COMMUTERS, CRIME RATE DENOMINATORS, AND CRIME RISK IN CHICAGO

by

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A thesis submitted to the Graduate Council of
Texas State University in partial fulfillment
of the requirements for the degree of
Master of Science in Criminal Justice
with a Major in Criminal Justice
August 2016

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ACKNOWLEDGEMENTS

I want to thank my thesis committee, including Dr. Marcus Felson, Dr. Lucia Summers, and Dr. Bob E. Vasquez for providing their time and expertise to assist me in the completion of this thesis. Without their commitment to my educational development, this thesis would not have been possible. A special thanks goes to my thesis chair, Dr. Marcus Felson, for generously giving countless hours of his time to develop my theoretical intuition, and skills as a researcher and communicator. Your lessons will never be forgotten.

I also want to thank my family, whose unconditional love and encouragement continues to support me through each stage of life. Finally, I want to thank my wife, Ashley --- my true love and my best friend. I couldn't do it without you.

This manuscript was submitted on July 12, 2016.

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I: INTRODUCTION

The measurement of crime continues to be a critical issue in the field of criminal justice. Crime is typically measured as a count or as a rate. Counts represent the *raw number of crimes* in a given area, while rates represent the *number of crimes per some denominator* in an area. Although neither measure of crime is necessarily better than the other, each serves a distinct purpose. Knowing the number of crimes in an area is important for understanding the amount of criminal activity. Police, for instance, want to know the amount of work they have, as represented by the crime count. Rates, on the other hand, measure the level of risk, and are most frequently presented as the number of crimes per capita (residential population). The public may be particularly interested in crime risk, because they want to know that their chances of being victimized are relatively low, given the number of people that live in their neighborhood or city.

Crimes rates as a general form of measurement are often well understood. The details of employing crime rates, however, are often overlooked. Specifically, the denominator used to calculate crime rates has received less attention. The residential population is pervasively used to calculate crime rates in the community and for research purposes, with seemingly little thought to the consequences of its exclusive use. To give one clear example, the Federal Bureau of Investigation publishes only crime rates per 100,000 inhabitants in the annual Uniform Crime Reports. Although some scholars have discussed the pertinence of alternative crime rate denominators (e.g., dwelling units, commercial buildings, parked cars), the field’s ability to study this topic in sufficient detail is often obstructed by crude measurement and poor data resolution. Consequently, relatively little is known about how alternative denominators affect the measurement and prediction of crime.

The first question is what measurement differences exist when alternative denominators are employed? Subsequently, one asks *if* these differences matter, to what degree do they matter, and how can this knowledge be used to improve the measurement or crime? This thesis addresses the first question by describing how three alternative denominators impact crime measurement in Chicago census tracts.

Boggs (1965) was among the earliest researchers to consider the importance of the denominator when calculating crime rates to describe crime occurrence. By deflating crime counts with a denominator, the calculated rate becomes a “probability statement” (Boggs, 1965, p. 900). This probability statement is used to explain the amount of crime in an area when controlling for the number of targets, termed the *population at risk*. Boggs examined whether the residential population was always the most appropriate measure of the population at risk despite its prevalent use for calculating crime occurrence rates. She calculated crime rates using alternative denominators and found that using the traditional, residential population led to inflated crime rates in some areas. This inflation was especially present in the central business district where targets were seemingly exploited at higher rates, but only if the (often small) residential population was used as the denominator. Research has since explored the population at risk and crime rate denominators (Andresen, 2006; 2011; Boivin, 2013; Brantingham & Brantingham, 1998; Chamlin & Cochran, 2004; Clarke, 1984; Cohen & Felson, 1979; Cohen, Kaufman, & Gottfredson, 1985; Copes, 1999; Erickson, Gibbs, & Jensen, 1977; Felson & Boivin, 2015; Frisbie, Hintz, Joelson, & Nutter, 1977; Harries, 1981; Jarrell &

Howsen, 1990; Lemieux & Felson, 2012; Malleson & Andresen, 2015; Pettiway, 1985; Phillips, 1973; Pyle et al., 1974; Sparks, 1980; Stipak, 1988; Stults & Hasbrouck, 2015), but many scholars still rely on residential population-based crime rates in crime and disorder research (for recent examples in major journals, see: Boggess & Hipp, 2016; Ferraro, 2016; O'Brien, & Sampson, 2015).

Other literatures in the field of criminology are also relevant to crime rates. Most important for this thesis is research regarding crime opportunity theories. Informed by this framework, this thesis uses alternative measures of the population at risk to examine crime risk in the iconic city of Chicago. Commuter data from the American Community Survey are used to estimate sharper measures of the daily population (at risk) within Chicago census tracts. These alternative population estimates are compared with the traditional residential population and a square area denominator in crime rate calculations. This thesis informs future research by revealing important differences in how denominators affect crime rates, crime rate percentile rankings, and crime rate clusters among census tracks. Potential impacts of the findings are discussed, including contributions to research and practical application of risk assessments within cities.

Theoretical Framework

Although research from multiple literatures will be discussed, the foundation for this thesis is primarily influenced by environmental criminology (Brantingham & Brantingham, 1981) and the routine activities approach (Cohen & Felson, 1979). Developed almost simultaneously yet independently, both of these theoretical frameworks take criminal offending for granted, tend to study crime *events* rather than criminality, and identify the tangible elements required for a crime event to occur.

According to both perspectives, an opportunity for crime is created when the necessary elements of a crime converge in time and space. Each perspective theorizes that *opportunity* is therefore the catalyst to crime. Shown in Figure 1, the purpose of both environmental criminology and the routine activities approach is to explain criminal events. The elements (or dimensions; Brantingham & Brantingham, 1981) of crime must come together to create an opportunity for crime. Several factors explain the frequency and likelihood of opportunities and become the focus of study. Although similar, the routine activities approach and environmental criminology will be discussed separately to provide a more complete understanding of how each theory relates to this thesis.

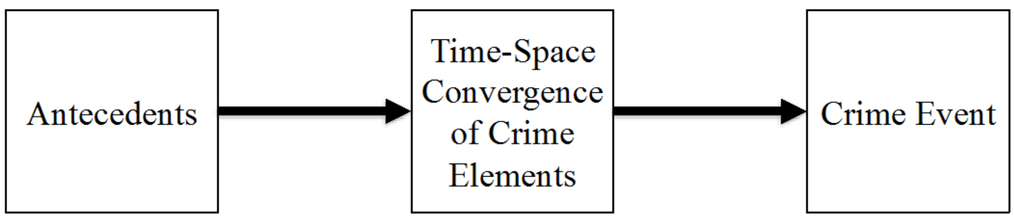

Figure 1
Simplified theoretical model for this thesis

Routine activities approach. Cohen and Felson (1979) argued that crime events require three critical elements: (1) a motivated offender; (2) a suitable target; and (3) the absence of a capable guardian. The opportunity for crime exists only when these three elements converge in time and space. Assuming offender motivation to commit crime inevitably exists in society, it follows that opportunities predict crime events, rather than potential criminality. In other words, crime in an area is predictably higher where more offenders and victims are present, absent guardians. For example, higher population areas have higher numbers of potential offenders and victims, predicting more opportunities for criminal behavior. However, some people in the area may also act as guardians who reduce opportunities. It is in this way that the description of crime – convergence of a victim and offender, absent a guardian – translates to predictions of risk under the routine activities approach.

In their seminal work, Cohen and Felson (1979) stated that crimes should be understood as "…events which occur at specific locations in space and time" (p. 589). This distinction between criminal events and criminality led them to examine opportunities for crime as functions of social activities rather than individual or group propensities for deviance. Cohen and Felson (1979) related a variety of social change indicators to crime rates, such as changes in female labor force participation, single female-headed households, unattended households, worker vacation time, and the availability of small, durable goods. They found that dispersion away from the household resulted in increased crime rates. For example, increases in property crime rates were explained by a lack of guardianship (decrease in capable guardians) around the home, due to increased female participation in the labor force. Increases in theft were related to an increase in lighter, durable goods that were more expensive and easier to steal (increase in suitable targets).

Most importantly for this thesis, the term "routine activities" refers to noncriminal activities that are part of everyday life. One of Felson's (1994[1]) primary works was titled *Crime and Everyday Life*, where he emphasizes the ordinary, unremarkable aspects of

[1] The volume cited here is the first edition. The current edition of this work is the fifth (Felson and Eckert, 2016).

crime.[2] This differs from other major criminological theories that focus on concepts that are typically undesirable or unfavorable in and of themselves, and therefore intuitively associated with crime and disorder. Examples might include learning deviant behavior (Akers, 1977), lacking self-control (Gottfredson & Hirschi, 1990), or living in social disorganized neighborhoods (Shaw & McKay, 1942). By contrast, the routine activities approach focuses on activities that are not, in most cases, undesirable or obviously risky in and of themselves. Recalling the previous paragraph, Cohen and Felson (1979) modeled crime as a function of females entering the workforce, workers taking vacation, and products becoming cheaper and easier to handle. None of these conditions seem inherently related to crime, yet were shown to contribute to 1947-1974 crime trends. Commuting to work is another noncriminal, routine activity that does not seem inherently related to crime, but impacts the number of potential victims and offenders in an area throughout the day. As such, commuting is one potential antecedent (recall Figure 1) that is explicitly considered in the measurement of crime risk in this thesis.

Environment criminology. Brantingham and Brantingham (1981) also assumed multiple elements, or dimensions, of crime. These dimensions include (1) a law to be broken, (2) an offender to commit the crime, (3) a target, and (4) a place for the event to occur. Environmental criminology involves studying the fourth dimension, namely the time and space where criminal events take place. To use examples, environmental criminologists ask questions such as where do victims tend to be targeted, how do offenders move throughout the city, where are certain laws enforced most heavily, and

[2] In fact, the first chapter to the most recent edition of *Crime and Everyday Life* (Felson & Eckert, 2016) is titled "Eight Fallacies About Crime" and seeks to de-sensationalize the discussion of crime.

what type of land uses attract the most crime events? Because these are questions of place, analysis tends to begin with the location of crime incidents. Patterns are identified and factors are examined that may be contributing to or detracting from crime occurrence patterns, via opportunities. Analyses take place at any scale, from international comparisons to street segment or address-specific concentrations, but Brantingham and Brantingham (1981) believed that the meso-scale of analysis (e.g., neighborhoods) had produced the most fruitful studies by that time.

Although implicit in the routine activities approach, environmental criminologists extend this general opportunity framework of examining criminal events to explicitly study offender motivation in the context of place (Brantingham & Brantingham, 1981). It is assumed that offenders are not continuously breaking the law because, as mentioned, crime events occur at a discrete time and space. Potential offenders receive cues from the environment that influence their decision to commit a crime at a particular place. In some cases, a motivated offender searches for the best target,[3] while in others the situational context motivates a person to commit a crime they had no intention of committing prior to entering that situation. For example, a person passes an expensive electronic device that is unattended and slips it into their pocket while no one is watching. Although they may not have had criminal intentions just moments prior, the environment presented an

[3] Although beyond the scope of this thesis, both the routine activities approach and environmental criminology operate on the basis of rational choice theory (see Clarke & Felson, 1993), whereby criminals calculate the risk-benefit ratio of crime when making the decision to commit or refrain from crime. When risks outweigh the benefit, a person is likely to refrain from the crime; when benefits outweigh the risk, the person is more likely to commit the crime. Compatible with the assumption that crime events are discrete, offender decision-making is also situational and can be influenced by altering the environment (see Clarke, 1997).

opportunity for crime in that situation. Therefore, the opportunity for crime becomes the intervening factor between environmental forces and the decision to commit a crime.

The environment also dictates where potential offenders and targets go during the course of a day, impacting the opportunities that offenders encounter and the targets that are selected. As such, environmental criminology examines the situations in which crimes occur and how offenders come into contact with their targets. Brantingham and Brantingham (1981) presented this combination of offender motivation and opportunity with the following equation:

$$crime = f(motivation, opportunity) \quad (1)$$

Equation (1) can be extended to model both *motivation* and *opportunity* as functions of other independent factors, resulting in crime events as interactions between offender motivation (criminality) and the opportunity backcloth.

Of importance to this thesis is that offenders are believed to move through the environment much like non-offenders when performing routine activities (Brantingham & Brantingham, 1981). This unfortunately reduces the precision of crime predictions derived simply from population movements (e.g., commuting to work or school, traveling to entertainment, shopping) because criminals and non-criminals behave similarly. It is therefore difficult to distinguish who will create or take advantage of crime opportunities, from those who will not take capitalize on opportunities for crime. When this information is not available, it is simply presumed that higher numbers of people at a given time and space result in higher crime counts at that place (Brantingham & Brantingham, 1981). However, more information is needed to calculate estimates that can more effectively differentiate movements of likely offenders from the movements of the rest of the population.

Short Note on Triviality

Before proceeding to discuss the relevant literature, the issue of theoretical triviality must first be discussed. It could potentially be argued that describing crime risk as a function of opportunities, exposure, or risk is trivial. However, Gottfredson (1981) argued the importance of seemingly “trivial” concepts for theory development early in the study of crime opportunity theories (i.e., routine activities approach, lifestyle theory). Rather than discuss risk in terms of opportunity, the lifestyle theory of victimization discussed by Gottfredson described risk in terms of exposure. First, he explained that “absolute exposure” and “probabilistic exposure” were different concepts, where absolute exposure refers to the “logical requisites” (p. 715) to crime (e.g., offender, target). Probabilistic exposure refers to “differences among people, objects, places, and times in their opportunity for victimization, given that victimization is logically possible” (p. 716). Recalling Figure 1, “exposure” is then the intervening mechanism between predictor variables and crime. Although the elements of exposure may be obvious, Gottfredson (1981) reminded that, “...if predictions based on the concept of absolute exposure [i.e., opportunity or convergence of crime elements] are indeed trivial-in the sense of ‘common,’ ‘obviously correct,’ or ‘true’---they would be important foundations for a theory of criminal victimization” (p. 715). In this way, he suggests that the simplicity inherent to discussing opportunity or exposure in relation to crime events is intentional, and used to provide a clear and understandable framework from which to build subsequent knowledge.

Previously, Jeffery (1971; 1977) also noted that many of the traditional criminological theories do not consider the basic elements or dimensions of crime (e.g., laws, offenders, victims, places, guardians). If these elements are indeed the foundations for crime, then Brantingham and Jeffery (1981) are also justified in stating that to neglect these elements and their role in crime "…impede[s] the development of an integrated theory of crimes" (p. 237). Further, Gottfredson (1981) pointed out that, at least at the time of the article, "[s]tatements about absolute exposure [or opportunity] have as yet to reach the heights of trivia…" (p. 715). He later concluded that:

> The principal assertion of the lifestyle model is that probabilistic exposure and its antecedents have a central role in the etiology of criminal victimization. The concept of opportunity for crime is not best regarded as only anecdotal or 'common sense' but should be regarded as 'scientific sense' and of explanatory power" (Gottfredson, 1981, p .723).

Although in a slightly different context (i.e., the lifestyle-exposure model of victimization), Gottfredson's (1981) discussion similarly applies to the routine activities approach and environmental criminology. The simplicity of understanding crime as a function of its critical elements is not to forget that the purpose of social research involves explanation. Understanding the elements of crime is important to directing attention to its proper antecedents, independent of crime itself.[4] In this thesis, it is assumed that opportunities act as the intervening variable between crime and its

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[4] Clear and crime-independent concepts have been noted limitations to social disorganization theory. For example, Felson (forthcoming) argues that many of the mechanisms critical to social disorganization theory (e.g., informal social control) have been unclear and difficult to measure. Bordua (1959) suggested that the concept of "anomie," implicit to social disorganization theory, is in fact tautological. In his critique of Lander's (1954) work, he points out that "Delinquency is a *species* of 'anomie'" (p. 237) and therefore anomie cannot be used to explain crime.

antecedents (i.e., commuting, some land uses). Opportunities for crime, created by convergence of victims and offenders, are not the "explanation" for crime per say, but rather the clearly articulated, tangible, and necessary link between the explanatory variables and crime events. Population movements predict opportunities, and these opportunities predict crime (recall Figure 1). It is by this logic, and the evidence that has accumulated since these frameworks originated, that this thesis resolves the issue of triviality and proceeds to study differences in crime risk as a result of population movement (i.e., commuting).

II: LITERATURE REVIEW

This thesis calculates alternative denominator-based crime rates and compares them with the traditional, residential population-based crime rate to explore important differences in the measurement of crime risk. As suggested above, this thesis is informed by multiple literatures described next. First, Chicago will be justified as a suitable and opportune study site for this thesis. Then, previous work on crime rate denominators, crime risk clustering, and the impacts of population movements on crime will be reviewed before discussing the methodology used here.

