Does Neighborhood Street Connectivity Influence Crime Safety in Neighborhoods?

Evidence from Salt Lake City, Utah

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Abstract: Crime and fear of crime has been a rising concern in cities. In the United States, safety concerns have been a hot topic for political disagreement, real estate price fluctuations and others. In the past decade, there has been a lot of research on street connectivity and its relationship to crime, and researchers have come up with seemingly conflicted results. Much of these differences are due to differences in methodology. In this study, I analyze all crime incidents in Salt Lake City in the year 2018, using three separate methodologies. Results imply that increased street connectivity is strongly correlated to low urban crime rates.

1. Introduction

Residential neighborhood culture has shifted in the last four decades. Where parents would freely allow children to move about in their community without adult supervision, this changed at the dawn of the millennium (Altheide, 2002). Children are less commonly left to go around their neighborhoods by themselves, and this is perhaps a direct safety outcome. Although violent crimes and property crimes have decreased significantly since 1993 (http://www.pewresearch.org/fact-tank/2019/01/03/5-facts-about-crime-in-the-u-s/), cities still strive for lower rates of both traffic accidents and crime. In the year 2016 alone, it is estimated that there are 386.3 violent crimes per 100,000 people, and 2,450.7 property crimes per 100,000 households (Uniform Crime Reporting Statistics Annual Report, 2017).

Street subdivisions are the starting point of a neighborhood design. In Salt Lake City, the Plat of Zion was used as the city's first masterplan to build an agrarian community in 1833. Blocks were set in a grid-iron layout, which was high street network connectivity. Grid-iron connectivity suited purposes in the mid to late nineteenth century, but as time evolved, the purpose of inner city blocks changed. New neighborhoods were designed with curved streets, cul-de-sacs, dead ends and so forth, to build the sense of privacy. Agrarian functions moved to rural areas. Over the next century, new neighborhoods came up with different street layouts – grid-iron, lollipop or cul-de-sac, curvilinear or mixed design. Currently, Salt Lake City's urban fabric has multiple street layouts, and it is important to know if there is a role of street layouts in affecting safety.

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Past research has talked in depth about crime safety and urban design, which forms the underlying theme for CPTED (Crime Prevention Through Environmental Design). This literature review will also provide an overview of methodologies to understand network connectivity, especially in the context of crime outcomes.

1.1. *Street Connectivity & Crime*

Connectivity in neighborhoods, and its relationship to crime, has been much discussed in academic literature. Connectivity in neighborhoods has been measured by qualitative concepts such as 'permeable street layout' or through-movement where neighborhood outsiders can enter into the core (Cozens, 2008; Nubani & Wineman, 2005; Armitage, 2011; Armitage, 2006). Connectivity has also been measured using quantitative concepts such as intersection density, street density, and number of cul-de-sacs per unit area in the neighborhood. Some studies have found that there is no relationship between street connectivity, and crime incidents (Ward *et al.*, 2014; Nubani and Wineman, 2005). But most of the studies researching this phenomenon have concluded that street connectivity has a strong relationship to crime outcomes.

Some studies have found that more connectivity, or a more efficient network, increases the probability of crime. In other words, cul-de-sac neighborhoods (also called lollipop neighborhoods), appear to have fewer crime incidents than those which have grid-iron layout, providing a greater possibility of through movement. This is based on the hypothesis that risk of crime is more on streets that are expected to be used more frequently; that is higher intended usage of roads *invites* risk (Armitage, 2017; Johnson & Bowers, 2010). This group of studies argue – potential offenders are likely to stake out their entry and exit points from a particular place or street, and having more than one end of a street open facilitates free movement (Johnson & Bowers, 2010). Studying a sample of more than a hundred thousand homes in England, Johnson & Bowers (2010) were able to quantify street connectivity and crime – an average private road (one with a dead end, may or may not be a cul-de-sac) has 43% fewer burglary incidents than a local road (connected on both ends); and for each additional connection to another road, chance of burglary rises by 3%. Additionally, some researchers found differences in crime between true cul-de-sacs, sinuous cul-de-sacs and leaky cul-de-sacs (Armitage, 2010; Johnson & Bowers, 2010; Hillier, 2004). Sinuous cul-de-sacs are those where all houses within the loop cannot be seen from the entry point, as in Fig. aa. Fig bb is a true cul-de-sac. Leaky cul-de-sacs are those which have a formal or informal footpath emerging from the cul-de-sac. The sinuous ones appear safest, where visual and physical discontinuity makes the place safer. Leaky cul-de-sacs apparently are less safe, as they have more than one entry/exit point, thus making it prone to risk (Cozens, 2008).

