into sub-categories based on the actual use of the property, and informed by the local area analysis (see Chapter 2 and Chapter 3). Broad road-based categories are divided based on proximity to arterial routes. Environmental features are represented within the model as follows:

$$(E_{i,t})$$

Where

E = Environmental feature

$i = 1, \dots, 6$ (representing 6 broad environmental classifications)

$t = 1, \dots, 7$ (representing 7 projected years within the current model
– 2009 to 2015)

A weighting measure called Workload per Call is then developed using the Coquitlam RCMP Detachment's 2009 CAD records. The CAD records, as described above, are cleaned, geocoded, and linked to detailed land use and road type information. From this data, all calls for service are selected where an officer was dispatched to the scene, and where associated time on scene attributes were recorded ($n = 23,491$). For every environmental feature classification and sub-category, the median time spent on-scene is determined. This data is then standardized by the overall median time on scene for all calls for service within the study area. The standardized measure is used as a proxy for workload per call. Environmental features that require more time or resources are weighted proportionally higher than those that require a lesser workload. This standardized weight is represented within the modeling framework as (S_i) and is calculated for each environmental feature category and sub-category (E_i) .

Police records by environmental feature

In an effort to account for the varying impact that environmental features have on the distribution of police records, the third modelling phase incorporates current police

¹⁵ The broad land use classification of “other” is a compiled category including the very small percentage of lots *not* falling into the three main categories of analysis. Land uses within this category include farm, SOFA (common areas within stratified units), industrial and TCU (transportation, communication and utility) land uses.

record data into the modelling process. The data included as primary input is the 2008 PRIME records for Coquitlam and Port Coquitlam. As these records are linked with the local environmental feature datasets, police records are grouped according to each environmental feature category (E_i) to calculate a rate of records per unit; a value denoted within the model as (a_i).

Urban growth estimates

Stage four of the model projects potential urban growth over a set number of years, based on past trends in urban development. The current model uses the 2008 and 2009 BCAA land use information for the cities of Coquitlam and Port Coquitlam to estimate future land use-based patterns from 2010 to 2015. Road network changes are estimated between 2008 and 2014 input years, and projected based on this relationship for 2015. All growth models are based on a logarithmic function, which projects a quick initial change prior to levelling out. This growth formula was selected to represent the patterns of development experienced within the Greater Vancouver area, which is expected to continue in incremental stages (City of Coquitlam, 2008). The urban growth as projected within the model is described as follows:

$$E_{i,t} = f(\ln(E_{t^*}))$$

Where

t^* = *initial input years of model –*
(2008 to 2008 for land use, 2008 and 2014 for road network)

The model requires an estimation of the number of units within each environmental feature category and sub-category for each of the years of interest as explored in the model. These projections can be manually adjusted upwards or downwards on an individual basis or using an alternative growth formula, or (preferably) fit to match city plans for the years of study through consultation with city planners.

Estimation of police records by environmental feature

Following the estimation of land use growth and development within the study area, stage five of the modelling process calculates a projected count of police records ($P_{i,t}$) for

each environmental feature category (E_i), for 2009 to 2015. This is accomplished by multiplying the projected number of units of a given environmental feature by the initial rate of records per unit for the same feature category. The resulting output is an estimate for the number of police records associated with each type of environmental feature for each of the target years of this study.

This is described within the model as follows:

$$P_{i,t} = a_i * E_{i,t}$$

Total projected police records for a given year (P_t) can then be calculated as follows:

$$P_t = \sum_i^n (a_i * E_{i,t})$$

Estimates of Workload

The final stage of the model uses several steps to arrive at an estimation of the police strength (FTE), required for Coquitlam and Port Coquitlam for each projected year. First, an adjusted workload per environmental feature measure is calculated, ($W_{i,t}$), to take into account the varied cost associated with events at different environmental features. This is calculated as follows:

$$W_{i,t} = S_i * P_{i,t}$$

This weighted workload per environmental feature is then summed to arrive at a total workload for a given year (W_t):

$$W_t = \sum_i^n (S_i * P_{i,t})$$

At this point, the model uses the initial ratio of full-time equivalents to Workload, as identified in 2008, to develop a new projected FTE estimate (FTE_t) for each modelled year. This calculation provides the total FTEs, and can be further divided to present the total

proportion of FTEs allocated to each municipality (Coquitlam and Port Coquitlam respectively). This is represented in the model as follows:

$$FTE_t = W_t * f\left(\frac{FTE_{t^*}}{W_{t^*}}\right)$$

Where

t^* = the starting phase of the model – 2008

The total model, then, can be conceptualized as follows:

$$FTE_t = \sum_i^n (S_i * (a_i * E_{i,t})) * f\left[\frac{FTE_{t^*}}{\sum_i^n (S_i * (a_i * E_{i,t^*}))}\right]$$