Social Research in Chicago

Beginning with work at the University of Chicago in the 1920s and 1930s, Chicago has served as an icon for neighborhood-level crime research. This city has been the subject of large-scale sociological studies since Burgess (1925) first introduced the novel concentric zonal model of urban growth. The Institute for Juvenile Research in Chicago was founded at the University of Chicago, and became the fountainhead for understanding urban crime dynamics. Social ecology erupted as the dominant standard by which sociologists committed to studying crime during what Brantingham and Brantingham (1981) termed the "second wave of interest in spatial criminology" (p. 12; also see a discussion by Brantingham & Jeffery, 1981).[5] Shaw and McKay (1942) then built off the work of Burgess to develop social disorganization theory, a perspective that

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[5] The first wave was characterized by the work of French researchers Guerry (1833) and Quetelet (1842) who were among the first to create maps of violent and property crimes in France. Following the second wave, Brantingham and Brantingham (1991) suggest that environmental criminology has shifted the focus of criminological research "…from a disciplinary to a criminological relationship, (2) …from concern with offender motives to concern with criminal events, and (3) …from the sociological to the geographic imagination" (p. 18). Although not explicitly stated, it is implied that environmental criminology could represent the third wave of spatial criminology.

has received copious attention since that time. To cite some of the most impactful research, Bursik (1988; also see Bursik & Grasmick, 1999) expanded on the foundation laid by Shaw and McKay, exploring informal social control as an influential factor in regulating crime. Later, Sampson and Raudenbush (1999) introduced systematic social observation as a viable means for studying neighborhood crime and disorder, also conducted "in the spirit of the early Chicago school of urban sociology…" (p.605). They pioneered this technique in Chicago to evolve the social disorganization perspective into the idea of collective efficacy (Sampson, Raudenbush, & Earls, 1997). The *Project on Human Development in Chicago Neighborhoods* (see Sampson, 2012) produced this research along with at least another 487 related publications (ICPSR, 2016).

Chicago has also been the focus of a plethora of influential research related to community policing (Rosenbaum, 1988; Skogan & Hartnett, 1997), fear of crime (Skogan & Maxfield, 1981), gang activity (Asbury, 2003; Block & Block, 1993; Thrasher & Short, 1963), the effect of liquor establishments (Block & Block, 1995; Roncek & Maier, 1991) and schools (Roncek & Faggiani, 1985; Roncek & Lobosco, 1983) on crime, organized crime (Landesco, 1929; Lombardo, 2013), race and crime (Spear, 1967), housing code inequality and crime (Hirsch, 1983), race rioting (Tuttle, 1970), and other vices (Reckless, 1933). Clearly, Chicago has been an important site in the development of criminological theory. Examining Chicago's contemporary crime risk processes therefore has high appeal. It is interesting to examine daily population flows and their impact on crime concentration, considering that transportation technology is vastly different than when early Chicago theorists were conducting research. To examine the influence of commuting in Chicago, attention will be given to crime risk measured as rates. Research regarding crime rate calculations is discussed next.

Crime Rates and the Population at Risk

Crime counts and crime rates each have utility. Police departments are often interested in crime counts, because they indicate the amount of crimes to be solved, the number of victims with incident reports to be collected, or the volume of calls that must be responded to. On the other hand, rates are important to potential victims, because they indicate the amount of risk associated with a particular area. One area may have many crimes, but also many people who could potentially be victims. For example, 4,000 crimes in an area where 4,000 people live (rate = 1,000 crimes per 1,000 population) represents lower risk than an area with only 400 crimes but only 40 residents (rate = 10,000 crimes per 1,000 population). In this case, the second area is much more dangerous. Rates are therefore useful for measuring victimization risk.

While the residential population is certainly a reasonable crime rate denominator, exclusive reliance on per capita crime rates assumes that residential population represents the most accurate population at risk. The population at risk, being both targets and offenders, must be either assumed relatively stationary throughout the day, or assumed to only victimize or be victimized near home. First, it is obvious that most people are not stationary near their homes throughout the day, and the proliferation of mass transportation has enabled residents to travel well beyond their home neighborhoods with great ease. Secondly, research to date has found that (1) offenders tend to commit their crimes away from their homes (Andresen, Frank, & Felson, 2013; Bernasco, 2010; Bernasco & Block, 2011; Groff & McEwen, 2007; Hakim & Rengert, 1981; Johnson, 2014; Rossmo, Lu, & Fang, 2012; Townsley & Sidebottom, 2010; Pyle, 1974); and (2) the activities for which potential victims are at the highest risk do not include being at or near home, but traveling to or from work or school (Lemieux, 2010; Lemieux & Felson, 2012). From these two arguments, the evidence contradicts the assumption that the per capita crime rates are *always* the most appropriate measure of crime risk.

Well before this research was published,[6] Boggs (1965) hypothesized that the calculation of crime rates should be sensitive to a variety of crimes types, victims, and offenders. She believed that crime rates should reflect the probability of risk, stating that "[a] valid rate...should form a probability statement, and therefore should be based on the risk or target group appropriate for each specific crime category" (p. 900). As described, the traditional method of dividing by the residential population for measuring crime occurrence is limited in its ability to account for all exposure to risk. For instance, the central business district of a city is typically dominated by commercial buildings and few residents. As such, these areas will likely show inflated crime rates because the small residential population is used to deflate the crime count. For each crime that is committed in the central business district, the measured risk (crime rate) increases by a greater degree than when one crime is committed in a densely populated area.

Boggs (1965) used alternative denominators that depended on the type of crime being analyzed to increase the accuracy of crime measurement in St. Louis, Missouri. Burglars target dwelling units, not residents. Therefore, Boggs calculated burglary rates by dividing the number of crimes by the number of dwelling units rather than residents. Untended parked cars served as the denominator for motor vehicle theft. Sidewalk and

[6] Although Burgess (1925) suggested that many crimes are committed outside of offenders' home census tracts.

street area was used as the crime-specific denominator for street robbery, while the residential population was used for robberies that occurred in and around homes (termed “miscellaneous robbery” by Boggs, 1965). It is clear that the denominator used for each of these crime types is intuitively connected to the crime-specific targets. As evidence for her predictions that alternative rates told a distinct story, Boggs (1965) found that rank-order correlations between the traditional crime rates and her crime-specific denominator rates were low for many crime types (less than $r = 0.35$ for property crimes, but greater than $r = 0.75$ for robbery, burglary, rape, and aggravated assault/homicide).

Beyond Boggs. Although Boggs’ (1965) methods sometimes involved the use of crude proxies, such as sidewalk area for estimating the amount of persons at risk, her intuition inspired much of the subsequent work on the topic of crime rate denominators. Building from Boggs’ (1965) study, Phillips (1973) used employee counts as the denominator when measuring rates for crimes against business (i.e., commercial robbery and burglary), finding that residential population-based crime rates were inversely related to employee-based crime rates. Phillips (1973) added that crime rates could potentially reach infinity in strictly commercialized areas where the number of residents was equal to zero. This explication revealed the illogic of relying only on residential population-based rates.

Although identifying the best denominator was not their goal, Pyle et al. (1974) sought the denominators that improved fit of their multivariate ecological models. Towards this end, correlations between crime counts and the alternative denominators led the researchers to use (1) residential population-based rates in violent crime models (i.e., homicide, rape, aggravated assault), (2) raw crime counts for unarmed robbery, commercial burglary, larceny, and auto theft models, and (3) commercial and living unit-based rates in armed robbery and residential burglary models. These findings suggest that the residential population can be better for some crime types, but inadequate for others.

Frisbie et al. (1977) used a variety of denominators to estimate opportunities for crime types, focusing on the inadequacy of many of the measures used to ascertain risk. For example, data at that time were not available to measure “person-hours” when calculating street robbery rates, and registered vehicles did not provide enough detail about motor vehicle theft. The importance of the work by Frisbie et al. (1977) was to show that the available data were inadequate for properly capturing the population at risk. Subsequent research has since overcome some of these limitations.

Skogan (1976) further examined risk, suggesting that crime statistics should more carefully consider the “potential opportunities for victimization.” He compared the use victimization surveys with official reports of crime, and the use of residential population-based with vehicle-based crime rates. In his study, both the numerator and the denominator were considered and displayed differences in risk measurement.

Harries (1981) provided the adaptable formula for measuring crime risk, C/O, where crime rates represent the number of crimes divided by the opportunities for crime. Harries examined “opportunity-based” crime rates in Oklahoma City with the intention of communicating their importance to a practitioner audience. His conclusion suggested that “the use of rather exotic (and perhaps expensive) denominators will not necessarily solve problems” (p. 164), but also that analysts should utilize adequate specificity when determining the most appropriate denominator. For example, it was suggested that burglary be disaggregated into commercial and residential burglary before employing an opportunity-based denominator to measure risk. In this way, commercial burglary risk should consider commercial units, while residential burglary risk considers residential living units.

Other denominators. More recently, alternative denominators have been used to match targets more closely to their corresponding crime types and settings. For example, researchers have examined differences in crime risk by dividing the number of crimes by the number of "person-hours" (overcoming the limitation suggested by Frisbie et al., 1977) that people spend doing various activities (Lemieux, 2010; Lemieux & Felson, 2012). This method measured which activities are riskiest, by dividing crime occurrence by time spent in daily activities. Riskier activities are those where crime is high in relation to the amount of time spent doing such an activity. The highest risk of crime victimization was found to be en route to and from work or school. Consistent with the routine activities approach, normal day-to-day activities were shown to be the riskiest activities, hour for hour (Lemieux & Felson, 2012). Other work has suggested that crime rates can differ largely across spatial, temporal, and spatio-temporal units (for a review, see Ratcliffe, 2010).

Population Movement and Crime

Land uses are intimately connected to the number of people at a given time and place. A focal area could have a very different number of people present at different times of the day, due to the land uses close-by. For example, the entertainment district may have many people in the local area during the night, especially on weekends, but fewer during weekdays. This change in population corresponds to a change in the number of potential crime targets and, thus, a change in the denominator of the crime rate. As more people gather at a given time and space, both the routine activities approach (Cohen & Felson, 1979) and environmental criminology (Brantingham & Brantingham, 1981) predict higher frequencies of criminal events. This may, however, decrease measured risk. Recent research considers that human crime targets are constantly on the move throughout the day. This movement contributes to higher concentrations of crime counts, *but lower measurements of crime risk*. One can easily see that a discussion of population movement is therefore relevant to crime risk, and is therefore a focal point of this thesis.

Ambient population. The "ambient population" represents the number of people at a certain place and time. Andresen (2006) was among the first to suggest the use of the ambient population for estimating crime risk as opposed to using the residential population. His initial study, and several subsequent studies, used data from the LandScan Global Population Database to estimate ambient population counts for areas within a city. This dataset assigns a probability coefficient value to each cell, quantifying the predicted daily average number of people in a given area based on land use attractiveness, road proximity, slope, land cover, and nighttime lights (Dobson, Bright, Coleman, Durfee, & Worley, 2000). These data allow for a better measure of the population at risk than the residential population, because they take these other factors related to population movement into account when making predictions.

Also using these data, Andresen and Jenion (2010) found that the ambient population had twice the variation than that of the residential population, justifying further exploration into the ambient population's utility for calculating alternative denominator-based crime rates. From a routine activity perspective, greater variation in the ambient population likely increases variation in the number of convergences between potential victims and offenders as well. Comparing rates, Andresen and Jenion (2010) showed that less than one percent of the variation in the ambient population-based violent crime rates could be explained by residential population-based violent crime rates in Vancouver. More importantly, they concluded that traditional residential population-based rates could be misleading estimates of crime risk, and that considering the ambient population could improve description of violent crime.

New data for social research. Malleson and Andresen (2015) estimated more precise changes in the ambient population using spatially-referenced social media data. These data used provide exact geographic coordinates of users at the time they post content to the web. The researchers suggested that these crowd-sourced data have the potential to provide "true" ambient population counts, however, they also note the clear limitations. It is unclear what proportion of the population uses the social media application used to collect the data (*Twitter*), and perhaps a smaller percentage of these users provide their geographic location when posting content online. Put simply, these data seriously sacrifice representativeness for increases in precision. Nonetheless, Malleson and Andresen (2015) showed that the apparent "city center" shifted dramatically with a change in the ambient population derived from the data. This shift led to changes in crime risk clusters, such as the elimination of the high crime risk cluster in the city center. Using these types of data could be the future of measuring the population at risk with enhanced precision and accuracy if sufficiently representative samples can be drawn. Nonetheless, the ambient population, or population in constant movement, appears to play a significant role in crime risk estimates.

Commuters and crime. In another recent study, Stults and Hasbrouck (2015) examined the effect of commuting on several crime types across 166 U.S. cities. Not surprisingly, they found that city crime rankings changed when comparing alternative denominator-based crime rates that included daily changes in population due to commuting. Most notably, cities were shown to change their ranking by an average of 4.63 positions for robbery and 8.85 positions for larceny. Moving beyond sample description, Stults and Hasbrouck (2015) conducted multivariate analyses to examine how the inclusion of a commuter variable confounded the effects of other independent variables commonly used in criminological research. Specifically, the commuter variable measured the percentage change in population due to commuting. Cities with increased population during the daytime (residents + commuter inflows – commuter outflows) had positive percentages, while cities that lose population during the daytime had negative percentages. The clearest result was that the effect of residential stability on the robbery rate declined by nearly 44 percent and was no longer significant when the commuting variable was included in analysis. They concluded that (1) commuting consistently had a strong, positive effect on crime; (2) including a commuting variable was critical for producing reliable findings in regards to other crime factors, and; (3) the impacts of commuting on both description and prediction of crime risk are most important for cities with large numbers of commuters. Building partially from this study, this thesis will also examine the impacts of commuting on description, but within a city rather than across cities.

A funneling hypothesis. Stults and Hasbrouck (2015) were limited in their ability to approximate all population flows, because they relied on commuters only. Recently, Felson and Boivin (2015) suggested that crime follows the flow of population as people move from place to place throughout the city, including travel to and from work, shopping, entertainment, and other movements. As more people enter a particular area, a greater number of potential crime opportunities exist (convergence of offenders and targets), resulting in higher crime frequency. Moreover, outsiders, or non-residents of a particular census tract, may be responsible for a considerable amount of crime that occurs in that census tract.

Felson and Boivin (2015) developed this funneling hypothesis from previous work on the topic. For example, Frank, Andresen, and Brantingham (2011, 2013) have illustrated how offenders display directional movement bias towards certain land uses, such as entertainment districts, to commit their crimes. Derived from this research and the conceptual framework of the routine activities approach (Cohen & Felson, 1979) and environmental criminology (Brantingham & Brantingham, 1981), Felson and Boivin (2015) offered the funneling hypothesis as a viable explanation of how the ambient population plays an important role in crime concentration. Their Canadian study considered population flow, such as to and from shopping and entertainment, which is beyond the scope of this thesis; but commuter flows specifically showed to be an important part of their findings, explaining roughly 77 percent of the variation in property crimes and 30 percent of the variation in violent crimes (Felson and Boivin, 2015). Building from this study and the other research discussed, commuters are an integral component in this thesis to understand crime risk measurement at the census tract-level.

III: THE PRESENT STUDY

Several interrelated literatures have been discussed as informants to this thesis. These included research on the city of Chicago, crime rate denominators, crime concentration, and how the movements of people across the urban landscape impact crime. This thesis further examines how crime rate denominators impact crime risk measurement. Alternative denominators are calculated from commuter data and square area of census tracts. To accomplish this task, Chicago crime data aggregated to the census tract level are combined with census tract-level data from the American Community Survey to address the following research questions:

1. Do spatial patterns in crime risk differ when alternative denominator-based crime rates are used to map crime rates?

2. Do spatial clusters in crime risk differ when alternative denominator-based crime rates are compared with residential population-based crime rates?

3. How large are percentile differences between residential population-based crime rates and alternative denominator-based crime rates?

4. Where do alternative denominators increase or decrease percentile ranking of crime risk, as compared to using the residential population denominator?

5. To what degree are alternative denominator-based crime rates correlated with residential population-based crime rates in Chicago census tracts?

6. Which crime rate denominator is most strongly associated with crime counts in Chicago census tracts?

IV: METHODOLOGY

This study utilizes secondary data analysis to address the research questions presented above. Demographic data used here come from the American Community Survey 2006-2010 estimates and crime data averaged over the years 2008-2010 come from the city of Chicago. All data are freely and publicly available. Before discussing these data in detail, the chosen unit of analysis is considered.

Unit of Analysis

All variables proposed for analysis are aggregated to the census tract-level. Although researchers continue to reduce analysis to smaller units (see Sherman, Gartin, & Buerger, 1989; Weisburd, 2015; Weisburd et al., 2012), the census tract is the most appropriate unit of analysis for this study. Practically speaking, census tracts are the smallest known unit of analysis with place-to-place commuter data in Chicago. The commuter data became recently available from the U.S. Census Bureau in 2015 for the United States, and they have not been used for the purposes of examining intra-city crime rates prior to this study. Second, the average census tract in Chicago (n = 787)[7] spans roughly 0.295 square miles. Areal units smaller than this may miss the commuter effect on crime. For example, a block-level analysis may be too narrow, as workers may commute to work in one block, but walk across the street to another block for entertainment after work. In this case, the worker may not contribute to crime in the block they work at, but rather to the block across the street. Although this problem is possible with any static unit of analysis, it is assumed to be less of an issue when using larger areas such as census tracts. Using smaller units increases the number of

[7] A total of 801 census tracts exist in Chicago. However, 14 census tracts have missing data and are therefore omitted from analyses. See section below for discussion on these 14 missing census tracts.

boundaries, thereby increasing the possibility for the confounding person crossover effect just described. For these reasons, the census tract is the unit used in this study (see Figure 2).