Other researchers have found opposite outcomes, trying to understand links between connectivity and crime (Utah Street Connectivity guide, 2018; Hillier & Raford, 2010; Hillier & Sahbaz, 2008; Harries, 2006; Porta *et al.*, 2006; Jacoby, 2006; Haughey, 2005; Batty, 2004). Most researchers in this group used principles of Space Syntax to measure connectivity. Space Syntax, an idea coined by Hiller and Hansen (1989) focuses on lines, not points – and streets, not junctions (Batty, 2004). Space Syntax is theory that is based on an eye-level perspective, measured by axial lines and visibility graphs. Jacoby (2006) used examples from Venice, Oxford Street in London, and Trafalgar Square – also in London – to argue why greater connectivity leads to lesser crime. The author pulls references from Newman's "defensible space" (1972) and Jacobs' "eyes on the street" (1961) to discuss why increased connectivity would see a decrease in crime incidents. A hybrid model consisting of space syntax theories, and ranking streets by hierarchy

Fig. aa Sinuous cul-de-sac

Fig. bb Typical cul-de-sac

Figure 1.

(Porta *et al.*, 2006) compared six cities across the world, and also concluded that connectivity and crime are inversely related. A combination of high residential density, and mixed landuse is observed to be a greater deterrent of residential crime compared to a suburban cul-de-sac (Hiller & Raford, 2010; Hillier & Sahbaz, 2010; Harries, 2006; Haughey, 2005).

This apparent contrast of conclusions is clustered by the choice of methods. Johnson and Bowers (2010) used a combination of GIS and hierarchical linear modelling (HLM) to understand the aforementioned relationship. As a measure of connectivity they used presence and density of cul-de-sac, which is a proxy for reduced connectivity. Armitage (2010) used photography and qualitative methods to study crime in places with and without cul-de-sacs. Both concluded that increased connectivity leads to increased crime. However, some researchers had exactly opposite findings – Porta *et al.* (2006), Hillier and Sahbaz (2008) used space syntax theory, which measures connectivity by number and density of street segments. Both methods of analysis are quantitative, and researchers use additional control variables in their models to arrive at conclusions. The basic difference in outcome is perhaps due to the difference in methodology – one uses cul-de-sacs, and the other method uses street segments as a measure of connectivity. Part of this research's objective is to identify how differences in methodology lead to differences in outcome, and part of it is identifying the benefit of using each methodology.

1.2. *Walkability and neighborhood crime*

Crime incidents have also been studied through the lens of walkability in a neighborhood (Frith *et al.*, 2017; Koohsari *et al.*, 2014; Foster *et al.*, 2014; Carr *et al.* 2010; Foster *et al.*, 2010). This is perhaps because, walkability and connectivity as concepts have many variables in common – such as visibility, distance to destinations within neighborhoods, and so on. Results were varied. Carr *et al.* (2010) found positive correlation between Walk Score (measurement of walkability of a neighborhood) and crime; Foster *et al.* (2014) found positive correlation between walking frequency and crime incidents, Frith *et al.* (2017) found that nonlocal pedestrian activity also increased crime frequency.

1.3. *Other measures of Street Connectivity*

Connectivity has also been measured in relationship to traffic outcomes. Traffic volume, traffic speed and traffic incidents have often been measured through the lens of connectivity. In this context connectivity has been measured by intersection density, length of street, link-node ratio, and total length of streets per unit area.

Like crime safety, the relationship of traffic safety and street connectivity is conflicted. Some researchers (Utah Street Connectivity guide, 2018; Mohan *et al.*, 2017; Osama & Sayed, 2017; Zhang *et al.*, 2015; Moeinaddini *et al.*, 2014; Gladhill & Monsere, 2012; Rifaat *et al.*, 2011; Marshall & Garrick, 2011;) have discussed the role of connectivity in influencing traffic crashes and fatalities within and around neighborhoods. Although most have identified some relationship – either positive or negative, between street connectivity and traffic crashes, there are some authors (Gladhill & Monsere, 2012) who conclude that there is no relationship between the two. Yet, whatever be the traffic outcome, their method of measuring connectivity is different from measuring crime and connectivity. Three studies that support greater connectivity in road network has been associated with more crashes, used ArcGIS or ArcView and GLM (general linear model) to arrive at their conclusions. They used intersection density and link-node ratio to arrive at their conclusions. Other researchers have measured traffic outcomes by using a geographically weighted regression model (GWR) in combination with ArcGIS or ArcView.

For studying traffic safety, intersection density appears to be the dominant variable to measure connectivity (Osama and Sayed, 2017; Moenaddini *et al.*, 2014; Rifaat *et al.*, 2011; Mohan *et al.*, 2017; Cai *et al.*, 2016; Marshall and Garrick, 2011). Each of these studies used more factors in addition to intersection density to measure connectivity such as blocks (area of blocks, number of nodes per block, number of blocks per unit area), streets (network density, street density, length of road, length of motorway, length of primary, secondary, local roads), street pattern (gridiron, warped, looped, mixed, curvilinear street), and interaction between streets and intersection (link-node ratio, sidewalk connectivity). All of the variables ultimately aim to measure street connectivity. In this paper, I have used traffic concepts to measure connectivity, to provide a third method to answer the research question.