Where

FTE = Full Time Equivalent (measuring police strength)

$t = 1, \dots, 7$ (representing 7 projected years within the current model
– 2009 to 2015)

S_i = Standardized weight, calculated for each environmental feature (i)

$i = 1, \dots, 6$ (representing 6 broad environmental classifications)

a_i = Rate of police records per unit

– calculated for each environmental feature (i)

E = Environmental feature (land use category or road feature)

t^* = the starting phase of the model – 2008

4.6.4. Model results

Model output is provided in two primary formats. A visual graphed output illustrating the total projected need for police resources is provided (Figure 9). In addition, the associated breakdown of FTEs by municipality is provided in tabular format (Table 9, below). The results of the initial model and several scenario tests are presented below.

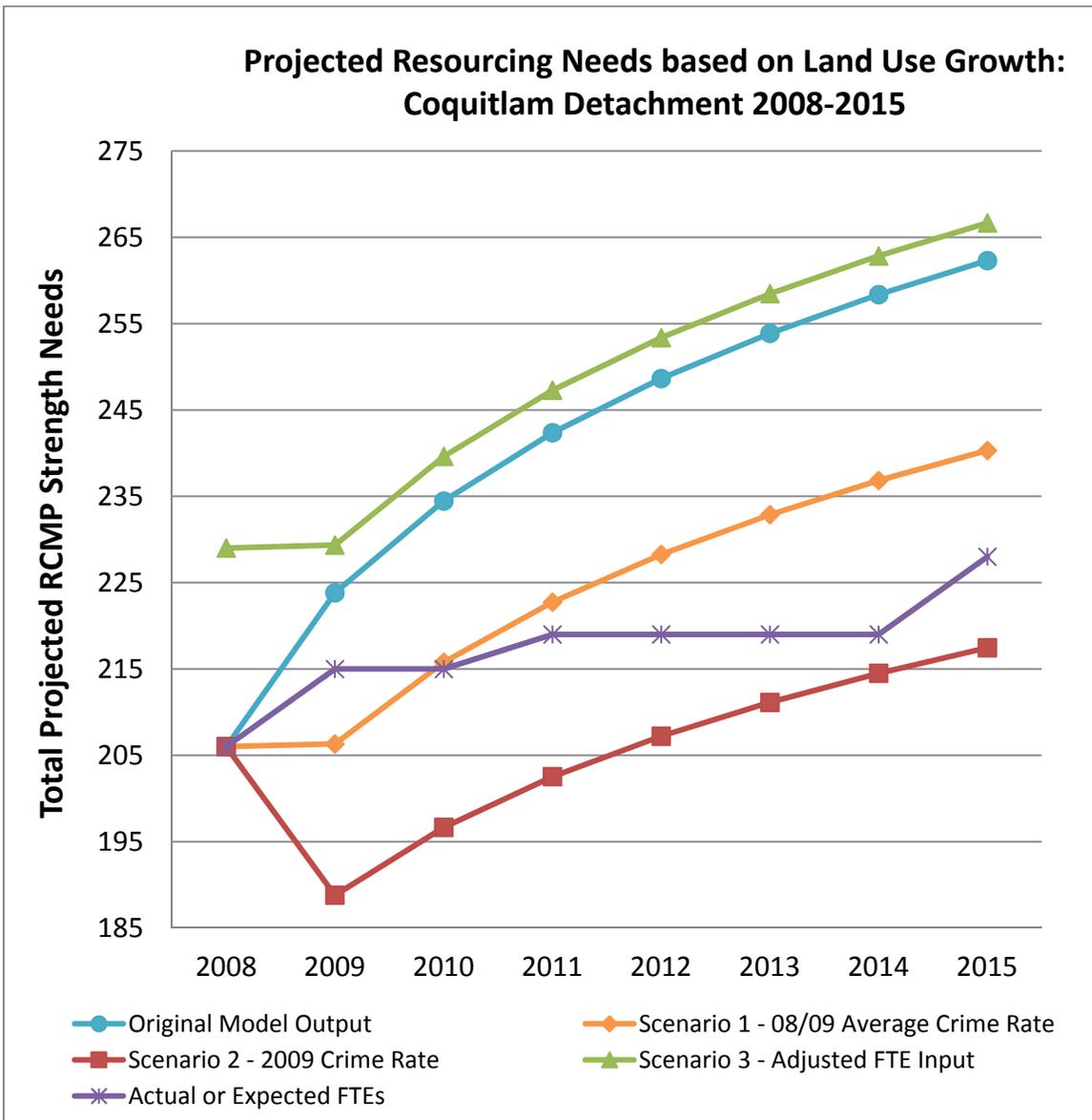


Figure 9: Graphed model output illustrating initial model output, as well as the results of a number of scenario tests.

Initial output

The initial model output, illustrated as a blue line in Figure 9, was derived using unadjusted input data at each stage of the model. The initial police strength needed to serve Coquitlam and Port Coquitlam was input at the 206 FTE positions; this was the actual combined authorized strength for the municipalities in 2008. The urban growth at each stage was maintained according to the input logarithmic calculations. The initial results suggest the need for a moderate increase in FTEs, with a need for 56 new positions

projected by 2015. Results from this initial output directed a number of additional test scenarios, as detailed in Table 9, below.

Scenarios 1 and 2: Crime rate adjustment

Initial model output identified a considerable projected need for increased police resources based on potential land use growth, and associated increase in police contacts. The initial model, however, is based on a stable rate of records by environmental feature (a_i) as identified within the 2008 input data. Recognizing that this rate is not stable, scenario 2 explores the impact of calculating an average rate of records per feature, based on available 2008 and 2009 data. This adjustment appears to result in a one-year lag time: the substantial urban growth experienced between 2008 and 2009 is mitigated by the drop in overall police records occurring within the same period. After this lagged year, no additional crime rate input is available, and the projected police records and need for resources increase as a result. Results are visualized via an orange line in Figure 9, and are included in Table 9, below.