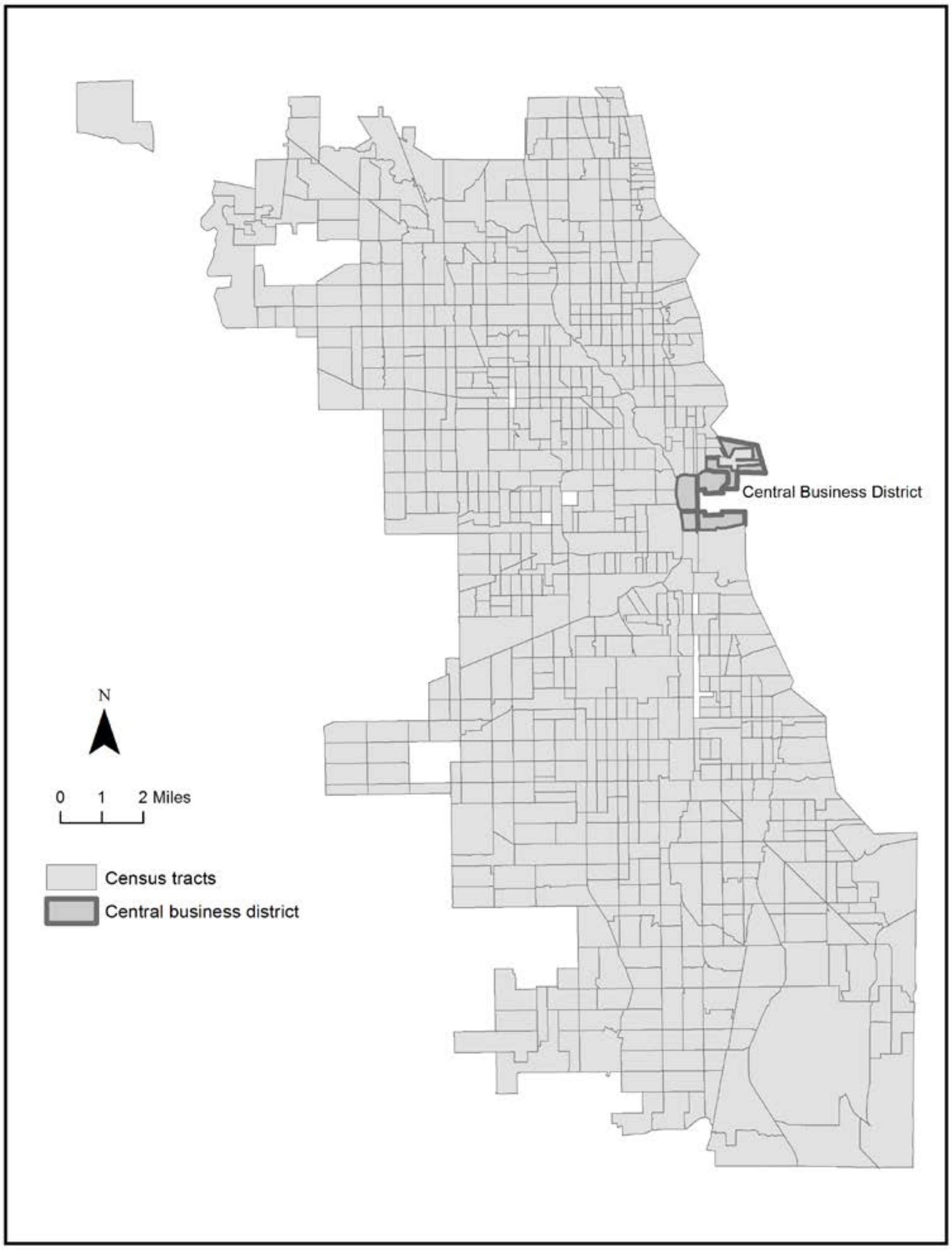

Figure 2
Chicago census tract boundaries (n = 787) and central business district

Crime Data

Crime incidents reported to the police were extracted from the Chicago Police Department's CLEAR (Citizen Law Enforcement Analysis and Reporting) System.[8] The number of crimes in each census tract is averaged over three years (2008-2010) to smooth year-to-year anomalies that could confound the results. The use of data from 2008-2010 are within the corresponding timeframe, and match the independent variables more closely than previous studies; for instance, Felson and Boivin (2015) compared 2008 transportation survey data with 2011 crimes.

The crimes used here include theft, motor vehicle theft, robbery, assault, and battery. According to the Chicago Police Department (2016), theft is a broad category of crimes involving the unlawful taking of another person's possession(s). Motor vehicle theft is self-explanatory. Robbery is defined as the taking or attempted taking of anything valuable from another person under "confrontational circumstances," which includes force or threat of force. Assault incidents involve the threat of harm, or involve the attack on another person that does not include the use of a weapon or result in bodily harm. Battery involves the bodily harm of another person. Both of these crimes can be further classified as aggravated offenses if severe bodily harm results from the attack. Although all incidents include more detailed descriptions allowing for further disaggregation of crime types (e.g., domestic versus non-domestic), broader incident classifications are used in this study to reduce bias associated with reporting errors.

[8] The city of Chicago Police Department does not guarantee the accuracy of these data. However, this is a common issue with any publicly accessible dataset and is not considered a serious limitation of the study.

Exact locations of the crime incidents (i.e., addresses, XY coordinates) are not included in the publicly available dataset to protect the privacy of victims. However, each incident includes XY coordinates (offset from the exact location) that places the crime's point location in the correct block where it occurred. Because the unit of analysis is larger than blocks, this level of imprecision is not problematic for analysis. Table 1 displays summary statistics for each crime incident type, averaged over the years 2008-2010.

Table 1

Summary statistics for crimes occurring in Chicago census tracts per year, 2008-2010 averages (n = 787)

Type	**Mean**	**Median**	**S.D.**	**Min.**	**Max.**	**Total**
Theft	82.6	62.0	89.7	0.7	1,581.0	65,008.3
Motor vehicle theft	18.2	15.7	12.8	0.0	88.3	14,295.3
Property total	100.8	78.3	95.1	1.0	1,614.3	79,303.7
Robbery	16.3	11.3	15.8	0.0	106.0	12,823.7
Assault	23.3	17.3	19.9	0.0	139.7	18,335.7
Battery	70.2	51.0	61.1	0.0	404.3	55,273.0
Violent total	109.8	80.3	95.4	0.0	615.7	86,432.3

ABBREVIATIONS: S.D. = standard deviation; Min. = minimum; Max. = maximum.

Demographic Data

Demographic data come from 2010 American Community Survey five-year estimates made publicly available online by the U.S. Census Bureau. Beginning collection in 2005,[9] the American Community Survey is a nationwide survey conducted by the U. S. Census Bureau. In contrast to the decennial census that collects data every ten years, the American Community Survey continuously surveys the U. S. population

[9] Although the decennial census collected long-form information since 1940, it was not until 2005 that the American Community Survey began full implementation, collecting long-form information on a continuous basis.

regarding demographic, housing, social, and economic characteristics. Each year, roughly three million homes are sampled and typically two million interviews are conducted. In the state of Illinois (where Chicago is located) during the years 2006-2010, an average of 117,262 homes were sampled each year (response rates exceeded 97 percent each year). Because the number of sampled homes in any given year is not sufficient to create estimates with sufficiently low standard sampling errors at the census tract level, estimates are combined over several years of data collection to derive multi-year average estimates. One-year, three-year, and five-year estimates are available to provide timely information to data users, but averages over greater time spans are considered better estimates. The first five-year average estimates became publicly available in 2010, but census tract-level commuter estimates were not released until 2015.

Residential population. The estimated number of residents living in a census tract is derived from the same five-year, American Community Survey average (2006-2010) from which the commuter data (described below) are derived. Summary statistics for the residential population estimate can be found in Table 2.

Table 2

Summary statistics for 787 Chicago census tracts, American Community Survey 2006-2010 five-year average estimates

Variable	**Mean**	**Median**	**S.D.**	**Min.**	**Max.**
Residential population	3,457.3	3,188.0	1,684.8	797.0	13,117.0
Commuter inflows	1,616.7	653.0	7,933.0	10.0	204,243.0
Commuter outflows	1,447.6	1,329.0	831.7	122.0	8,187.0
Daily population [a]	3,626.5	2,699.0	8,020.0	620.0	206,147.0
Average daily pop. [a]	3,541.9	3,011.0	4,238.1	800.0	104,555.0
Square miles	0.3	0.2	0.4	0.0	8.3

ABBREVIATIONS: S.D. = standard deviation; Min. = minimum; Max. = maximum; pop. = population.
NOTES: [a] – indicates alternative denominator.

Commuter flows. The American Community Survey asks respondents to report the address of their workplace. This information is then geocoded by U.S. Census Bureau staff to a specific place (when possible) and aggregated to the block level. These data are then aggregated and made publicly available to estimate the number of commuters traveling from each focal census tract to workplace ("destination") census tracts. Summing the number of commuters who report leaving a focal census tract ("original tract") for work measures the estimated number of daily *outflows* from that tract. Summing the number of commuters who report working in a focal census tract ("destination tract") measures the estimated number of daily *inflows* to the tract. The data file also contains rows for flows within the same census tract. Before proceeding, these observations were deleted, because they do not correspond to outflow or inflow situations.

Missing Data

Before proceeding, missing data must first be explained. As mentioned above, 14 census tracts are excluded from the analysis due to missing data. When downloading American Community Survey residential population estimates, these 14 tracts are not included in the publicly available data set. However, commuter inflows and outflows (downloaded from a separate location) and crime figures are available for these tracts. Table 3 describes known characteristics of these census tracts for comparing with the tracts with non-missing data. Comparison shows that the missing census tracts have a larger average number of commuter inflows and lower average number of commuter outflows. Perhaps this indicates that the missing tracts had lower population, yielding unreliable population estimates. Also, the average number of crimes in the 14 missing census tracts is lower than in the 787 census tracts included in the analysis.

Table 3

Summary statistics for 14 missing Chicago census tracts, American Community Survey 2006-2010 five-year average estimates

Variable	**Mean**	**Median**	**S.D.**	**Min.**	**Max.**
Commuter inflows	4,932.4	207.0	10,634.12	95.0	30,391.0
Commuter outflows	110.7	72.5	111.2	0.0	332.0
Square miles	0.7	0.1	2.0	0.0	7.7
Theft	76.1	17.3	143.5	2.3	487.3
Motor vehicle theft	7.2	6.0	5.8	2.0	20.3
Property total	83.4	21.8	146.6	4.3	496.3
Robbery	6.4	4.8	8.4	1.0	34.7
Assault	13.3	10.3	12.3	2.3	42.0
Battery	34.6	24.3	24.9	6.7	85.7
Violent total	54.3	35.3	41.9	13.7	146.0

ABBREVIATIONS: S.D. = standard deviation; Min. = minimum; Max. = maximum.

Crime Rate Calculation

The primary focus of the proposed thesis is to examine crime rates and crime rate percentile rankings in Chicago census tracts. As discussed in the literature review, crime rates are commonly used to rank the relative safety risk of areas in a city. Per capita crime rates are often used with little thought to the possible effects that their form may have on results. Most commonly, the residential population is used as the denominator when calculating crime rates. Multiplying by a factor of 10,000 provides a more meaningful result that can be interpreted as the number of crimes per 10,000 population.[10] Equation (2) is used to calculate the traditional residential population-based crime rate:

$$traditional\ crime\ rate = \frac{\#\ crimes_i}{residential\ population} * 10{,}000 \qquad (2)$$

[10] Recall that the denominator represents the population at risk, or the number of potential crime targets or offenders.

The residential population intuitively represents the number of potential offenders and targets in an area (i.e., population at risk) if one assumes that residents are most frequently involved in crime as offenders or victims. While this assumption is likely correct, one aspect of this thesis is comparing the residential population with other proxies for the number of potential offenders and targets in an area.

Alternative denominators. Two alternative crime rate denominators are computed using commuter flow data. The first alternative denominator is termed the *daily population* and represents the simplest combination of the residential population, commuter inflows, and commuter outflows, using Equation (3):

$$daily\ population = residents + commuter\ inflows - outflows \tag{3}$$

An alternative crime rate is then calculated that accounts for daily shifts in population due commuter inflows and outflows. The daily population is used in the calculation of the first alternative crime rate using Equation (4):

$$\begin{aligned} daily\ population\ crime\ rate &= \frac{\#\ crimes_i}{daily\ population} * 1{,}000 \\ daily\ population\ crime\ rate &= \frac{\#\ crimes_i}{(r + c_{in} - c_{out})} * 1{,}000 \end{aligned} \tag{4}$$

where:

$r = Residential\ population$

$C_{in} = Commuter\ inflows$

$C_{out} = Commuter\ outflows$

To obtain a more conservative proxy for the number of potential victims and offenders present daily, the residential population and the daily population are weighted equally. This second alternative denominator is termed the *average daily population*, and considers the amount of time that the *residential population* and the *daily population* are assumed to be present in a focal census tract. Following the logic presented in Stults and Hasbrouck (2015), this denominator assumes that people spend roughly half of their day at home and half of their day away from home.[11] However Stults and Hasbrouck (2015) suggested that the majority of a city's commuter inflows occurred Monday through Friday, and weighted the residential population as 9/14ths and the daily population as 5/14ths. Rather than follow this precedent here, the values are weighted equally by taking the average, because this thesis examines census tracts rather than cities as the unit of analysis. Intra-city and across-city analyses are conceptually different; in the case of this intra-city study, many workers may commute to areas where they work during weekends and nights in addition to during the daytime. Many businesses within the central business district (especially entertainment and service) are open during the weekend and during the night hours and may even be more important for the commuter effect on crime rates. While those that live outside the city are perhaps more likely to commute to a standard weekday occupation, intra-city commuting will presumably capture a wider range of occupational categories, including those that work in entertainment or service occupations. As a result, the following equation is used to estimate the average daily

[11] In this study, being away from home is when a person is within their work (destination) census tract. This assumption has limitations, namely that spending time away from home could include activities that are not located within respondents' work census tract, such as entertainment, shopping, or recreation. The transportation survey used in the Felson and Boivin (2015) study asked respondents to report where they traveled for entertainment, shopping, and recreation, making their estimates stronger than those in the proposed study. However, it could be argued that respondents tend to spend most of their time during the week in their workplace census tract. Most people may shop or search for entertainment and recreation close to their workplace for convenience as well.

population (summary statistics in Table 2), averaging the residential population and the daily population as shown in Equation (5), where:

$$Average\ daily\ population = \frac{r + (r + C_{in} - C_{out})}{2} \quad (5)$$

where:

$r = Residential\ population$

$C_{in} = Commuter\ inflows$

$C_{out} = Commuter\ outflows$

This denominator is used to calculate another alternative denominator-based crime rate. Equation (6) is used to calculate this alternative denominator-based crime rate as follows:

$$average\ daily\ population\ based\ rate = \frac{\#\ crimes_i}{average\ daily\ pop.} * 1{,}000$$

$$average\ daily\ population\ based\ rate = \frac{\#\ crimes_i}{(\frac{(r + c_{in} - c_{out}) + r}{2})} * 1{,}000 \quad (6)$$

where:

$r = Residential\ population$

$C_{in} = Commuter\ inflows$

$C_{out} = Commuter\ outflows$

The final alternative denominator used in this study is a crime density measure. Rarely are crime counts deflated with a measure of the square area. However, it is examined here how deflating crime counts by the spatial area of a focal census tract impacts crime description. Equation (7) is used to calculate crime rates per square mile:

$$crimes\ per\ sq.mile = \frac{\#\ crimes_i}{square\ miles} \tag{7}$$

Visualizing Chicago

Choropleth maps are created in ArcGIS to illustrate the spatial distribution of variables described above (Figures 3 through 12). For each map, value classes are created to render “natural” breaks in the data values. More specifically, Jenk’s (1967) natural breaks classification technique is used to maximize the differences between each class’s mean value. Note in each map that several census tracts are white, representing the 14 missing census tracts. The central business district is identified in each map for context. It should be noted that crime counts are mapped in this section, as opposed to crime rates. Comparisons among crime rates will be conducted later, but crime counts are first presented to provide the initial context for understanding later analyses.

A few things can be observed in this first series of maps showing the variables of interest. First, the residential population map (Figure 3) and commuter outflows map (Figure 5) look very similar. This similarity could be predicted if one assumes that most of the population commutes outside of their home census tract to go to work. However, this may not be the case in other cities where the population is more localized. Secondly, it is clear that the high concentration of commuter inflows (Figure 4) in the central business district dominates the concentration of the alternative population denominators (Figure 6 and Figure 7). Although the more conservative measure of population movement, the average daily population, disperses the concentration of the estimated population somewhat, Figure 7 still shows a high concentration of expected population near the central business district.