1.4. *Methodological gap*

There remains a methodological gap in understanding the relationship between street connectivity, and objective safety in neighborhoods. As seen from past literature, it is evident that especially in the relationship between crime incidents and street connectivity, whether increased connectivity increases crime or decreases crime is hotly debated. A deeper look into the literature reveals that connectivity in relation to crime has been measured in two completely different ways – one cluster of researchers has used number of cul-de-sacs as a proxy for low connectivity, another cluster of researchers has used connectivity of street segments as a proxy for measuring connectivity. Using separate ways of measuring connectivity can have different outcomes. Marshall & Garrick (2011) have elucidated that different ways of measuring connectivity can give different results. For example, the authors found that street networks with higher intersection density correlate with fewer crashes across all levels of severity. On the other hand, they also concluded, that increased street connectivity (measures by link-node ratio) was significantly associated with an increase in crashes. This apparent contradiction is perhaps observing, that ways to *measure* connectivity has an effect on the outcome. The authors concluded that the two variables may not be measuring the same exact thing

It appears that the difference in contexts and measuring connectivity has resulted in the difference in outcome. In this research, I will use three separate factors (cul-de-sacs, space-syntax principles, and intersections) as measures of connectivity, and interpret and explain how different constructs affect different outcomes. The advantage of using the same context and data for the analysis is that this process will remove some of the variability. Resolving the methodological conflict will allow me to answer the main research question, free from methodological bias.

2. Methodology

The main research question that will be answered in this research is – *Does street connectivity in residential neighborhoods affect crime rates in neighborhoods?*

I hypothesize that an increase in neighborhood connectivity leads to a decrease in crime following the theory of "eyes on the street", where Jacobs (1961) states that having more people use a street reduces the possibility of crime on that street.

2.1. *Data*

The Salt Lake City Police Department (SLCPD) has recorded over thirty-seven thousand crime incidents in the year 2018, out of which about five thousand are violent crimes. Crime rate per person and crime rate per unit area are the two dependent variables I have used for this research. This is a quantitative project, and I have depended on multiple softwares to arrive at conclusions. Some of these softwares are Arcmap and ArcCatalog, IBM SPSS (for statistical analysis), DepthmapX (developed by Space Syntax research group), Autocad, and Microsoft Excel.

2.2. *Study Area*

This study is focused in Salt Lake City at the scale of neighborhoods. Census block groups are to be used as proxy as "neighborhoods". Weiss *et al.* (2007) compare different ways to measure boundaries – census block groups, homogeneity in housing type, plot size, density, other built environment features, and level of connectivity or segregation of a place. The authors conclude that there is no one perfect way of measuring neighborhoods, but the lack of remarkable differences between the methods mean that any one of the methods could be used to delineate neighborhoods, without much difference in the outcomes. The purpose of this research is to find out relationship between street network connectivity and crime rate. Naturally, I will conduct this research at the neighborhood scale. I will study all neighborhoods within the city. Salt Lake City is a mid-sized city in the south-west quadrant of the United States, and home to approximately two hundred thousand people. The city is a part of the north-south contiguous Wasatch Front, and a major city in the Great Basin Region. The city is the headquarters of the Church of Jesus Christ of Latter Day Saints. A strong network of transit connects the city from north to south. The regional population is expected to double by year 2040, and this undoubtedly requires a well-functioning city to accommodate the growth. By understanding how street connectivity and network can influence safety outcomes, this research will help plan for a safer city.

This research question will be answered by estimating three different regression models for three different ways of measuring connectivity 1) space syntax principles 2) presence of cul-de-sacs and 3) intersection density. I will use the same crime data from Salt Lake City, to eliminate possible differences in change of context.

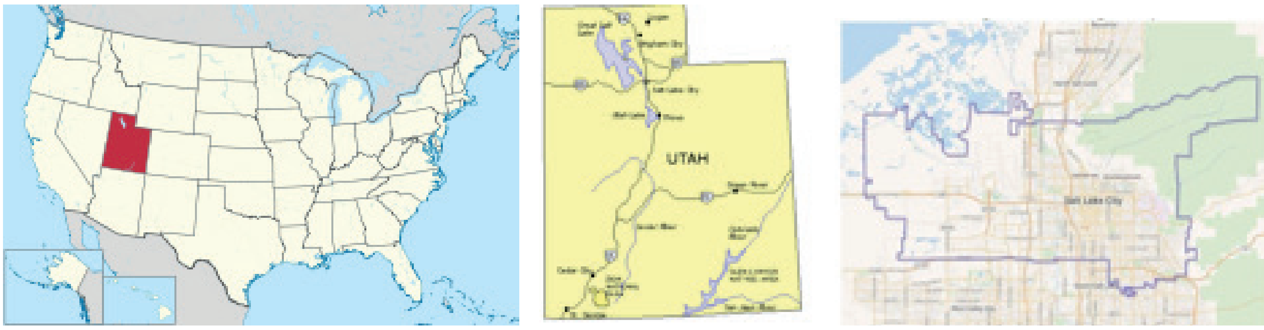

Figure 2. *Location of Salt Lake City and Utah in the context of United States*

2.3. *Crime Data*

Crime data for visualization purposes is publicly available from SLCPD. To obtain a data format that is compatible with ArcGIS software, I have used the crime data publicly available from SLCPD. Crime incidents are grouped under four headings: violent crimes, property crimes, quality of life, and other 911 calls. "Quality of life" includes drugs, liquor and disorder related disturbances, 'property crime' includes crime in homes and cars, and all other crimes with actual or risk of physical harm is considered violent crime. Each of the incidents have a latitude and a longitude location with it.