A number of existing models of crime emphasize that in the absence of additional contextual information, the most recent data provides the best approximation for future hotspots of crime (Chainey et al., 2008; Gerber, 2014). With this in mind, the input rate of records per environmental feature (a_i) is adjusted once again in Scenario 2, based on the 2009 relationships alone. Modeled results highlight the impact of the dropping counts of police records within these years, and identify a corresponding dip in needed police resources. The 2009 projected police strength needs actually drop by 17 FTE positions (illustrated as the red line in Figure 9, and listed in Table 9). Subsequent resourcing needs climb from this point onward, reaching a projected 2015 demand of 217 FTE positions.

Table 9: Model output: initial results, as well as three scenario tests.

Model:	2008	2009	2010	2011	2012	2013	2014	2015
Initial Model: Total Projected FTE Needs	206	224	234	242	249	254	258	262
Initial Model: % Growth (Year to Year)	0.0	8.6	4.7	3.4	2.6	2.1	1.8	1.5
Scenario 1: Total Projected FTE Needs	206	206	216	223	228	233	237	240
Scenario 1: % Growth (Year to Year)	0.0	0.1	4.6	3.2	2.5	2.0	1.7	1.5
Scenario 2: Total Projected FTE Needs	206	189	197	203	207	211	214	217
Scenario 2: % Growth Year-Year	0.0	-8.4	4.2	3.0	2.3	1.9	1.6	1.4
Scenario 3: Total Projected FTE Needs	229	229	240	247	253	258	263	267
Scenario 3: % Growth Year-Year	0.0	0.0	1.3	1.0	0.7	0.6	0.5	0.4

Scenario 3: Adjusting the full time equivalent inputs

The results from Scenario 2 highlight a gap within the model in that the current tests do not account for the potential existing shortage in police resources as experienced within Coquitlam Detachment during the input years. The third scenario test of the model builds off of Scenario 1 by incorporating the average 2008/2009 rate of records per feature (a_i), but further adjusts the input police strength data (FTE_{t*}). This adjustment is designed to increase the initial FTE input to a level that would allow Coquitlam and Port Coquitlam to match the province-wide average Population-Per-Officer ratio for similarly sized RCMP detachments of 775. This translates to an initial increase in police strength of 23 FTE positions: 15 allocated to Coquitlam, and 8 to Port Coquitlam. The results, illustrated in green in Figure 9, and in Table 9, above, emphasize a slight increase over the initial model projections, as the magnitude of this impact is mitigated by the concurrent adjustment to the input rate of records per environmental feature (a_i).