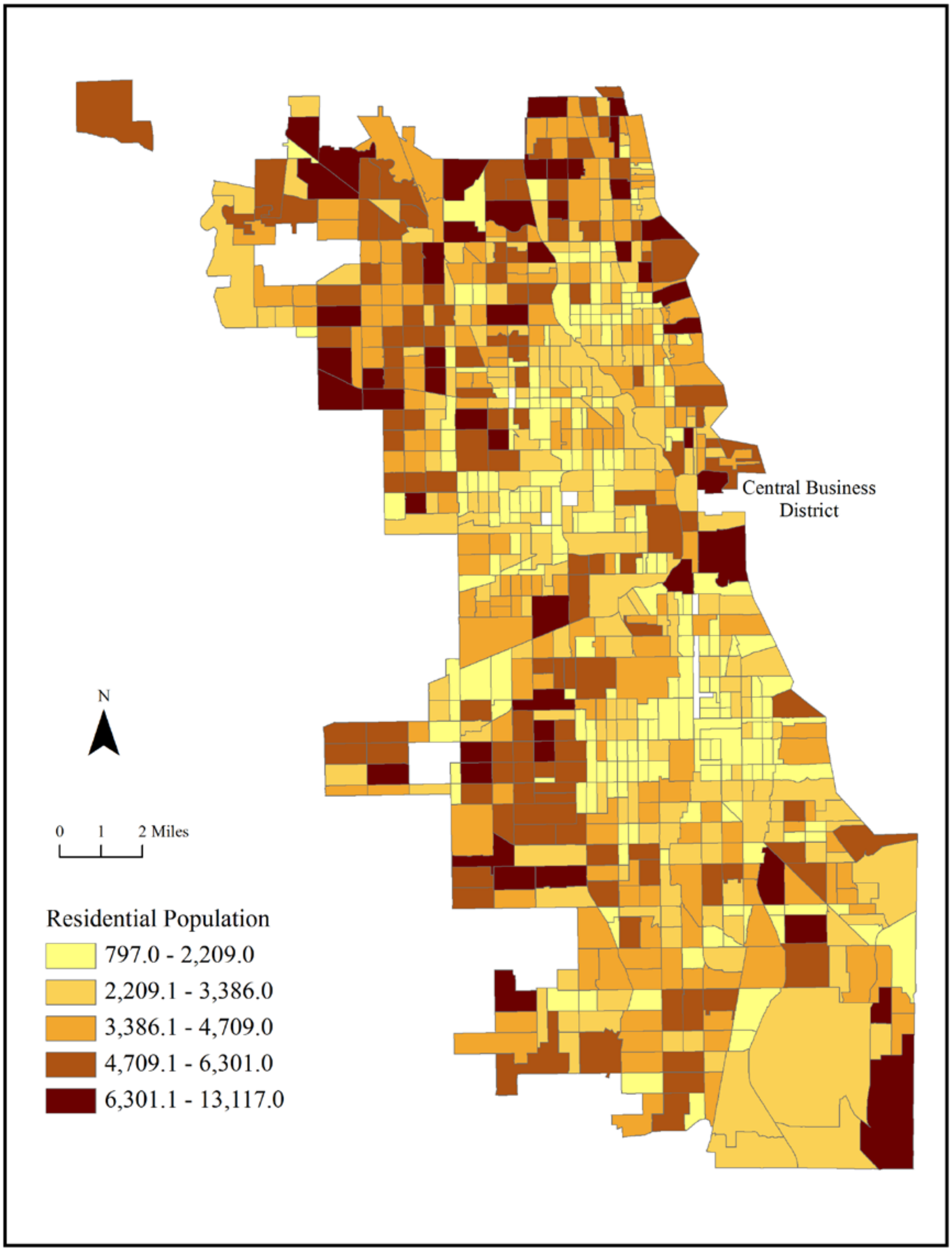

Figure 3
Residential population in Chicago census tracts (n = 787), 2006-2010 average

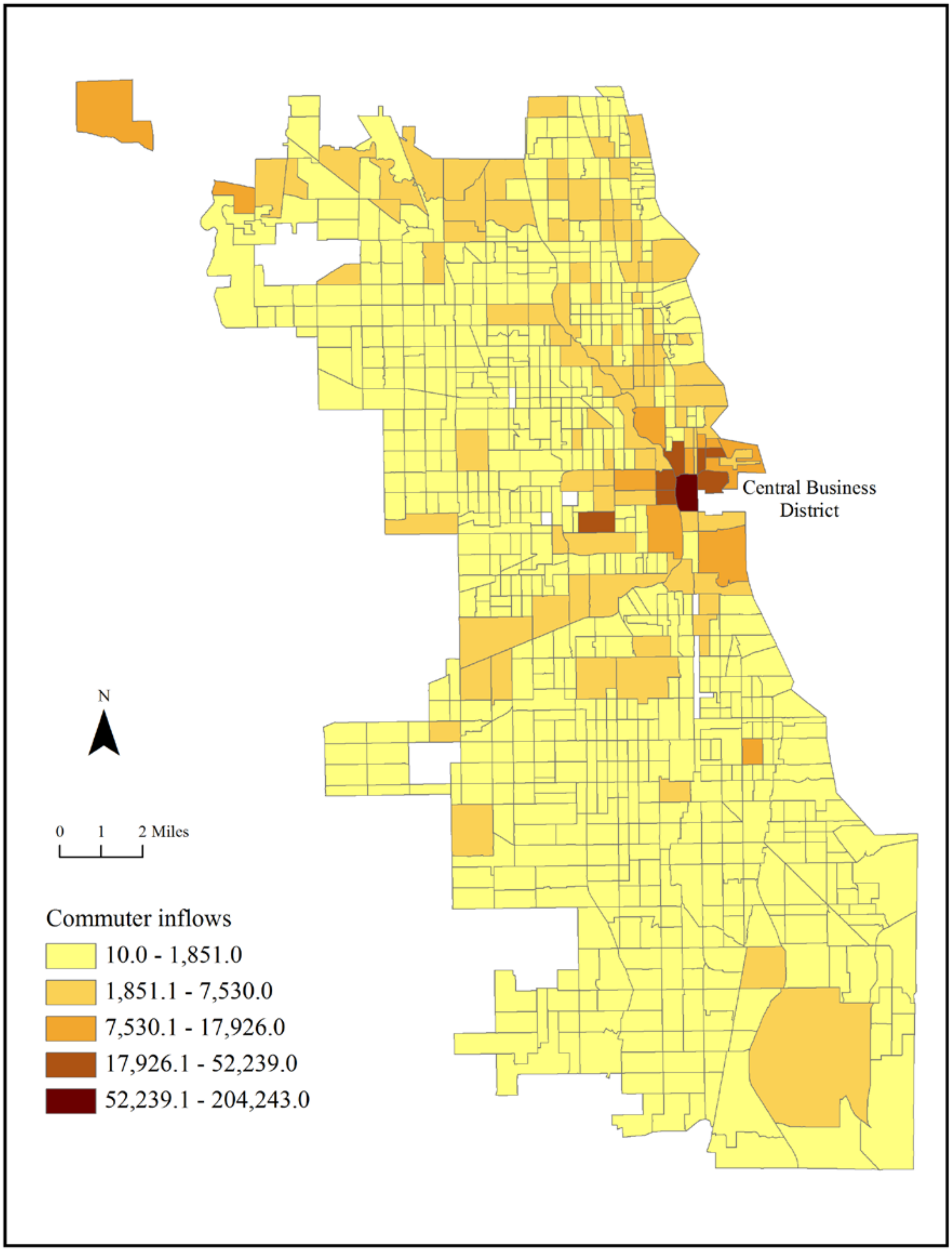

Figure 4
Commuter inflows in Chicago census tracts (n = 787), 2006-2010 average

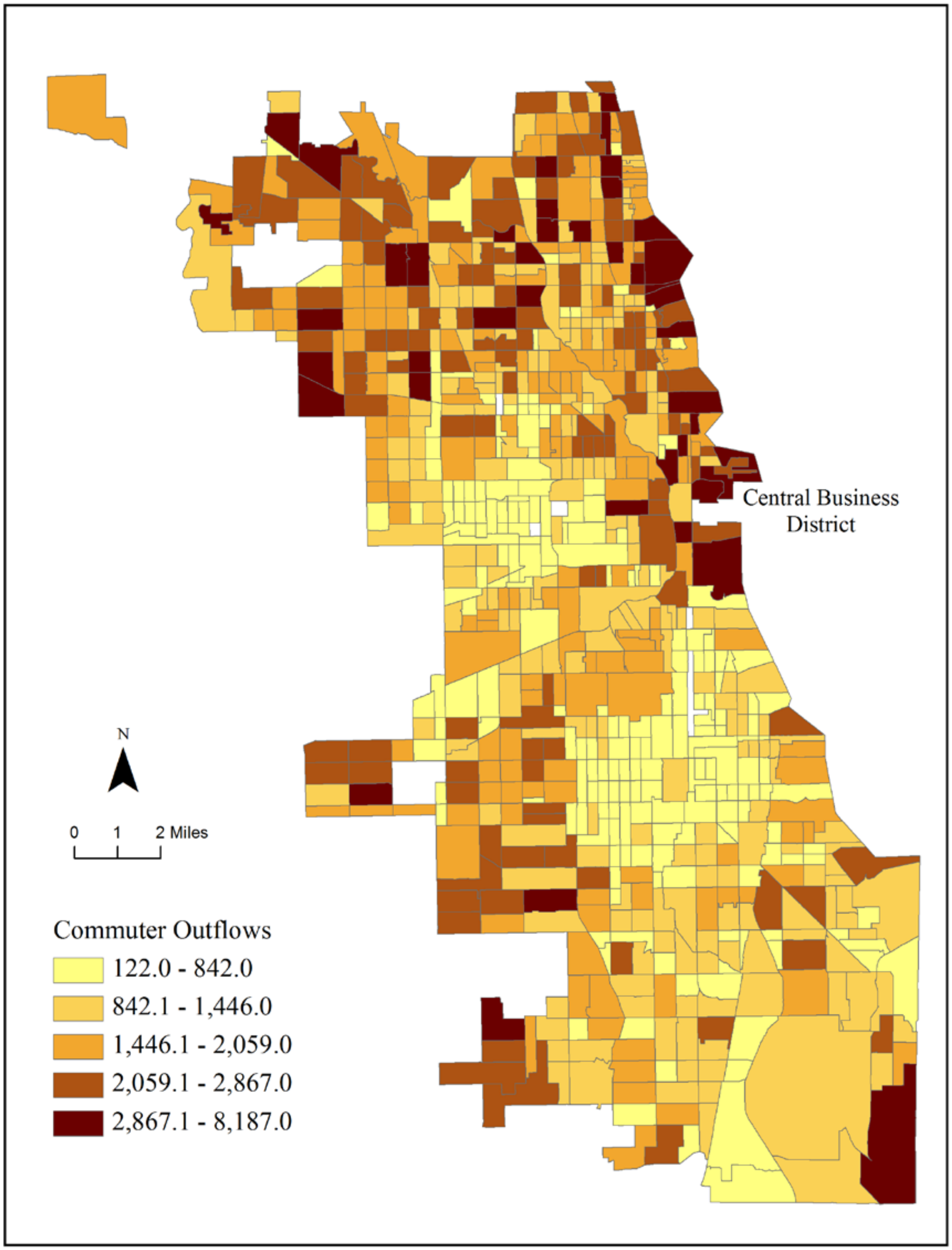

Figure 5
Commuter outflows in Chicago census tracts (n = 787), 2006-2010 average

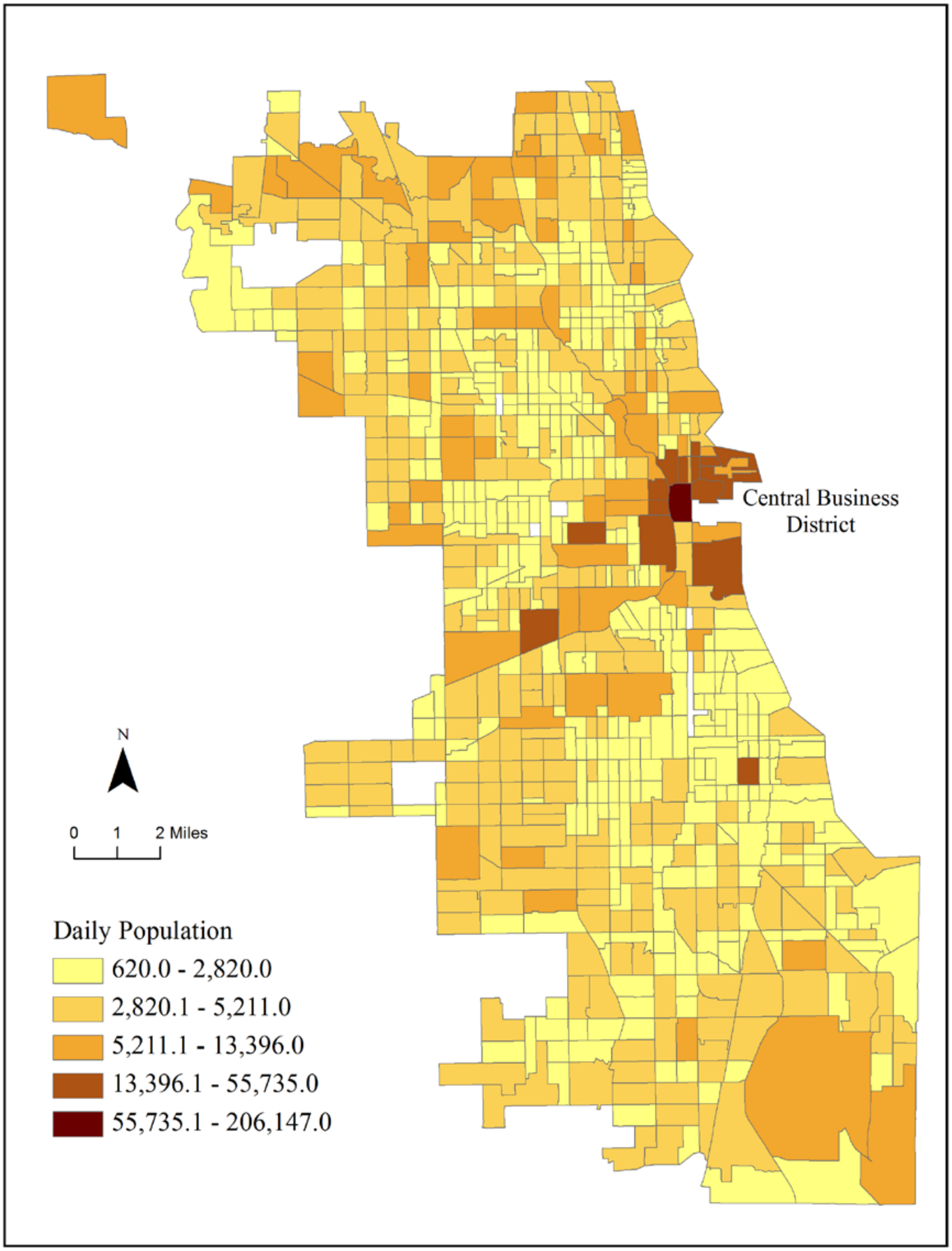

Figure 6
Daily population in Chicago census tracts (n = 787), 2006-2010 average

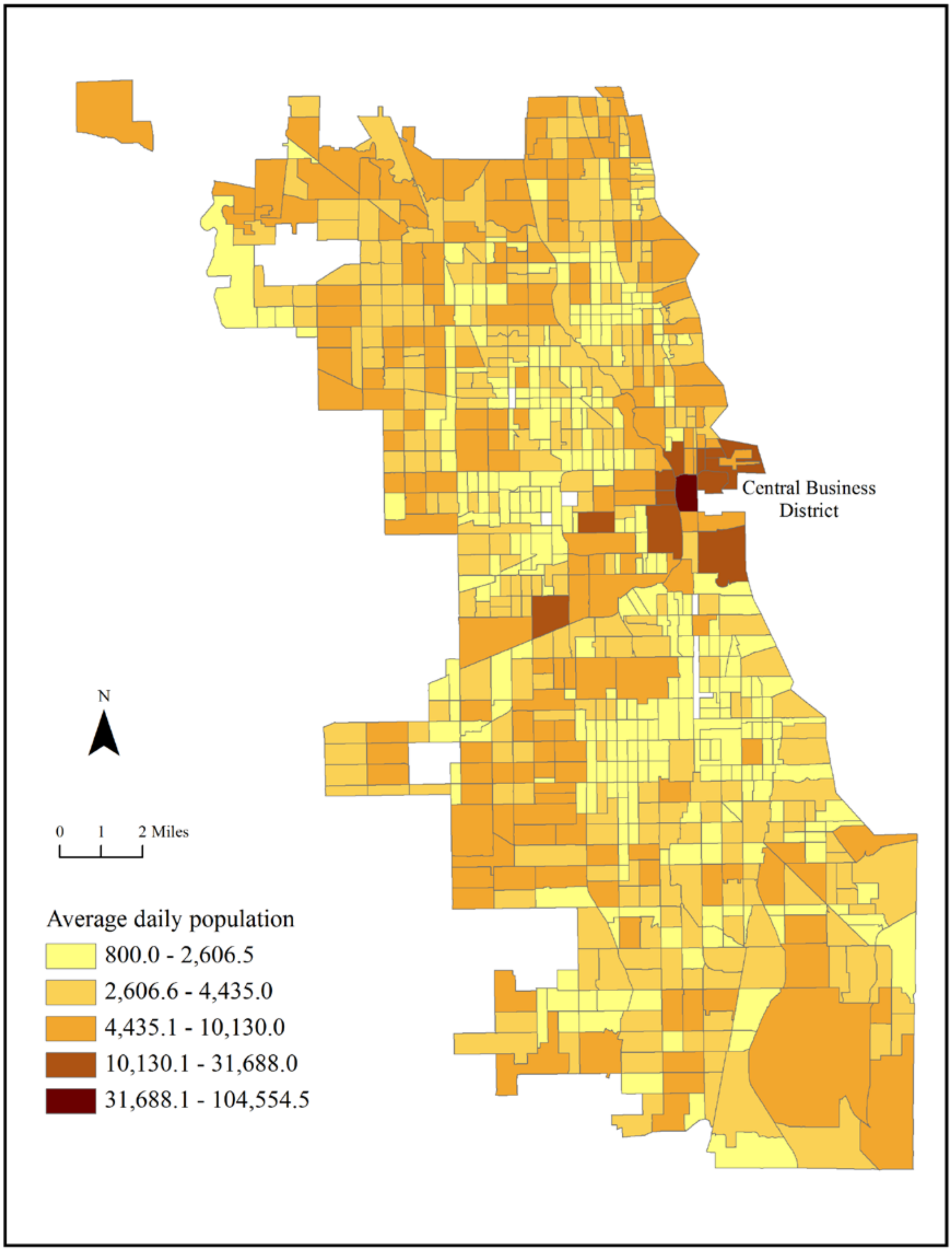

Figure 7
Average daily population in Chicago census tracts (n = 787), 2006-2010 average