Crime incidents are typically spatially correlated, which are also called 'crime hotspots', which is clustering of crimes over a certain area (Schumacher and Leitner, 1999). An established method of understanding clustering is by estimating the Moran's Index or the Moran's I. The Local Moran's I (of a particular neighborhood in this case) defines clustering in relation to its immediate neighbors (other neighborhoods in this case). The Global Moran's I is clustering in relation to the entire dataset, in this the for the entire of Salt Lake City. I estimated both indices of Salt Lake City crime data in ArcGIS. Both indices were significant at 95% confidence level, with p-value < 0.001. This shows that crime incidents have strong spatial relationships.

2.4. *Other variables (Census data)*

Population / Population density: Population of a neighborhood has been previously seen to influence crime and safety outcomes. I hypothesize, that total population or population density in the context of Salt Lake City has some influence on the outcomes of neighborhood safety. For this research, a census block group is used as a proxy for neighborhoods. Hence, total population and population density per acre within the block group is added to the regression models.

Percentage of Hispanics and Blacks: Presence of blacks is observed to have effect on crime rates in neighborhoods. The argument is, presence of minority and / or disadvantageous groups lead to increase in crime. In the context of Salt Lake City, Hispanic population has prominent presence. In early regression models, I used different combinations of race and ethnic groups – such as Asians, Pacific Islanders, Alaskan Natives, and American Natives. The combination of Hispanics and Blacks seemed to be most responsive in the regression models. This data is from the published US census data of 2010.

Median Income of Neighborhood & Percentage of neighborhood parcels below poverty: Income and poverty have a close relationship with crime. Prevalence of violent crimes is higher in low income neighborhoods, and prevalence of property crime is prevalent in higher income neighborhoods. Nevertheless, total crime in low income neighborhoods is appreciably higher than in high income neighborhoods. I use the median income per block group and the fraction of poverty parcels (properties) in each block group in the regression models. Information about median income of each neighborhood is from projected census information, 2017. Data on poverty levels is derived from census 2010.

Youth population (15-25) in the neighborhood: Presence of young people appears to be a strong predictor of crime occurrences within residential neighborhoods. Literature has sometimes included young adult population (18-25), sometimes juvenile population (15-18). For a comprehensive understanding of crime occurrences, I have included all youth population between 15 and 25 years of age. A percent of youth population in relation to total population of each block group is calculated, and used as a control variable in the regression models.

Total renter occupied housing units: The fraction of owner occupied households in a neighborhood has been observed to influence crime rates. This is an important control variable in the analysis, and should be included. Census data was last published in 2010, and in the last few years, housing characteristics in Salt Lake City has undergone an impressionable change. However, the lack of other reliable source of renter data has resulted in using census data in regression models. Renter occupied and owner occupied household information is available for each block group. I use the percent of owner occupied households in the analysis.

Neighborhood area: Some researchers have found that area of the neighborhood, number of blocks in the neighborhood, average block length has influence on the rate of crime. Each of these variables are closely correlated, and using one accounts for the others. For all three models, I have used area of the neighborhood as a control variable.

3. Analysis/Results

To arrive at conclusions, I have built three separate statistical models. Each of the models uses the basic concept of previous methodologies, but have strictly depended on quantitative methods. For dependent variables, I have used crime per person, and crime per acre. Mapping crime per acre clearly shows that crime incidences are clustered.