The results of each scenario are visualized on the output graph (Figure 9, above), along with an indicator of the actual or anticipated resources available to serve the municipalities. This actual police strength line, displayed in purple, illustrates the difference between the need for, and availability of resources. Initial municipal budgets within

Coquitlam and Port Coquitlam had allotted funds for a total of nine new FTE positions per year between 2009 and 2015. These positions were provided in 2009, but a slower-than-expected economy resulted in budget changes throughout the modeling timeframe. The graphed output reflects the actual authorized police strength for 2008 to 2014, and anticipated resources (9 new FTE positions) for 2015, as actual strength had not been released at the time of this report.

Table 10, below, illustrates the excess or shortfall in FTE positions as indicated by each modelled result, throughout the study period. All outputs, with the exception of Scenario 2, indicate a shortfall in resources that grows until 2014, then begins to lessen in 2015 upon receipt of the (as-yet unconfirmed) 9 expected FTE positions. Scenario 2 illustrates the reverse trend, with an excess in staffing, which decreases until 2014, prior to increasing once again.

Table 10: Actual or expected police strength for Coquitlam and Port Coquitlam, and modelled excess or shortfall in resources: 2008 to 2015

	2008	2009	2010	2011	2012	2013	2014	2015
Actual or Expected FTEs	206	215	215	219	219	219	219	228
Excess or Shortfall: Original Model	0	-9	-19	-23	-30	-35	-39	-34
Excess or Shortfall: Scenario 1	0	9	-1	-4	-9	-14	-18	-12
Excess or Shortfall: Scenario 2	0	26	18	16	12	8	5	11
Excess or Shortfall: Scenario 3	-23	-14	-25	-28	-34	-39	-44	-39

4.7. Discussion

The modeling tool presented within this case study provides a relatively straightforward framework for incorporating a variety of data sources to explore some of the potential social impacts of urban development. The model was designed in partnership with the Coquitlam RCMP Detachment, the City of Coquitlam and the City of Port Coquitlam, with the goal of providing a tool to identify the potential crime implications and public safety needs within a rapidly growing and expanding urban area. It begins with large-scale spatial data, connecting address-level police records and environmental feature

inputs, and provides a flexible and adaptive framework in which one may adjust these inputs at any stage of the modelling process. This flexibility allows for the addition of new data sources throughout the modeling process, such as professional opinions and existing land use plans, while providing for instantaneous updates of subsequent modelling stages to reflect such adjusted inputs.

The model provides interesting outputs at a variety of stages. From enabling users to compare and contrast workloads by environmental feature at the outset, to exploring the proportion of police records attributed to specific land use types and subtypes, the model furthers understanding about the complex relationships between the built urban environment and local police records. The modelling framework incorporates key concepts from both the geometry of crime theory and crime pattern theory, by exploring the relationship between key activity nodes, common pathways and proportions of police records. In providing sub-types of environmental feature categories based on locally-informed research, this model ensures that the unique local relationships between crime and the urban environment are incorporated into the tool itself. While this locally-focused development prevents direct model application within other jurisdictions, the framework and modeling process laid out can certainly be replicated elsewhere.

This case study tested one initial output and three additional scenarios to provide an understanding of model sensitivity and ease of data input. These four output examples are not exhaustive of the potential for scenario testing and development using the model, but are included to show simple examples of data editing for model testing and verification (as with Scenarios 1 and 2) and for scenario development (as with Scenario 3). The scenarios explored provide outputs with ease, and produce results in multiple formats designed for direct comparison.

The model validation process for this prototype tool is iterative, occurring throughout the development, exploration and testing stages (Batty and Xie, 2005; Kopec et al., 2010). This effort builds upon a firm theoretical basis, informed by a strong and growing research field, and supplemented with locally-identified relationships (Kilbridge et al., 1969; Brantingham et al., 2009). The modeling approach in itself was selected to minimize potential barriers to access and use by the intended stakeholders. While the

choice to build a tool within a standard spreadsheet application limits some modeling ability, the minimal costs and reduced learning curves associated with the common software provided strong reinforcement for this approach.