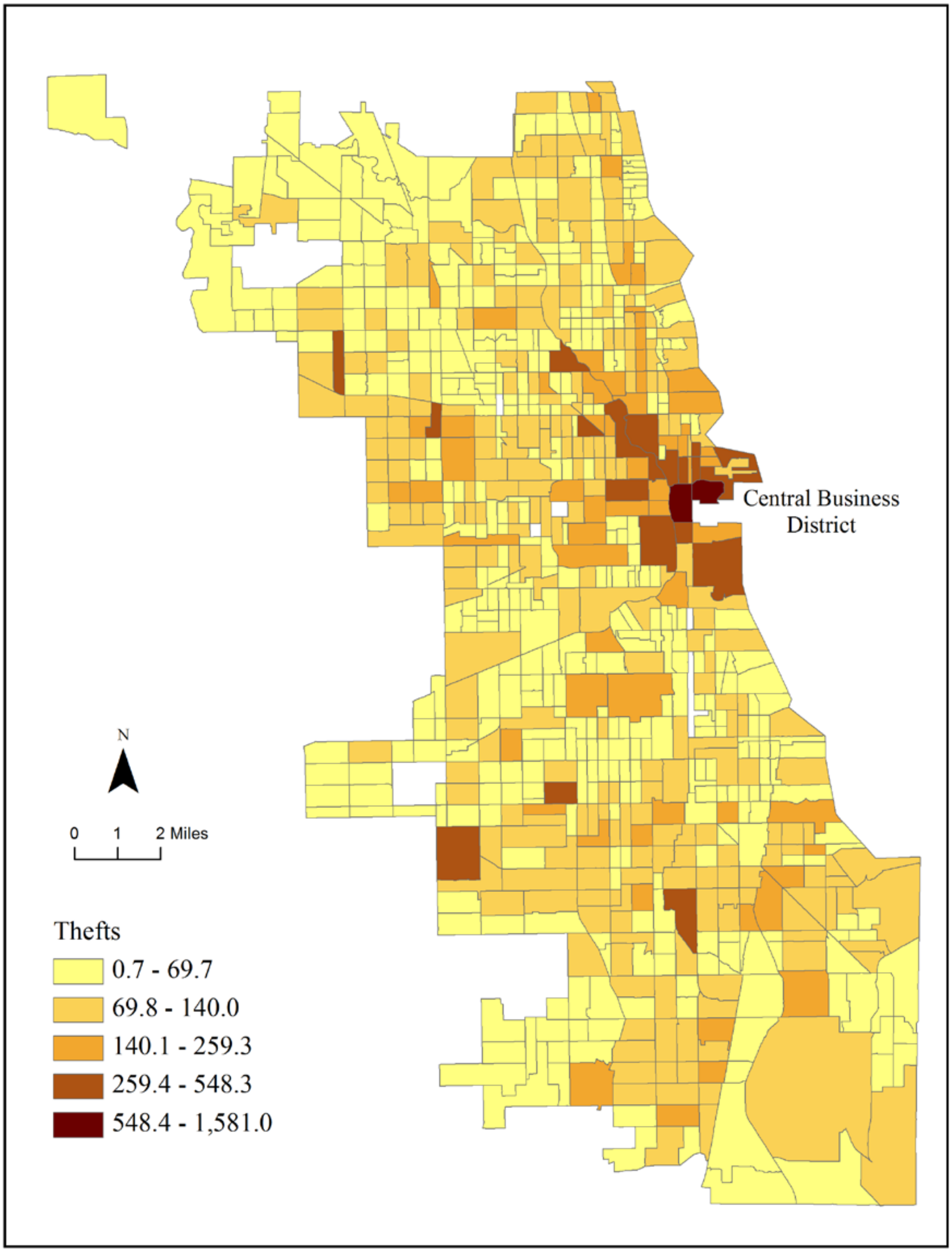

Figure 8
Theft counts in Chicago census tracts (n = 787), 2008-2010 average

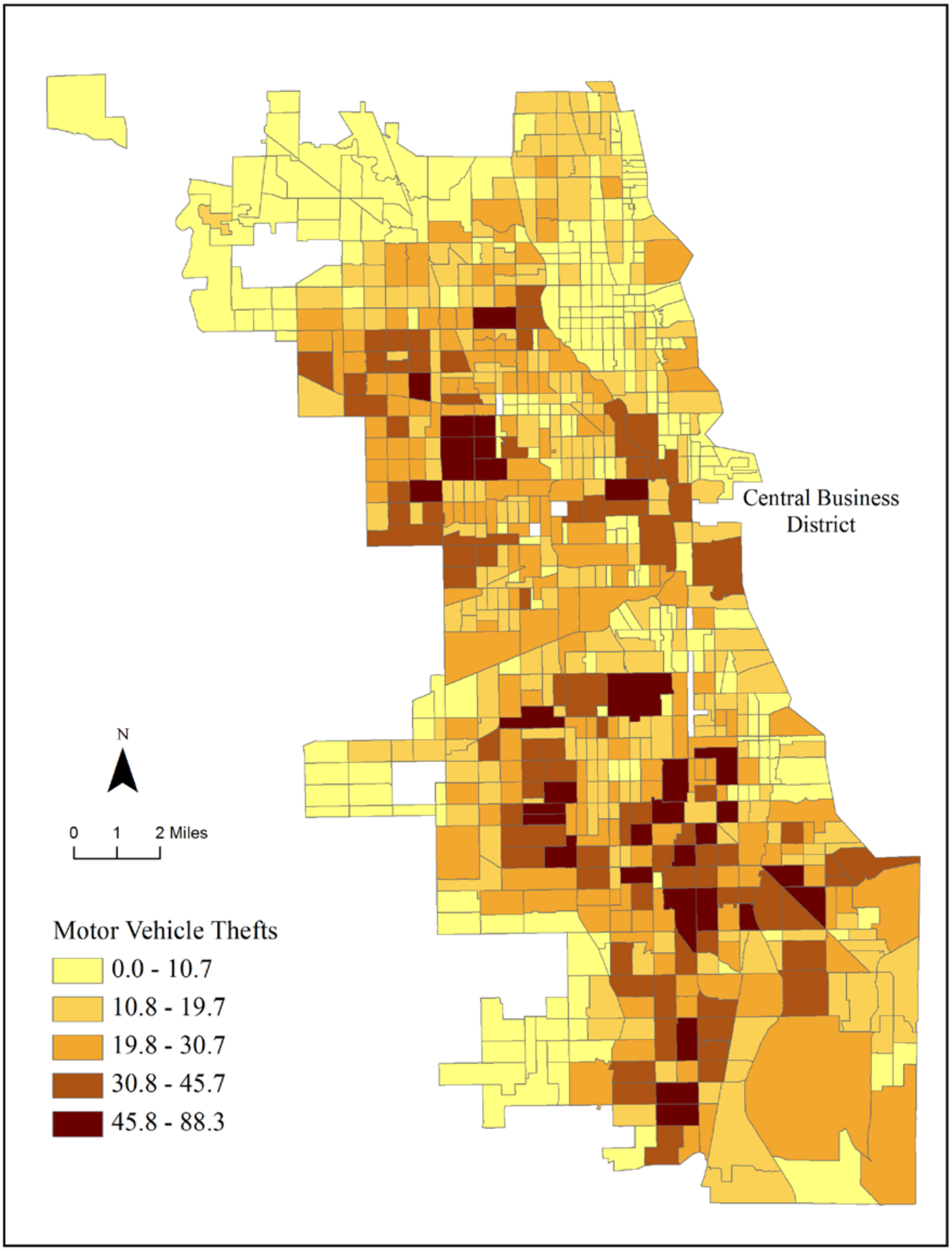

Figure 9
Motor vehicle theft counts in Chicago census tracts (n = 787), 2008-2010 average