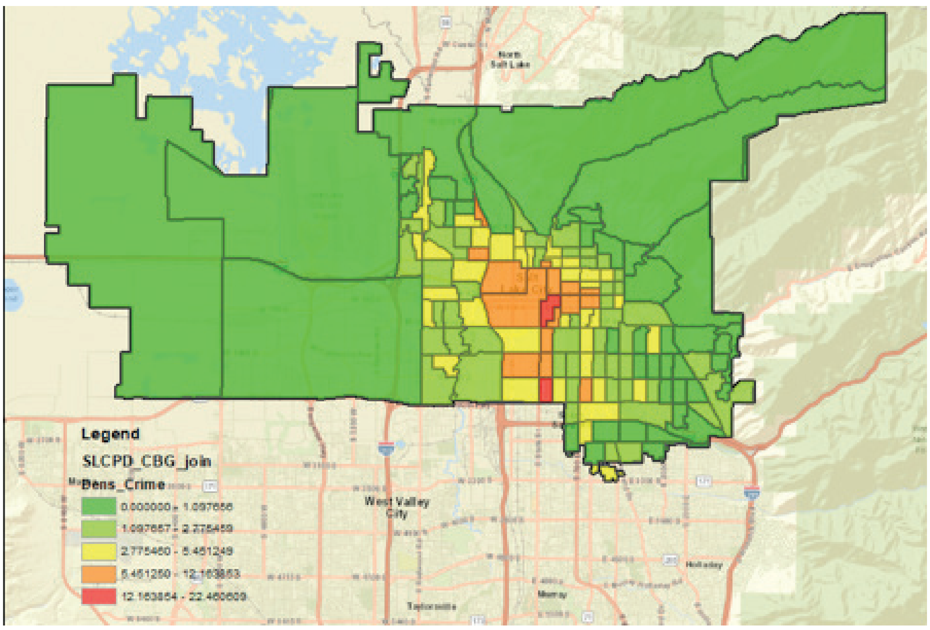

Figure 3.

Model I

The first model uses the presence of cul-de-sac as measure of low connectivity. I have emulated Johnson and Bowers (2010) where they used presence, count and density of cul-de-sacs to arrive at their conclusions. Borrowing their methods, I will use the presence of cul-de-sacs as a proxy for low connectivity. Johnson and Bowers manually counted cul-de-sacs, and characterized neighborhood street patterns to arrive at their conclusions.

Street network data was bought from TomTom, a private map making agency who create data for navigation systems. After appropriate data cleaning and cutting, I mapped Salt Lake City street network data in ArcGIS, using appropriate coordinate systems. I used GEOIDs, which are unique numbers for each block group, to match data from different sources. The street network data has a combination of street segment (as road networks) and points (intersections). Points include 4-way, 3-way and dead ends or cul-de-sacs. To select cul-de-sacs, I used "Select dangles" function in ArcGIS, and exported the selection to a new layer. I then calculated number of dead-ends or cul-de-sacs in each of the neighborhoods. I also calculated cul-de-sac density in each of the neighborhoods, as a predictor for the final model. I exported data from ArcGIS into SPSS (version 19), and used linear regression for analysis

Model I Results

The dependent variable for the model is Crime per person. Since number of people in every neighborhood is very different, comparing total number of crimes across neighborhoods as the dependent variable is avoided. Instead, a crime rate will provide more comparable means. Crime per person gives a statistic about the possibility of crime per each individual. The R-square for this model is 0.415. Some critiques may infer that robustness need to be stronger. I expect that changing kind of regression analysis may help a better fitted model. The following table provides a summary of the results.

Variable	Standardized Coefficient	t-coefficient	p-value
Total Cul-de-sacs	0.451	6.342	0.000***
Total Households	0.854	5.698	0.000***
Total Population	-0.865	-5.401	0.000***
Percentage of Hispanics & Blacks	0.353	3.597	0.000***
Percentage of renter occupied households	-0.001	-0.008	0.993
Youth percentage	-0.088	-0.656	0.513
Area of neighborhood	-0.06	-0.935	0.351

The most important finding of this analysis is that number of total cul-de-sacs in a neighborhood is strongly correlated with crime rate in every neighborhood, that is increase in number of cul-de-sacs in a neighborhood sees an increase in crime rates in that neighborhood. Percentage of minority communities – especially Hispanics and Blacks, is positively correlated to crime rate – increase in fraction of Hispanics and Blacks also increases crime rate. Increase of number of households see an increase in crimes, but increase in population sees a drop in crime rate. This apparent anomaly can be related to "eyes on the street", where homes attract property crime, but more residents create more opportunities for vigilance, which decreases crime.

Model II

Depthmap X software, developed by the Space Syntax group of researchers, is based on the principles of space syntax (Hillier & Hanson, 1989), which uses axial lines and visibility graphs to produce a measure of connectivity. The software uses street network layers, and produces two main outputs – connectivity score and integration score. The scores are not of the segments, but of the intersection between streets. The connectivity score is a whole number, which indicates the number of segments the intersection is connected to. The integration is a mathematical expression which denotes the normalized distance from any space of origin, to any other space in the data set (Space Syntax website). Conceptually, it can be understood as a measure of relative asymmetry and relative depth.

I converted the street network layer from shapefile format (ArcGIS) to Autocad format, which I then exported into the depthmapX. Here I calculated the connectivity and integration scores in the entire area of study – in this case Salt Lake City. I converted the information into a format which is compatible with ArcGIS, and imported the data into ArcMap. To the best of my knowledge, space syntax information has not been aggregated to neighborhood level for analysis. Past work with space syntax and crime has been conducted at the individual units. But, for the sake of consistency, I have aggregated the information to the neighborhood level. Again, using ArcGIS analysis, I sum connectivity and integration scores from each intersection in a neighborhood to a single connectivity and integration score for every neighborhood. I exported this information into SPSS, and conducted linear regression.

Model II Results

Model II results were inconclusive. I estimated two separate models for two dependent variables. The first dependent variable is crime rate per person, but it did not explain a relationship between crime and connectivity. The second model with dependent variable as crime rate per acre showed a relationship similar to that of Model I and Model III, where increase in connectivity leads to decrease in crime. However, more analysis is required of space syntax principles to arrive at a conclusion.