As a necessary simplification of complex and dynamic social phenomena, this preliminary model excludes a number of important social, economic and environmental relationships that, if incorporated, could result in increased predictive accuracy. However, the simplicity of the current format provides a natural mechanism for internal validation by allowing for consideration of the plausibility of preliminary results (Kopeck et al., 2010). Furthermore, the model is designed to be interactive, and for input adjustment throughout the projection timeframe. This allows for a relatively straight-forward process of adding and adjusting data to facilitate alternative scenario testing and to hone the model itself. The initial model output, for example, results in a considerable increase in the anticipated number of police resources needed throughout the modeling timeframe. When considering the magnitude of this output, which is the direct result of a predicted increase in crime, questions about the validity of this finding emerged. As the actual count of local police records dropped between 2008 and 2009, scenarios 1 and 2 emerged from this inquiry, exploring alternative methods to more appropriately model the relationship between the built environment and local crime. While these approaches are limited by current data availability, further explorations on best methods to represent this complex relationship are needed.

Returning to the initial model results, an increase in 56 FTE positions over 7 years appears to be quite a considerable cost. However, the magnitude of this increase is not unexpected; indeed, the model actually requests fewer additional officers than the amount that both municipalities had tentatively budgeted for at the time of the model's development. During a time of high anticipated growth, the City of Coquitlam had agreed to fund six additional officers each year from 2009 to 2015, while Port Coquitlam had agreed to three additional officers per year. The initial model results indicate a need for seven fewer officers than the original municipal budgets had planned; in this sense, the end result is a more conservative estimation of police resource needs. The modelled timing of increases in police resources follows the same logarithmic growth curve as the potential urban development: more officers are needed in earlier stages, with this need levelling off

as the anticipated growth slows. This potential need for police resources contrasts with the municipality-level plans to provide a set increase in FTE positions per year: while the planned linear increase may reduce initial cost, the model emphasizes that this decision could result in a considerable resourcing shortfall for a delayed period of time.

The motivation for the planned yearly increase in 9 FTEs per year was, in part, to address the existing shortfall in police resourcing as identified within Coquitlam and Port Coquitlam in 2008. While the original model identifies potential FTE needs based on the *initial* relationship between workload and police strength, a considerable amount of evidence suggests that Coquitlam detachment has been experiencing chronic understaffing (Ministry of Public Safety and Solicitor General, 2009, 2015). This consideration led to Scenario 3, which explores the impact of adjusting the base crime rate, along with increasing the initial FTE input to reflect levels more consistent with provincial averages. Scenario 3 results in the highest modelled need for additional FTEs, with 61 additional officers needed by 2015. However, these final results still project a need for two fewer FTE positions than initially budgeted for in 2008. While the *actual* authorized strength for Coquitlam and Port Coquitlam did not meet this budgeted level due to an economic slowdown, these economic delays are not yet considered within the current potential growth. With this in mind, based on the input relationships between crime and the built environment, and initial projections for concentrated urban development, the modeled need for police resources is similar to the anticipated needs as identified within the municipal planning process.

The current model provides a strong contribution to existing research by providing a prototype example of how the core connections between the built environment and patterns of criminal activity can actually be utilized within urban planning and police resourcing environments (Brantingham and Brantingham, 1995). While preliminary in nature, this model takes an important step to illustrate how local research can be broadly operationalized to inform such planning decisions. While this framework shows potential, there are several limitations associated with its current format, each of which form future directions for this model. First, existing research has emphasized the importance of using disaggregate crime data, as the spatial relationships exhibited by all police records are unlikely to be representative of the patterns of more congruent sub-groups (Andresen and

Linning, 2012; Song et al., 2016). Future iterations of this model must explore options for disaggregating crime categories, particularly given the decision to include non-criminal police events and contacts in the analysis. As these events are under-researched, there is limited common understanding about how such occurrences may relate to the local urban structure.

Second, the current model was developed as an iterative process, but was based on only two complete snapshots of crime and the built environment. Additional data inputs from Coquitlam, Port Coquitlam, and surrounding areas will help to hone and update the model, and may result in stronger predictive results. Such input could enable the model to account for changes in economic growth, thus providing resource estimations that reflect actual (rather than anticipated) development. Finally, this model has been developed based on the needs and data availability associated with one policing detachment and two local municipalities. Future directions must explore how similar models may be developed in other locales to address unique local concerns and needs.

4.8. Conclusion

The built environment plays a pivotal role in shaping the spatial patterning of criminal activity. Urban structural elements, comprised of specific land uses and vast transportation systems, impact the accessibility of neighbourhoods, and in doing so, impact human decisions. In spite of decades of research establishing the existence of a relationship between the built environment and criminal events, few attempts have been made to contextualize the complex relationship between land use, transportation networks and criminal events within a modelling environment. Progress in this area is necessary in order to develop a more complete understanding of this interrelationship.