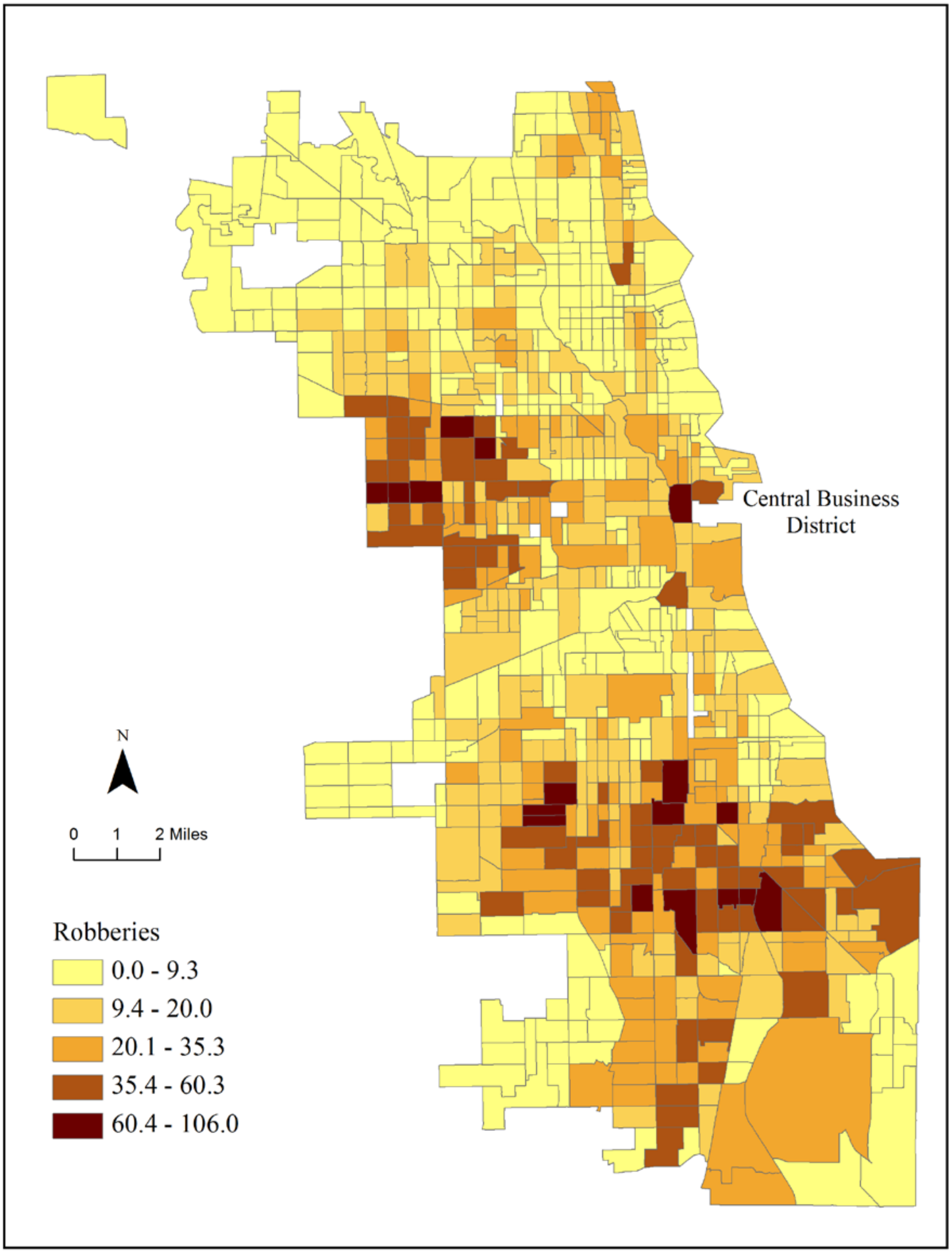

Figure 10
Robbery counts in Chicago census tracts (n = 787), 2008-2010 average

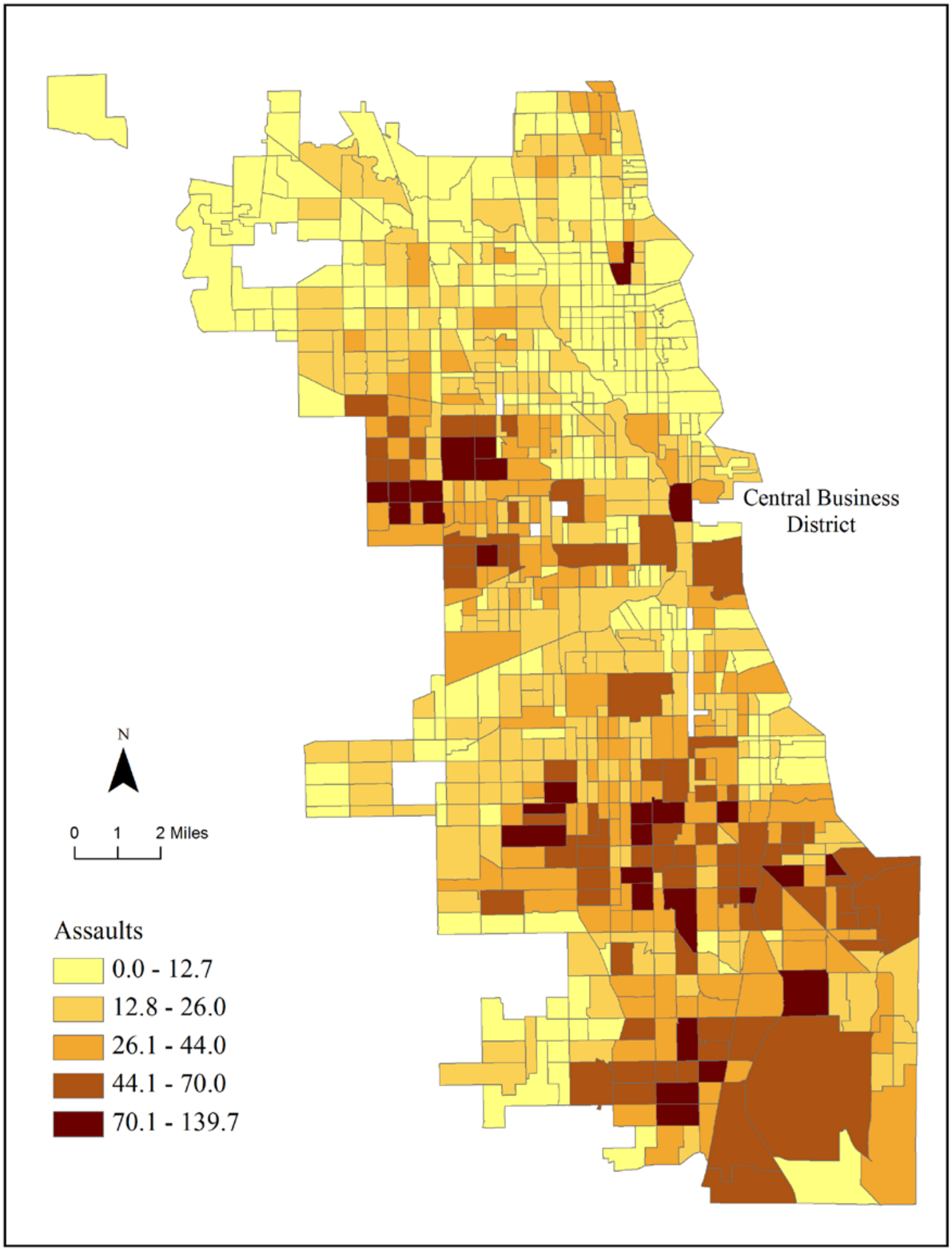

Figure 11
Assault counts in Chicago census tracts (n = 787), 2008-2010 average

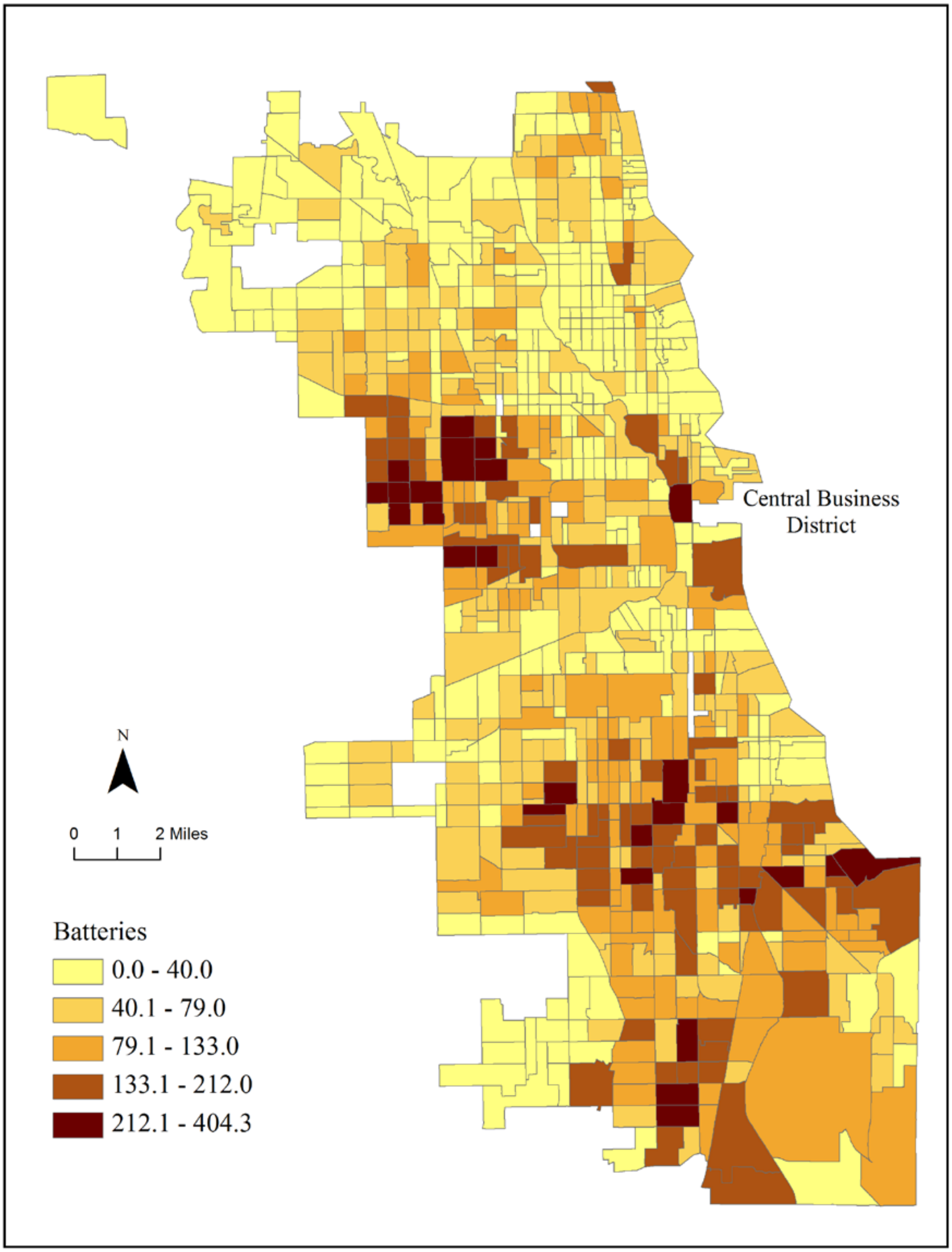

Figure 12
Battery counts in Chicago census tracts (n = 787), 2008-2010 average

Regarding the crime count maps, it is clear that thefts (Figure 8) are also highly concentrated exclusively in the central business district. By contrast, the other crimes all share a different general pattern of concentration. Specifically, motor vehicle thefts (Figure 9), robberies (Figure 10), assaults (Figure 11), and batteries (Figure 12) are frequent in the southern and western regions, in addition to the central business district. From this basic visualization, it is clear that the spatial distribution of all of the studied phenomena are highly patterned.

Data Analysis Plan

To address the research questions posed above, a series of descriptive analyses of crime rates are performed using ArcGIS and Stata software programs.

Spatial shifts in crime risk. A first step in assessing the impact of alternative denominators on crime risk is to examine maps created using alternative measures of risk. Each choropleth map presented uses Jenk's (1967) natural breaks classification method to maximize differences between the mean values of each group. Four maps are created for each crime type, resulting in 20 total maps. The maps of each crime type are compared among each other to ascertain differences in the general spatial patterning of crime risk that depends on denominators employed.

Spatial clusters in crime risk. In addition to examining patterns of crime risk considering single census tracts at a time, risk can also be conceptualized as a cluster. A common way to assess spatial clustering in areal units is the Getis-Ord Gi* statistic (Getis & Ord, 1992), which identifies hot and cold spot areas of a particular variable. For each area, the local sum is calculated by adding values of the focal area and its neighbors. This local sum is compared proportionally to the summed value of all areas. This proportion represents the difference between the local area and all areas; these differences are then converted to Z-scores. A higher Z-score indicates that the local area is part of a spatial clustering of high values; negative Z-scores indicate that the local area is part of a clustering of low values. The "null" hypothesis states that the focal census tract is not part of a high or low clustering of values. In other words, the null hypothesis states that the characteristic of interest is not clustered in that area (i.e., random). Each Z-score is compared with the Normal distribution to identify areas that have substantially high (greater than 1.96 standard deviations) or substantially low (less than -1.96 standard deviations) clusters.

It is expected that using alternative denominators yields different crime rate clusters, suggesting that census tract crime rates are influenced by the denominator used. For example, crime rate hot spots are expected to exist in the central business district when the traditional residential population is used as the crime rate denominator. However, these crime rate hot spots are hypothesized to disappear when alternative denominators are used, suggesting that the residential population-based crime rate inflates estimates in these areas.[12] Addressing this research question involves visually inspecting a series of maps showing hot and cold spots of each crime rate deflated by each of the alternative denominators.

Crime risk percentile shifts. To address the third research question, crime rates are first calculated in census tracts for each crime type using the four denominators discussed above. For each resulting crime rate, percentiles are calculated to indicate the relative risk ranking of each tract. Percentiles represent the percentage of tracts that have

[12] This hypothesis is supported by Boggs (1965) who suggested that crime rates are inflated in the central business district.

values at or below the value of the target tract. For example, a census tract at the 90th percentile can be said to have an equal or greater crime rate than 90 percent of all other tracts in the city. In this way, percentiles can be used as a method for standardized comparison among tracts.

The third research question regards differences between percentile rankings calculated for residential population-based crimes and percentile rankings calculated for alternative denominator-based crime rates. The absolute percentile difference is calculated between pairs of crime rates for each census tract, and that difference represents how much the alternative denominator has an effect on its crime risk percentile ranking. The average difference is reported for each crime type to summarize the percentile differences.

The fourth research question pertains to the spatial location of these percentile differences. Choropleth maps are used to illustrate where the alternative denominator increases or decreases the risk percentile ranking of tracts. It is expected that the daily population and average daily population denominators will reduce risk percentile rankings of census tracts located in or near the central business district.

Crime rate correlations. A correlation matrix is presented below to measure the degree to which alternative denominator-based crime rates and residential population-based crime rates are correlated (fourth research question). The Spearman's Rho correlation coefficient is used here as a nonparametric measure of association because of the positively skewed crime rate distributions. It is expected that correlations between pairs of crime rates will be low or moderate to demonstrate distinct measures of crime risk.

Crime count correlations with alternative denominators. The final research question is addressed by calculating Spearman's Rho rank-order correlations among crime counts and alternative denominators. The crime rate correlations discussed above provide a measure of association among the various crime rates, but does not suggest which crime rate is, per say, better than another. If one is willing to assume that the population at risk should correlate with the crime count, the final correlation matrix can be useful for identifying the most appropriate denominator for each crime type.

V: RESULTS

Varying Spatial Patterns in Crime Risk

The first series of choropleth maps (Figures 13 through 17) illustrate the spatial patterning of crime rates across Chicago census tracts. Lighter values represent fewer crimes per denominator, while darker values represent a greater number of crimes per denominator. Each page contains maps of one crime type, but crime counts are deflated by various denominators to show differences. These smaller-sized maps allow for a more general assessment of patterning, rather than a close examination.

Figure 13 displays substantial spatial shifts in theft risk measurement across Chicago. In the top-left map showing thefts per 10,000 residents and the bottom-right map showing thefts per square mile, theft risk is highest in or near the central business district. The two remaining maps (top-right and bottom-left) show theft risk as much more dispersed across the city, illustrating high risk census tracts in the south and central northern regions of the city.

The motor vehicle theft rate maps shown in Figure 14 show fewer discrepancies than what is seen for theft, but subtle differences can be found. Most noticeable are reductions in risk seen in the northeastern region of the city and in the central business district for motor vehicle thefts per 10,000 daily population (top-right) and 10,000 average daily population (bottom-left), as compared to the map showing motor vehicle thefts per 10,000 residents (top-left).

The maps in Figure 15 showing robbery rates are somewhat comparable to each other. In all maps, the high robbery risk census tracts can be found in the southern and western regions of the city, with low risk census tracts in the north. However, slightly

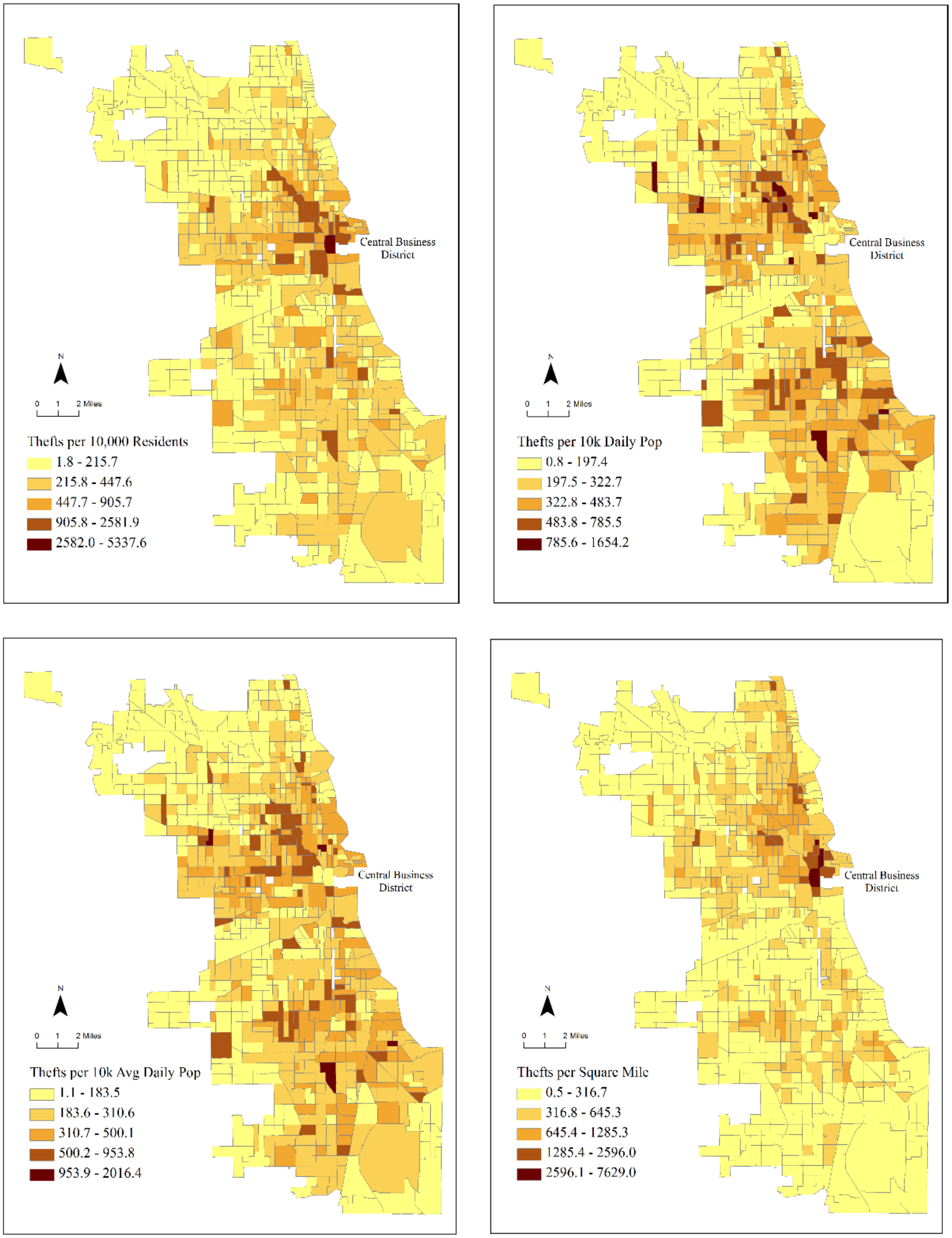

Figure 13
Theft rates calculated using alternative denominators in Chicago census tracts (n = 787), 2008-2010 averages

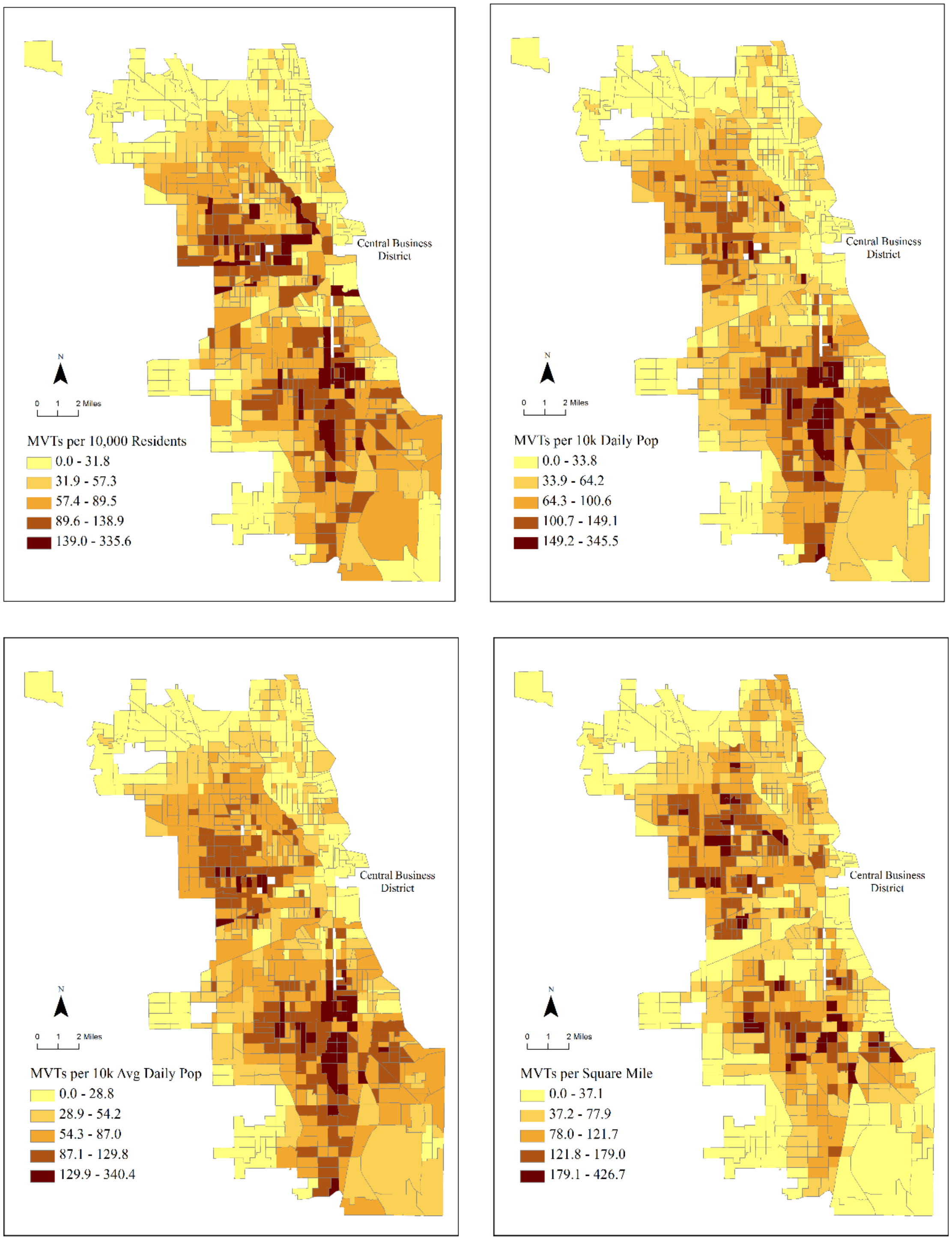

Figure 14
Motor vehicle theft rates calculated using alternative denominators in Chicago census tracts (n = 787), 2008-2010 averages