One reason of this could be because of aggregation of data at the neighborhood level. Perhaps, aggregating connectivity and integration scores do not express something different at the neighborhood aggregation scale, and are best analyzed as individual data points.

Model III

As explained in the literature review, intersection density and link-node ratio is often used to measure connectivity in the context of traffic outcomes such as crashes. Unanimously, all studies using intersection variables to study probability of traffic incidents occurring, used general linear regression (GLM) to arrive at their conclusions. However, GLM is used when there are categorical variables, which is common for traffic crashes. But, in understanding crime safety, crime rates are continuous variables. For that reason, I will use linear regression, controlling for multi collinearity.

In ArcMap, I created two new variables – intersection density and link node ratio. The formulas for each calculation is provided below.

Intersection density of a neighborhood = {(3way intersections + 4way intersections + dead-ends) / Area of the neighborhood}
Link-node ratio of a neighborhood = {Total links (road segments) in the neighborhood / Total nodes (intersections) in the neighborhood}

From TomTom data (previously described), I extracted 3way intersections, 4 way intersections and dead-ends or cul-de-sacs. A summation function added them up providing one number for each neighborhood, which was then divided by the total area of the neighborhood (in acres) to give the intersection density. This is exactly according to the principle of traffic analysis. However, while calculating "links" I have deviated from the traditional way of calculating links as explained by Ewing (1996). Conventions in traffic analysis calculate connections between any two intersections as a link, irrespective of the geometry of the road segment. However, calculating links as different numbers at every change in direction is an established convention in urban design (Space Syntax principles). For straight line connections between two intersections, I will calculate it as one link. For connections that change in direction between two intersections (such as curved streets), I will calculate them as more than one link.

I exported data from ArcMap to SPSS for statistical analysis, and the results are described in the table below.

Model III results

The dependent variable for this analysis is crime per person. Since total crime is widely varied across neighborhoods, it is normalized as a rate per person, for ease of comparability. The main explanatory variable is intersection density. Link-node ratio was added in the initial variables, but were removed in the final model because of strong correlations with both "intersection density". The R-square for the final model is 0.558, and the adjusted R-square is 0.538. This means the predicted model aligns with the data with as much as 54%. The following table provides a summary of the results.

Variable	Standardized Coefficient	t-coefficient	p-value
Intersection density	-0.123	-2.023	0.045*
Total Households	0.78	8.121	0.000***
Total Population	-0.867	-8.243	0.000***
Percentage of Hispanics & Blacks	0.365	5.564	0.000***
Youth percentage	0.11	0.193	0.847
Area of neighborhood	-0.055	-0.988	0.325

The most important result of this analysis is that, increase in crime rate per person is associated with decrease in intersection density, or increase in intersection density is associated with decrease in crime rate. Increase in intersection density per unit area is associated with increased connectivity, so this model clearly shows that increased street connectivity can be correlated to decreased crime rate. This is in agreement with Model I results. Furthermore, like Model I, increase in fraction of Hispanics and Blacks also increases crime rate. Increase of number of households see an increase in crimes, but increase in population sees a drop in crime rate. This apparent anomaly can be related to 'eyes on the street', where homes attract property crime, but more residents create more opportunities for vigilance, which decreases crime.

4. Discussion/Conclusion

This study has implications in criminology theory and crime-reductive planning. The research question about the influence of street connectivity on design is not new – yet, researchers have seemingly ended up with conflicting results. Part of the attempt of this paper was to understand how context and choice of methodologies shape outcomes. To address the contextual question, I used data from Salt Lake City for three models. Some part of Salt Lake City has a grid iron layout, also known as the Plat of Zion. Other parts – the relatively newer neighborhoods have a combination of grid (following continuity from the old plan) and dead ends and cul-de-sacs.

In brief, results are heavily weighted towards the hypothesis – more connectivity within neighborhoods is correlated to lesser risk of crime. Results clearly show that the presence of cul-de-sacs and dead ends increase the possibility of crime, and this is in accordance with Hillier & Raford, 2010; Hillier & Sahbaz, 2008; Harries, 2006; Porta *et al.*, 2006; Jacoby, 2006; Haughey, 2005; Batty, 2004 – who use Space Syntax theories to measure connectivity. However, Johnson & Bowers (2010) established a difference between leaky cul-de-sacs, sinuous cul-de-sacs and linear cul-de-sacs for analysis, and the concluded that the geometry of cul-de-sacs can predict burglary. With the current dataset, it was impossible to segregate these three kinds of dead ends or cul-de-sacs. I will attempt at least a segregation between sinuous and linear cul-de-sacs in later models, and it will be interesting to see how that could potentially change outcomes.