The need for such increased understanding has become increasingly urgent, as the local urban landscape within Coquitlam and Port Coquitlam undergoes rapid changes and adjustments in response to regional growth. Through the exploration of modelling literature developed to explore land use and transportation growth, key concepts, frameworks and modelling challenges have been identified. When possible and relevant, these contributions have been adapted and incorporated into an integrated planning tool.

This study incorporates a variety of large-scale spatial datasets into a multi-stage mathematical model aiming to estimate potential police resourcing needs within a dynamic urban environment. While early in developmental stages, the model integrates a variety of rich data sources and provides a flexible and intuitive framework, allowing for data analysis, exploration and scenario-testing that extend well beyond police resourcing estimates. Future iterations of the modeling framework will incorporate more nuanced local relationships in an effort to provide a more detailed understanding of the complex connections between key features within the built environment, land use development, crime and disorder, and police resourcing needs.

Chapter 5.

Conclusion

Crime occurrences cluster across the urban landscape, concentrating at specific environmental features, and avoiding other areas. Decades of research within environmental criminology has emphasized the spatial association between crime events and specific features within the urban landscape. Studies have illustrated that crime concentrates along major roadways, within commercial shopping districts, at liquor serving establishments and at schools, to name just a few locations (Brantingham and Brantingham, 1982, 1991, 1993c; Roncek and LoBosco, 1983; Roncek and Faggiani, 1985; Rengert et al., 2000; Kinney et al., 2008; Johnson and Bowers, 2010; Groff, 2011, 2013; Ratcliffe, 2012; Weisburd et al., 2012; Frank et al., 2013; Groff and Lockwood, 2014; Curman et al., 2015). A subset of research within this area has also emphasized that crime does not just cluster at the site of these facilities and features, but also in the spaces beyond them as well (Brantingham and Brantingham, 1994; Kinney, 1999; McCord and Ratcliffe, 2007, 2009; Groff, 2011; Ratcliffe, 2012; Groff and Lockwood, 2014). When considered together, the collective results of this body of research emphasize the importance of considering the environment within which criminal events occur.

This collection of existing research illustrates that different places have different associations with criminal events. While some general consistencies exist across studies, differences have been identified between urban environments as well: findings within one study site cannot be consistently applied within other urban areas (Frank et al., 2013; Song et al., 2016). In addition, the relationships between crime and urban features also vary *within* study sites: crime concentrates at and around different criminogenic features in different ways. Further, not all *similar* features have similar relationships with local crime patterns. Some shopping malls, bars or blocks may be associated with considerably more crime than other similar malls, bars or blocks within the same urban setting (Eck et al., 2007; Kinney et al., 2009; Bowers, 2010; Groff and Lockwood, 2014; Curman et al., 2015). This emphasizes the importance of multi-scale analysis, with particular attention to crime patterns at the micro-level.

When aiming to understand local patterns of crime, place clearly matters. Research within this area serves to uncover important contextual information about the local connections between crime and the built environment. Such context can help to focus local crime reduction or crime prevention initiatives, and can inform overall city planning and development decisions (Brantingham and Brantingham, 1995; Lockwood, 2007; Groff and McCord, 2007; Ratcliffe, 2012; Groff and Lockwood, 2014). Within this compilation, three related studies extend this existing body of research through a series of in-depth investigations centred on two mid-sized suburban municipalities within the Metro Vancouver area. The first contribution explores the relationship between crime and the physical landscape within the suburban environment. Using a multi-scale analytical approach, it identifies local features associated with a disproportionate amount of crime. Findings from this analysis inform the second investigation, which explores the areas surrounding local high-crime features to determine if, and how crime clusters within these micro-spaces. The final study switches the focus from analytical research towards application, through the development of a modeling tool that explores the potential impact of urban growth and development on both crime, and the need for police resources. This prototype tool is built upon the local relationships between crime and the urban environment, as identified within the two prior studies. In aggregate, these contributions seek to advance understanding about the connections between crime and the urban landscape within an under-studied research environment; and to provide a mechanism for planners and policy makers to consider these relationships at the development stage.