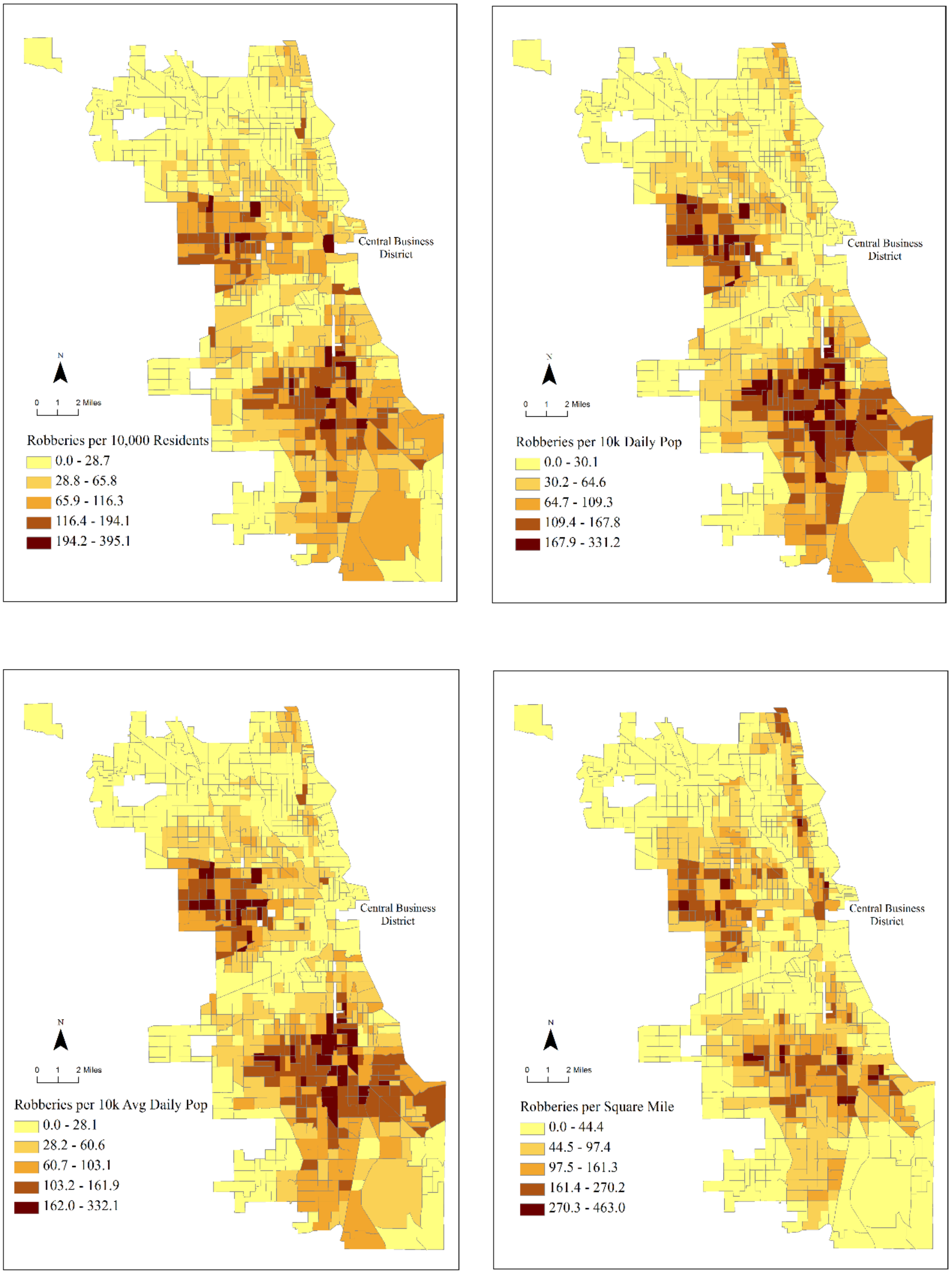

Figure 15
Robbery rates calculated using alternative denominators in Chicago census tracts (n = 787), 2008-2010 averages

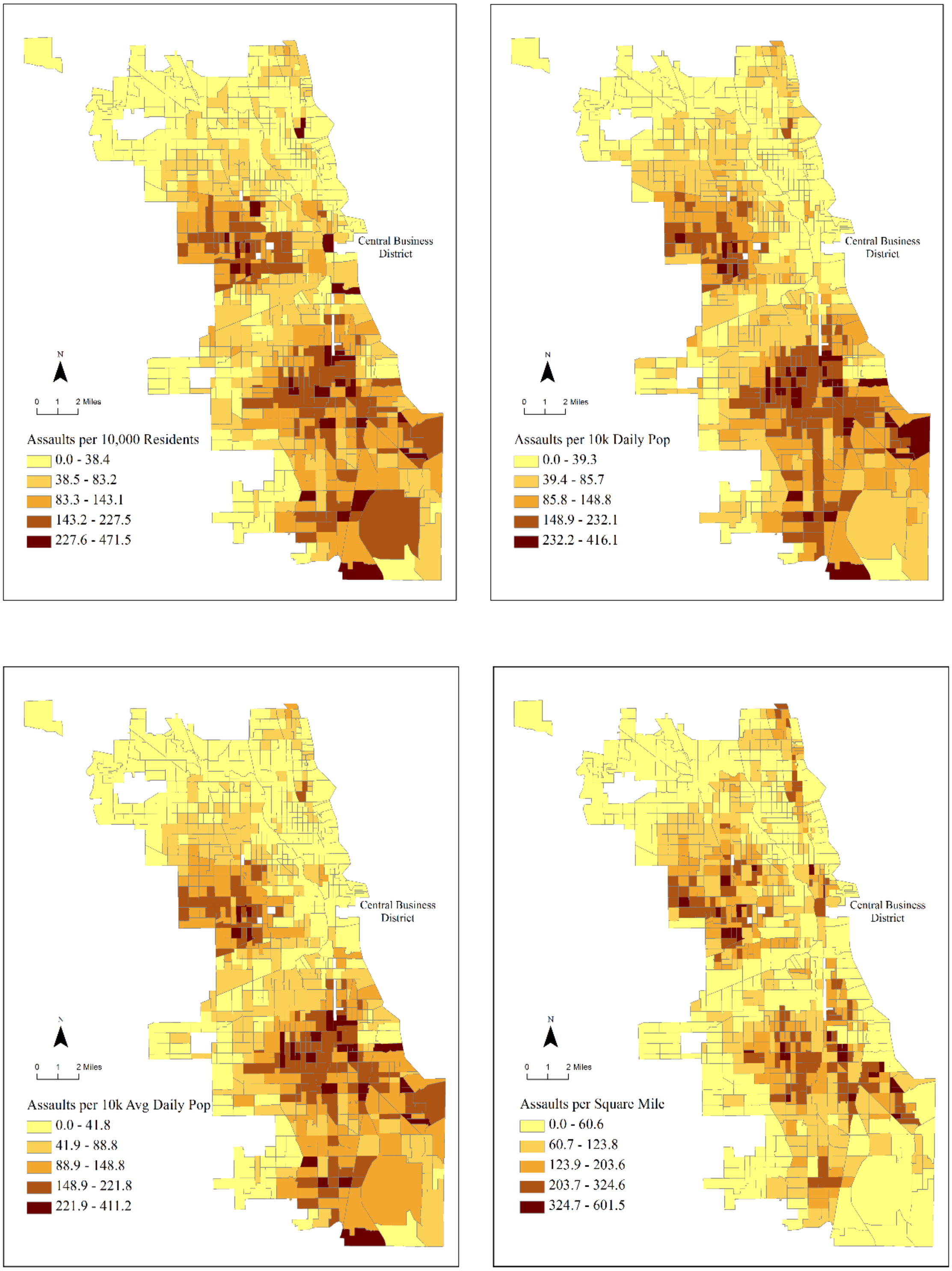

Figure 16
Assault rates calculated using alternative denominators in Chicago census tracts (n = 787), 2008-2010 averages

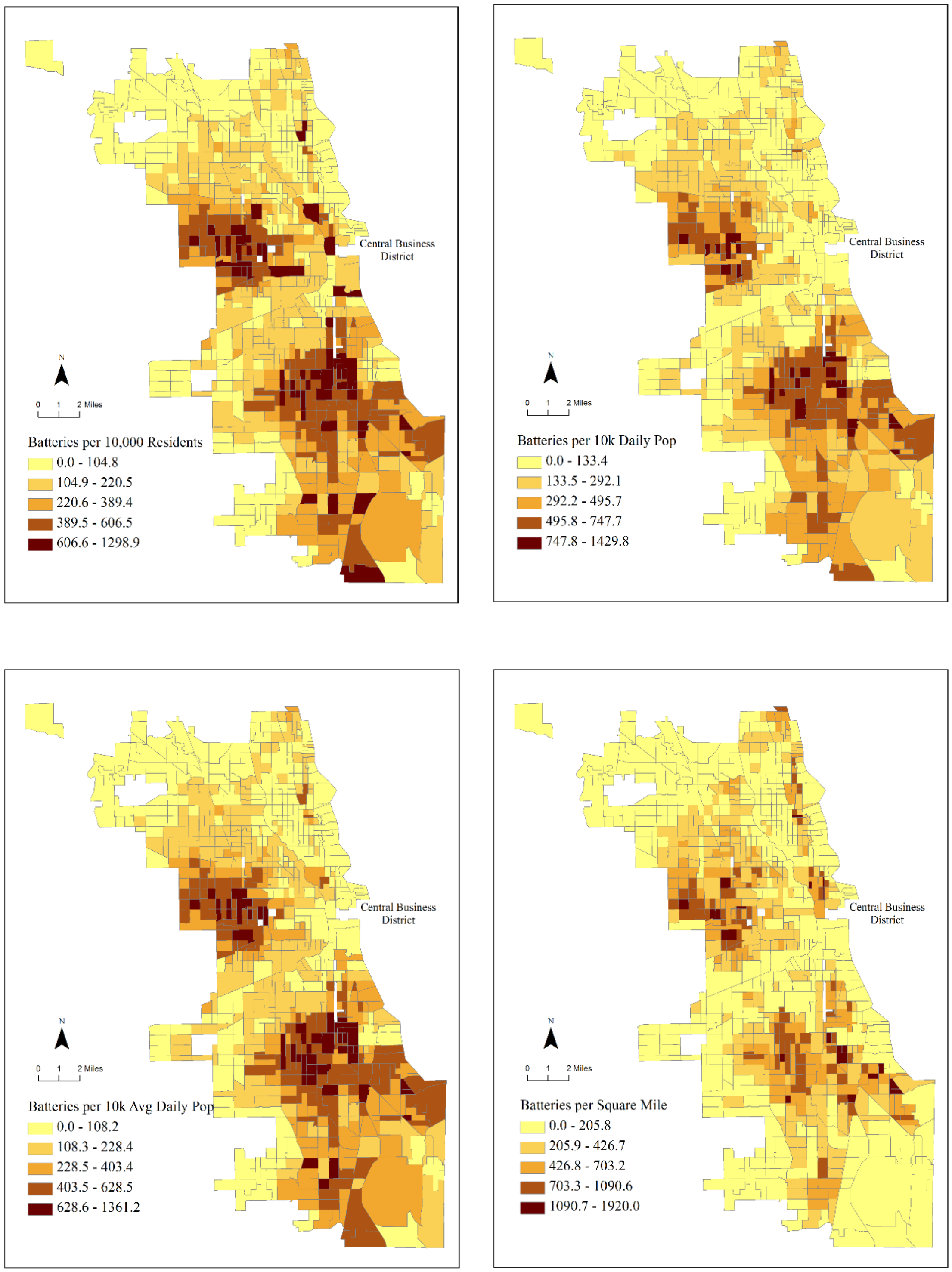

Figure 17
Battery rates calculated using alternative denominators in Chicago census tracts (n = 787), 2008-2010 averages

different patterns appear depending on which denominator is used. For example, the central business district is shown to have higher risk for robberies per 10,000 residents (top-left) and robberies per square mile (bottom-right). In all cases, an interesting linear pattern of risk is radiating from the central business district extending northward, but risk along this corridor is relatively higher in the robberies per square mile map (bottom-right).

The assault maps in Figure 16 show the most comparable spatial distribution of crime rates of all crime types. The general pattern of assault risk persists across all four maps, with the exception of a few discrepant census tracts in or near the central business district. Finally, Figure 17 displays the maps for battery rates, which tend to show similar patterns as well. Similar to the assault maps, a few census tracts in or near the central business district have relative risk patterns that appear to shift. Interestingly, the map showing batteries per square mile (bottom-right) has an unusually large number of census tracts with relatively low battery risk across the city, suggesting that this measure of battery risk may have a distribution that is more positively skewed than others.

Crime Risk Clusters

Another series of maps was created to display crime rate clusters, represented as hot and cold spots (Getis-Ord Gi* statistic) in Chicago census tracts. A map was created and examined for each crime type (i.e., theft, motor vehicle theft, robbery, battery, assault) and each rate (i.e., crimes per residents, crimes per daily population, crimes per average daily population, crimes per square mile). The most distinct differences exist between the maps showing crimes per residents and crimes per daily population. Only these maps are shown below in Figures 18 through 22.

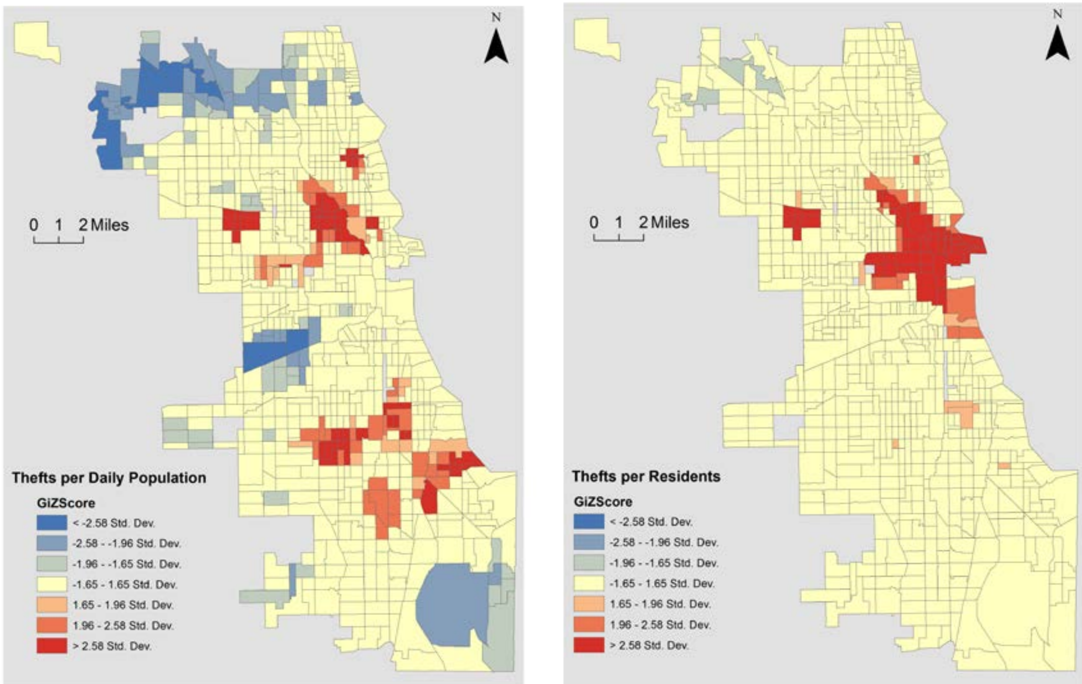

Figure 18
Comparing hot spots and cold spots of theft rates in Chicago census tracts (n = 787), 2008-2010

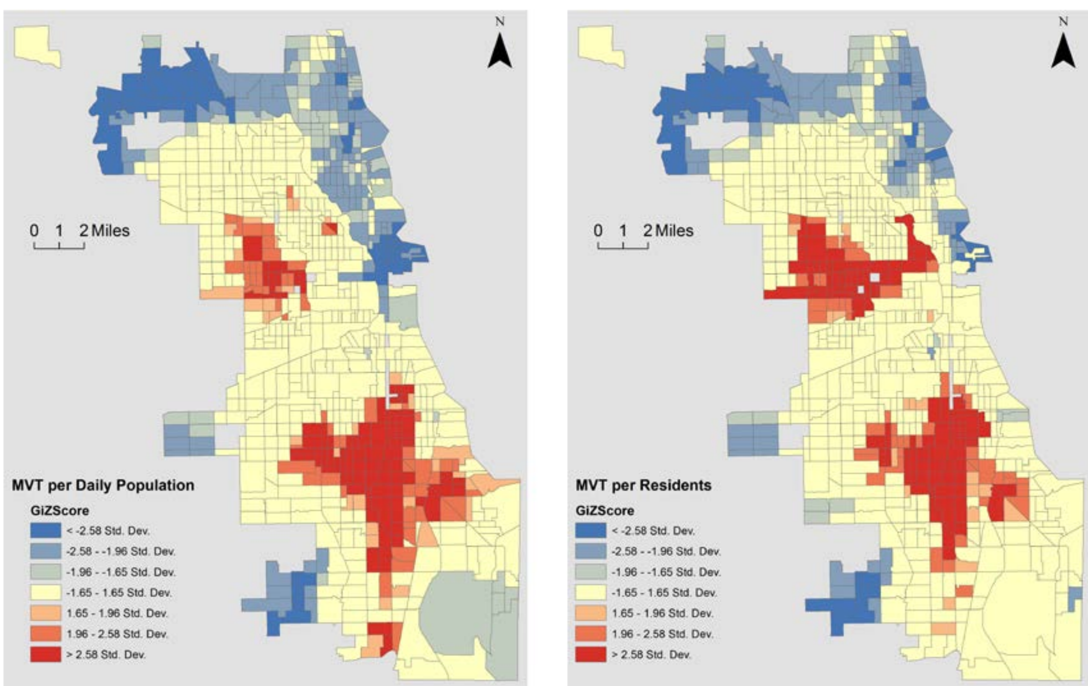

Figure 19
Comparing hot spots and cold spots of motor vehicle theft rates in Chicago census tracts (n = 787), 2008-2010