On the other hand, borrowing from traffic theories, intersection density was used to measure connectivity. Regression analysis shows that lower intersection density leads to lower crime rates per person. This result is also in accordance with researchers who have used Space Syntax theories to arrive at conclusions. To the best of knowledge, using intersection density to find the relationship between crime and connectivity has never been conducted before. I have attempted to translate methodologies across disciplines, and provide a third perspective to the problem. However, using principles of Space Syntax at the aggregate level (consistent with two other methodologies) have provided inconsistent results. Past research on this topic has analyzed connectivity scores and integration scores from space syntax at an individual level. Regression analysis with crime rate per person as the dependent variable shows no relationship between integration scores of connectivity (space syntax). Regression analyses with crime rate per unit area has different results, that is increase in connectivity is correlated to less crime. Using two crime rates (dependent variables) gives inconsistent results, although they are possibly measuring the same thing.

This research contributes to the academic argument of crime versus connectivity. As shown in literature, different ways of measuring connectivity lead to different outcomes. By controlling for context, I am removing much of the variations. Academically, this is a contribution for understanding the role of street connectivity in planning neighborhoods. Apart from this, there are also policy implications of the research. Implementing strategies for high connectivity within neighborhoods can automatically lead to a reduction of crime. This has implication is better quality of life for the residents.

Although it is attempted to make the research as robust as possible, there are some limitations to the choice of regression. The regression used here (linear regression) is not the ideal choice of regression. Estimated Moran's I shows that there is a strong clustering between crime locations, that is there are crime hotspots. A preferred regression would be a spatial regression, using statistical softwares such as R or STATA. I have used linear regression in SPSS. However, previous literature has shown that using linear regression instead of spatial regression will not change the direction of the relationship, but can change the strength of it. Additionally, the structure of Salt Lake City is unique because of the combination of grids and curves, and the combination of high density downtown and medium density residential neighbors within close range. The three models might produce different results when the context is a dense, dominantly grid iron city (such as New York) or a typical American suburb.

As next steps, I will separate violent and non-violent crimes, and consider if non-violent crimes such as burglary, property crime, car break-ins, fraud have a different predictive value than violent crimes such as robberies, gun-violence, domestic violence, sexual crimes and so on. Additionally, I will explore other statistical analysis methods such as spatial regressions (using softwares R and STATA), and see if the results differ.

In Models I & III, total number of households and total population of the neighborhood are significant predictors of the model. Total number of households invite crime, but more number of people increase the possibility of vigilance, hence have a negative effect on crime rate. In earlier models, median income, percent of poverty and percent of minority (Hispanics and Blacks) were strongly correlated. Including all three factors in the model were giving faulty results, so I used factor reduction function in SPSS to keep one of the three variables. I finally estimated the model with percentage of Hispanics & Blacks, and which also accounts for income and poverty. Percentage of Hispanics and Blacks were significant predictors of crime rate – increase in one variable is correlated with decrease of the other. Thus, in more affluent neighborhoods, crime rate is automatically low.

To summarize, the results of this study support the hypothesis that increase in connectivity is correlated to a decrease in crime. The precise mechanism for this is not simplistic or linear, so future research in the outlined direction is required.

References

Altheide D.L. (2002), Children and the discourse of fear, in Symbolic Interaction 25, no. 2, pp. 229-250.

Armitage R. (2006), Predicting and preventing: developing *a risk assessment mechanism for residential housing, in Crime Prevention a*nd Community Safety 8, no. 3, pp. 137-149.

Armitage R. (2011), The impact of connectivity and through-movement *within residential development*s *on* levels of crime and anti-social behaviour.

Armitage R. (2017), Design, crime and the built environment, in Handbook of Crime Prevention and Community Safety, 234.

Batty M. (2004*), A new theor*y *of* space syntax.

Cai Q., Jaeyoung L., Naveen E., Mohamed Abdel-Aty (2016), Macro-level pedestrian and bicycle crash *analysis: Incorporating spati*al *spi*llover effects in dual state count models, in Accident Analysis & Prevention, 93, pp. 14-22.

Carr L.J., Dunsiger S.I., Marcus B.H. (2010), Walk score™ as a gl*obal estimate of neighborhood* walkability, in American journal of preventive medicine, 39(5), pp. 460-463.

Cozens P.M. (2008), New urbanism, c*rime and the suburbs: A re*view of the evidence, in Urban Policy and Research, 26(4), pp. 429-444.

Foster S., Giles-Corti B., Knuiman M. (2010), Neighbourhood design and fear of crim*e: a social-ecological examina*tion of the correlates of residents' fear in new suburban housing developments, in Health & place, 16(6), pp. 1156-1165.

Foster S., Knuiman M., Villanueva K., Wood L., Christian H., Giles-Corti B. (2014), *Does walkable neighbourhood design* i*nfl*uence the association between objective crime and walking?, in International Journal of Behavioral Nutrition and Physical Activi*ty, 11(1),* p. 100.

Frith M.J., Johnson S.D., Fry H.M. (2017), Role of the street network in burg*lars'spatial decision-making, in Criminology, 55(*2), pp. 344-376.

Galster G. (2001), On the nature of neighbourhood, in Urban studies 38, no. 12, pp. 2111-2124.