5.1. Research Contributions

Given the overarching goal of this composition, each of the three contributions aim to advance understanding about the distribution of crime within mid-sized suburban communities. Each study centres on Coquitlam and Port Coquitlam, British Columbia, and each study seeks to introduce and apply novel adaptations of analytical techniques in order to identify the links between crime and the local built environment. Chapter 2 investigates the relationship between crime and the urban landscape at multiple levels, and introduces an adapted metric with which to identify crime concentrations. The category quotient (CQ) acts as a standardized rate, facilitating comparisons regarding the relative proportions of

crime found at each environmental feature of interest. This measure provides an easy-to-calculate and easy-to-interpret metric, highlighting features where crime concentrations are considerably over-represented in comparison to the city as a whole.

Chapter 2 further reveals nuanced differences that emerge as spatial scale increases. Findings within Coquitlam and Port Coquitlam are consistent in many ways with existing findings within both larger, and neighbouring suburban locales. At each analytical scale, a more focused understanding of these connections emerge, providing insight into some local relationships between crime and the built environment that are unique to these municipalities. Crime within these locales is largely concentrated along arterial roads, as well as at shopping centres; hospitals, recreational facilities and schools also emerge as locally relevant facilities. Noticeably absent from the list of local criminogenic features are alcohol serving establishments. Such facilities are perhaps the most common focus of land use- or facility-based analysis and are frequently identified as crime attracting sites (see for example, Brantingham and Brantingham, 1982; McCord and Ratcliffe, 2007, 2009; Groff, 2011, 2014; Ratcliffe, 2012; Snowden and Pridemore, 2013; Groff and Lockwood, 2014). This is not to say that such facilities are not a concern within this study locale; rather that the features identified within the analysis are associated with a higher proportion of local crime than are the alcohol-linked sites. Further, the aggregated crime categories presented in Chapter 2 may mask some important local relationships between the built environment and *specific* crime types. This is an important topic for future research. Nevertheless, results from this chapter emphasize the importance of adopting a local-level, multi-scale approach when considering the impact that the built urban environment may have on local patterns of crime.

The specific local environmental features, as identified within Chapter 2, provide the foundation for further investigation within Chapter 3. This analysis explores the spaces immediately beyond each locally-identified criminogenic feature, in order to identify the concentrations of crime in proximity. While a small number of existing studies have explored the spatial impact of multiple facilities, none of the identified studies select features based on an analysis of local crime attractors (Rengert et al., 2005; McCord and Ratcliffe, 2007; Groff and Lockwood, 2014; Song et al., 2016). Further, in building off of best practices identified within existing research, this chapter identifies proximity using

network-based distance measures, coupled with micro-level bandwidth classifications (Groff, 2011; Ratcliffe, 2012; Song et al., 2013, 2016). The results from this chapter emphasize that a disproportionate amount of crime clusters around each locally identified criminogenic feature; however, the micro-level spatial patterns of this clustering vary from feature to feature. This contribution further emphasizes the importance of analysis conducted at a large spatial scale, in order to fully capture the nuanced relationship between crime and the built urban environment.

The results of Chapter 2 and Chapter 3 identify a number of important relationships between crime and the urban landscape. By identifying the specific areas where crime patterns concentrate, these chapters contribute to a more nuanced understanding of local crime, which in turn has potential implications for urban planning and police resourcing. The potential value of such research is emphasized within the findings of much of the related literature (see for example, Brantingham and Brantingham, 1995; Lockwood, 2007; Groff and McCord, 2007; Caplan et al., 2011; Ratcliffe, 2012; Song et al., 2013; Groff and Lockwood, 2014). However, in spite of this identified value, this research remains under-used at the planning stage (Brantingham and Brantingham, 1984; Cozens, 2007, 2011; Paulsen, 2012). Chapter 4 illustrates an example of how such locally-identified relationships can be actively utilized within planning and policy environments to explore the potential impacts of local growth and development. Local relationships between crime and the built environment are used as input within a spreadsheet-based model, designed as an interactive tool to explore the potential impacts of multiple growth and development scenarios on both crime and police resourcing. While this preliminary model is necessarily simplistic, it is flexible and adaptable, and allows the user to consider the connections between crime and the surrounding environment at the planning stage.