Gladhill K., Monsere C.M. (2012), Exp*loring traffic saf*ety *a*nd urban form in Portland, Oregon, in Transportation research record, 2318(1), pp. 63-74.

Guo J.Y., Chandra R.B. (2007), Operationalizing the concept of neighborhood: Applic*ation to residentia*l *lo*cation choice analysis, in Journal of Transport Geography 15, no. 1, pp. 31-45.

Harries K. (2006), Extreme spatial variations in crime density in Baltimore County, MD, in Geoforum 37, no. 3, pp. 404-416.

Haughey R.M. (2005), Higher-density development: Myth and fact, ULI--Urban Land Institute.

Hillier B. (2004), Can streets be made safe?, in Urban design international 9, no. 1, pp. 31-45.

Hillier B., Hanson J. (1989), The social logic of space, Cambridge university press.

Hillier B., Raford N. (2010), Description and discovery in socio-spatial analysis: the case of space syntax, The Sage Handbook of Measurement.

Hillier B., Sahbaz O. (2008), An evidence based approach to crime and urban design, or, can we have vitality, sustainability and security all at once, Bartlett School of Graduates Studies University College London.

h*ttp://www.slcp*d.com/open-data/crimereportsmap/

https://slcgov.maps.arcgis.com/apps/MapSeries/index.html?appid=326333659bcb4873b64cc9a40e3749d5

Jacobs *J. (1992), The death and life of great* Ame*r*ican cities. 1961, Vintage, New York.

Jacoby K. (2006), What is space syntax? Does the urban form of th*e city affect the level* of *bu*rglary and crime, Séminaire de Master Architectures et villes face ala Mondialisation, Royal Institute of Architecture*, Stockholm.*

*Johnson S.D., Bowers K.J. (2010), Perme*ab*ility* and burglary risk: are cul-de-sacs safer?, in Journal of Quantitative Criminology 26, no. 1, pp. 89-111.

Koohsari M.J., Sugiyama *T., Lamb K.E., Villanueva K., Owen N. (2014), Street connectivity and walking for transport: role of neighborh*ood destinations, in Preventive medicine, 66, pp. 118-122.

Marshall W.E., Garrick N.W. (2011), Does street network design a*ffect traffic safety?, in Accident Analysis & Prevention, 43(3), pp. 769-781.*

Moeinaddini M., Asadi-Shekari Z., Shah M.Z. (2014), The relationship between urban street networks and the number of transport fatalities at the city level, in Safety science, 62, pp. 114-120.

Mohan D., Bangdiwala S.I., Villaveces A. (2017), Urban stree*t structure and traf*fic safety, in Journal of safety research, 62, pp. 63-71.

Newman O. (1972), Defensible space, Macmillan, New York.

Nubani L., Wineman J. (*2005, June), The role of space syntax* in identifying the relationship between space and crime, in Proceedings of the 5th Space Syntax Symposium on Space Sy*ntax, Delft, Holland.*

*Osama A., Say*ed T. (2017), Evaluating the impact of connectivity, continuity, and topo*graphy of sidewalk network* on pedestrian safety, in Accident Analysis & Prevention, 107, pp. 117-125.

Porta S., Crucitti P., Latora V. (2006), The network an*alysis of urban streets: a dual* approach, in Physica A: Statistical Mechanics and its Applications, 369(2), pp. 853-866.

Pourmohammadi M.R., Ghorbanian M. (2013), Crime Prevention in Ur*ban Design: towards Space Syntax Approach as a Quantitative An*alytic Modeling of Qualitative Issue of Security (Based on Spatial Configuration).

Rifaat S., *Tay R.,* De Barros A. (2010), Effect of street patt*ern on road saf*ety: are policy recommendations sensitive to *aggregations of crashes by severity?, in* Transportation Research Record: Journal of the Transportation Research Board, (2147), pp. 58-65.

Schumacher B.J., Leitner M. (1999), Spatial crime displacement resulting from large-scale urban renewal programs *in the city of Baltimore, MD:* a GIS modeling approach, in IV International Conference on GeoComputation, Fredericks*burg, VA, http:*//www. geovista. psu. edu/sites/geocomp99/Gc99/047/gc_047*.htm.*

Summers L., Johnson S.D. (2017), Does the configuration of the street network influence where outdoor serious violence takes place? Using space syntax to test crime patt*ern theory, in Journal of quan*titative criminology, 33(2), pp. 397-420.

Ward J.T., Nobles M.R., Youstin T.J., Cook C.L. (2014), Placing the neighborhood accessibili*ty–burglary link in social-structural co*ntext, in Crime & Delinquency, 60(5), pp. 739-763.

Weiss L., Ompad D., Galea S., Vlahov D. (2007), Defining neighborhood boundaries for urban health research, in American journal of preventive medic*ine, 32, no. 6, pp. S154-S159.*

*Zhang Y., Bigham J., Ragland D., Chen X. (2015), Investigating the associations between road network s*tructure and non-motorist acciden*ts, in Journal of transp*ort geography, 42, pp. 34-47.