5.2. Future planning: Upcoming directions and concluding remarks

This collection of research has provided an in-depth overview of the connections between crime and the built urban form of Coquitlam and Port Coquitlam. Extending beyond the borders of these suburbs, however, this research has further highlighted the importance of locally-based and micro-level analysis. Further, it has identified a potential

framework for connecting the results of such analysis with stakeholders within the planning and policy realm. Throughout the research process, several identified limitations emphasize the need for continued investigation within the area. First, much of this analysis focused on crime as an aggregate category, or crime as a broad sub-classification. Just as the results of these studies have emphasized the importance of a nuanced, micro-level, and disaggregate analysis, so too must this disaggregation extend to crime types. Existing research has emphasized the different spatial patterns associated with specific crime categories, and with this in mind, it is likely that new urban features may emerge as locally relevant when considering disaggregated crime types (Andresen and Linning, 2012; Song et al., 2016). Further, the current analyses do not include consideration of the impact of time. Time itself is fundamental to the theoretical frameworks upon which this analysis is built; yet explicit consideration of the variation in crime patterns according to hour, day, and time of year are often excluded from analysis. The clear links between time of day and concentration of crime within and around criminogenic land uses have been illustrated in several relevant studies (Kinney, 1999; Ratcliffe, 2004b, 2012; see also Malleson and Andresen, 2015a). Future iterations of the current analyses must also explore the impacts of both space *and* time on the connections between crime and land use.

When considering future directions of the proposed modeling tool, several additional extensions emerge. This model was designed within the limits of existing spreadsheet software in order to facilitate transition to stakeholders. Due to this limitation, explicit visualization of spatial growth patterns were excluded from the preliminary model. While the addition of mapping software must consider stakeholder access to software and extensions, this is an important future direction to explore. Several existing modeling programs are available that facilitate the prediction of one aspect of the current model. For example, the *iCity* and *Agent iCity* models are designed to illustrate urban growth and development within a vector-based GIS environment (Stevens et al., 2007; Jjumba and Dragičević, 2012). Similarly, the work of Caplan and colleagues in the area of Risk Terrain Modeling provide an advanced method to forecast spatial patterns of future crime (Caplan et al., 2011). Existing tools such as these lay the important complex modeling groundwork, and may provide the foundations for further modeling development.

The relationship between crime and the built environment varies across urban settings. It further varies within urban settings, across environmental features, and within environmental feature types. The complex connections between crime and the urban landscape must therefore be understood at the local level, through multi-scale analysis in order to capture the nuanced, site-specific relationships that emerge. Further, these local relationships can (and indeed *should*) be used to inform local planning and policy decisions. Such context must be adapted into a modeling tool that allows for the consideration of the impact that urban growth and development scenarios may have on both crime, and public safety needs. While this compilation takes initial steps to move towards such a framework, continued research is needed facilitate further development within this area.

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Appendix A.

Supplemental Table

Table A-1: Crime events by actual use sub-category of event address: Top categories by count of event within Residential, Commercial, and CIR land use categories (2009)

a) Top Residential Property Sub-Categories	Property Units	% of All Residential Units	Crime Events	% of All Residential Events	Events /Unit	CQ
Single Family Dwelling	27634	78.19%	2614	49.63%	0.09	0.63
Strata Lot Residence (Condominium)	284	0.80%	870	16.52%	3.06	20.56
Single Family Dwelling with Basement Suite	4380	12.39%	656	12.45%	0.15	1.00
Multi-Family Apartment Block	100	0.28%	413	7.84%	4.13	27.71
Row Housing – Single Unit Ownership	547	1.55%	238	4.52%	0.44	2.92
Top 5 Residential	32945	93.22%	4791	90.96%	0.15	0.98
b) Top Commercial Property Sub-Categories	Property Units	% of All Commercial Units	Crime Events	% of All Commercial Events	Events /Unit	CQ
Community Shopping Centre	7	0.71%	424	12.51%	60.57	17.53
Regional Shopping Centre	1	0.10%	396	11.68%	396.00	114.59
Storage and Warehousing - Closed	313	31.91%	306	9.03%	0.98	0.28
Neighbourhood Shopping Centre	15	1.53%	272	8.02%	18.13	5.25
Commercial Strata-Lot	152	15.49%	231	6.81%	1.52	0.44
Top 5 Commercial	488	49.75%	1629	48.05%	3.34	0.97
c) Top CIR Property Sub-Categories	Property Units	% of All CIR Units	Crime Events	% of All CIR Events	Events /Unit	CQ
Schools and Universities	65	12.82%	439	48.94%	6.75	3.82
Recreational and Cultural Buildings	16	3.16%	114	12.71%	7.13	4.03
Parks and Playing Fields	150	29.59%	93	10.37%	0.62	0.35
Hospitals	2	0.39%	85	9.48%	42.50	24.02
Churches and Bible Schools	44	8.68%	55	6.13%	1.25	0.71
Top 5 CIR	277	54.64%	786	87.63%	2.84	1.60