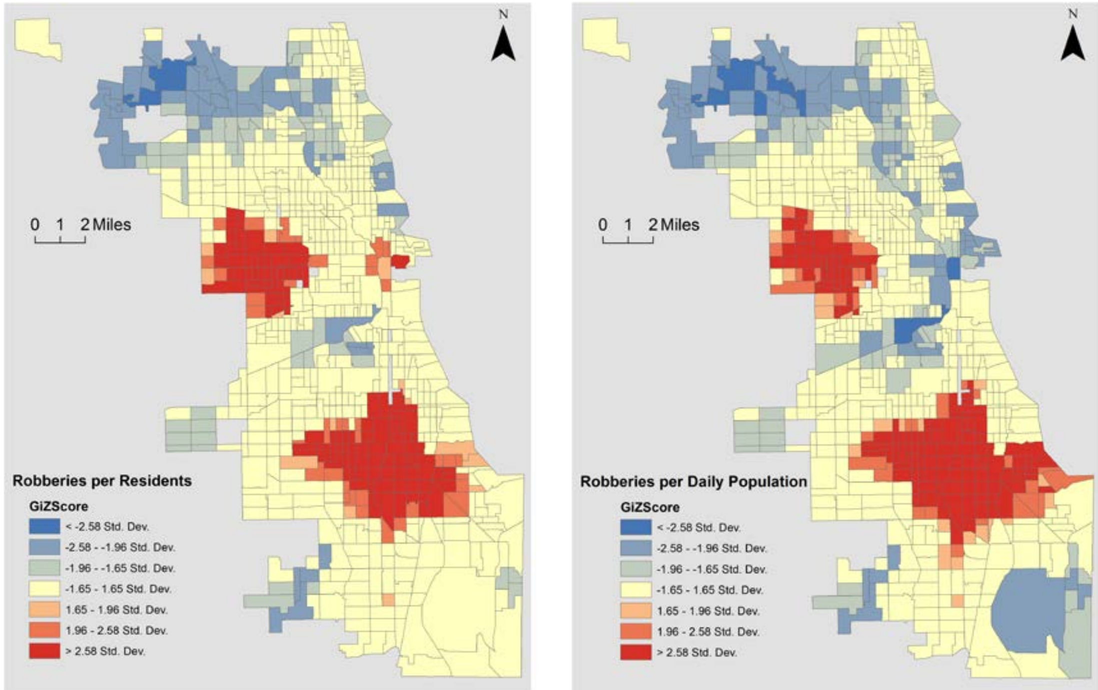

Figure 20
Comparing hot spots and cold spots of robbery rates in Chicago census tracts (n = 787), 2008-2010

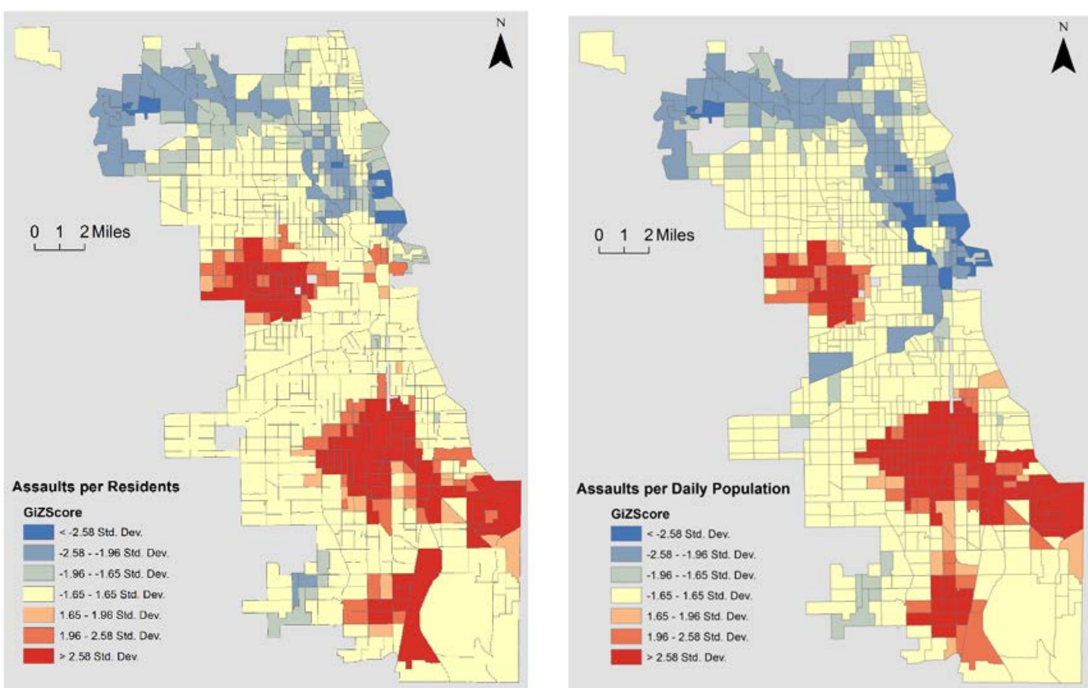

Figure 21
Comparing hot spots and cold spots of assault rates in Chicago census tracts (n = 787), 2008-2010

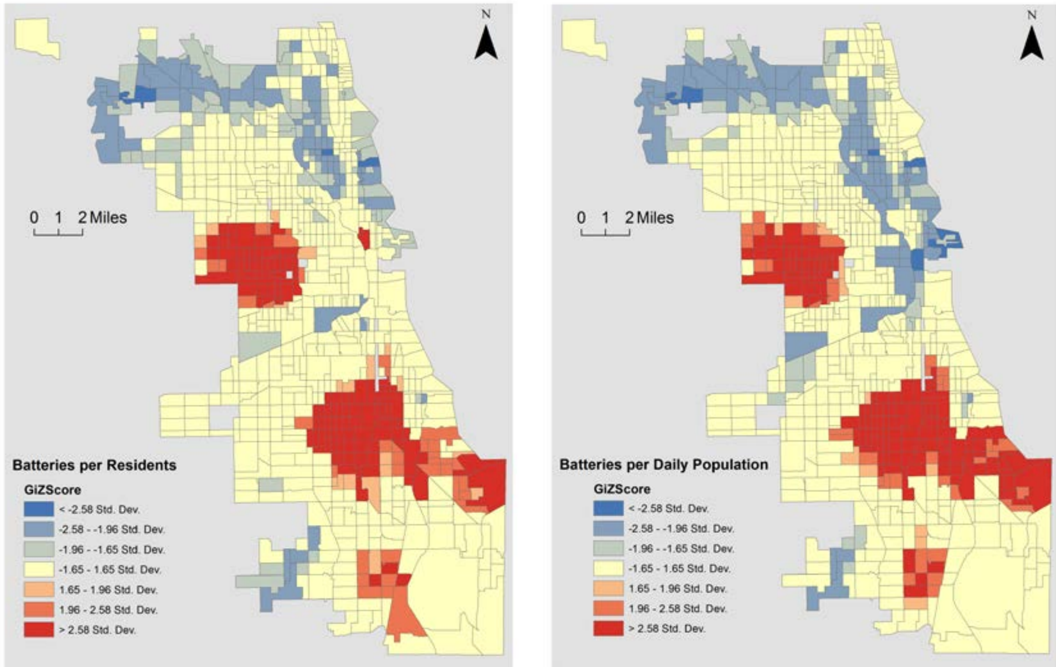

Figure 22
Comparing hot spots and cold spots of battery rates in Chicago census tracts (n = 787), 2008-2010

Recall that the calculated Gi* statistic is converted to a Z-score, representing the number of standard deviations away from the mean value. Displaying the resulting Z-score for each census tract on a choropleth map assists with identifying clusters of crime. In each map, the darkest two red colors represent census tracts where the amount of crime in the focal and neighboring tracts is equal to or greater than 1.96 standard deviations above the mean value (hot spot). The two darkest blue colors represent census tracts where the amount of crime in the focal and neighboring tracts is equal to or less than 1.96 standard deviations below the mean value (termed cold spot). The three middle range colors portray census tracts that do not have values greater than 1.96 standard deviations from the mean, termed here as "null spots."

Figure 18 compares theft hot spots calculated using different denominators. The left map shows thefts per residents, while the map on the right shows thefts per daily population. A stark contrast in the pattern of hot spots and cold spots can be seen across Chicago census tracts. Several census tracts in the central business district reduce from hot spots to "null spots." Additionally, several census tracts in the northern-most part of the city change to cold spots when the daily population denominator replaces the residential population. Cold spots appear in the western-central region of the city, and hot spots appear in southern region when using the daily population denominator. These differences are important because they suggest that using a different denominator (e.g., the daily population) to calculate the theft rate results in a very different description of how theft concentrates. Whereas the residential population-based theft rate shows hot spots in the central business district, the daily population-based theft rate shows hot spots in both the central business district and in the south, and cold spots in the western and northern regions.

The maps showing motor vehicle thefts (Figure 19) have fewer differences than what is seen in the theft maps. However, several hot spot areas disappear in census tracts in the middle of the city when using the daily population rate denominator. The maps for robbery (Figure 20), assault (Figure 21), and battery (Figure 22) also show similar general patterns between the compared maps, but a pocket of census tracts in the central business district appears as hot spots of crimes per residents, but reduces to cold spots of crimes per daily population in all cases.

Percentile Differences in Crime Rates

Table 4 displays the average and maximum percentile difference between alternative denominator-based crime rates and residential population-based crime rates. Using the daily population to deflate theft rates rather than the residential population results in an average 10.9 difference in percentile rank for census tracts (Panel 1). In other words, on average, census tracts shift 10.9 percentile ranks if the daily population, rather than the residential population, is used as the denominator in the theft rate. The average difference ranged from 6.9 to 10.9 percentile ranks for daily population-based crime rates across all crime types (Panel 1). The average daily population, a more conservative measure, displays average percentile rank differences that range from 4.0 percentiles for robbery, to 5.2 percentiles for theft (Panel 2). The largest shifts in percentile rankings are shown when measuring crimes per square mile, where the largest average difference exceeds 20 percentiles for theft (Panel 3).

Table 4

Average and maximum difference in census tract percentile rankings between alternative denominator-based crime rate and the residential population-based crime rate in Chicago census tracts (n = 787), 2008-2010 averages

Compared to residential population:	**Panel 1. Crimes per Daily Population**		**Panel 2. Crimes per Avg. Daily Population**		**Panel 3. Crimes per Square Mile**	
	Percentile difference		Percentile difference		Percentile difference	
	Average	**Max**	**Average**	**Max**	**Average**	**Max**
Theft	10.9	97.3	5.2	76.6	20.1	97.7
MVT	9.1	93.4	5.1	89.7	19.9	97.6
Robbery	6.9	94.7	4.0	87.8	13.6	69.6
Assault	7.5	97.3	4.4	92.1	15.5	96.2
Battery	7.6	97.7	4.3	96.6	15.0	95.6

ABBREVIATIONS: CT = census tract; Max = maximum difference; MVT = motor vehicle theft.

In most cases across all crime types and denominator comparisons, the maximum percentile difference exceeded 85 percentiles. This suggests that at least one census tract changes its percentile ranking by more than 85 percent if the alternative denominator is used in place of the residential population to calculate crime rates. Generally speaking, theft and motor vehicle theft rates were most impacted by alternative denominators, while the violent crimes examined here show the smallest percentile differences.

In addition to the absolute differences presented above in Table 4, the raw differences in percentile rankings are also calculated. These raw differences (both positive and negative) are mapped to examine *where* alternative denominators appear to increase or decrease the crime risk percentile ranking of census tracts. Figures 23 through 27 show the percentile differences between crimes per residents and crimes per daily population rates. To avoid redundancy, maps comparing the residential population denominator with the average daily population denominator are not shown because they closely resemble the maps for the daily population.

Figure 23 shows how the daily population denominator changes theft rate percentile ranks that were first calculated using the residential population. Many census tracts in the central business district show decreased percentile rankings between 20 and 97 percent. By contrast, several census tracts just north of the central business district show higher crime rate percentile rankings when the daily population denominator replaces the residential population denominator. Both increases and decreases in percentile rankings are scattered across the city; however, the modal condition is a relatively small 20 percentile rank difference.

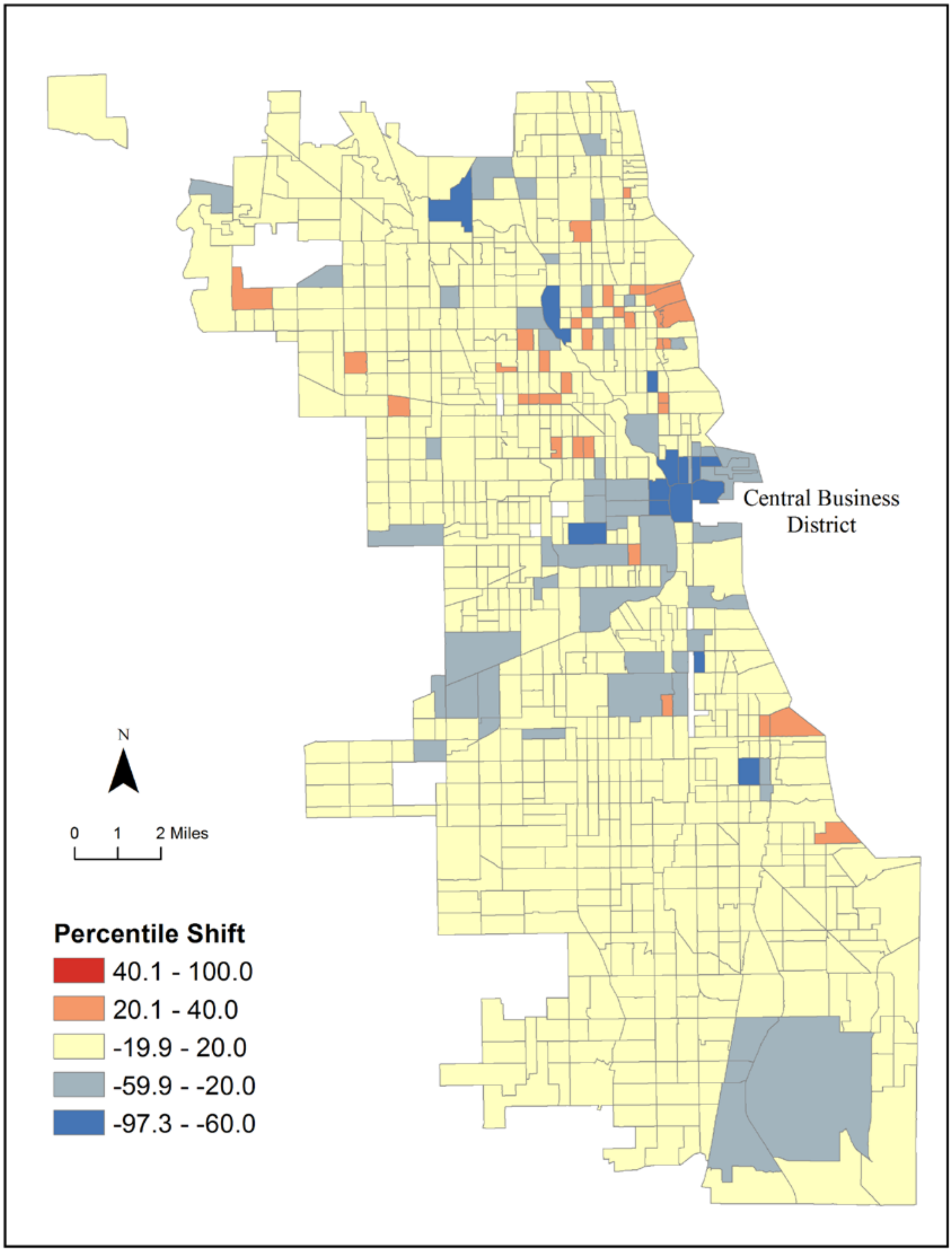

Figure 23
Percentile differences in theft rates when the daily population replaces the residential population as the denominator in Chicago census tracts (n = 787), 2008-2010 averages

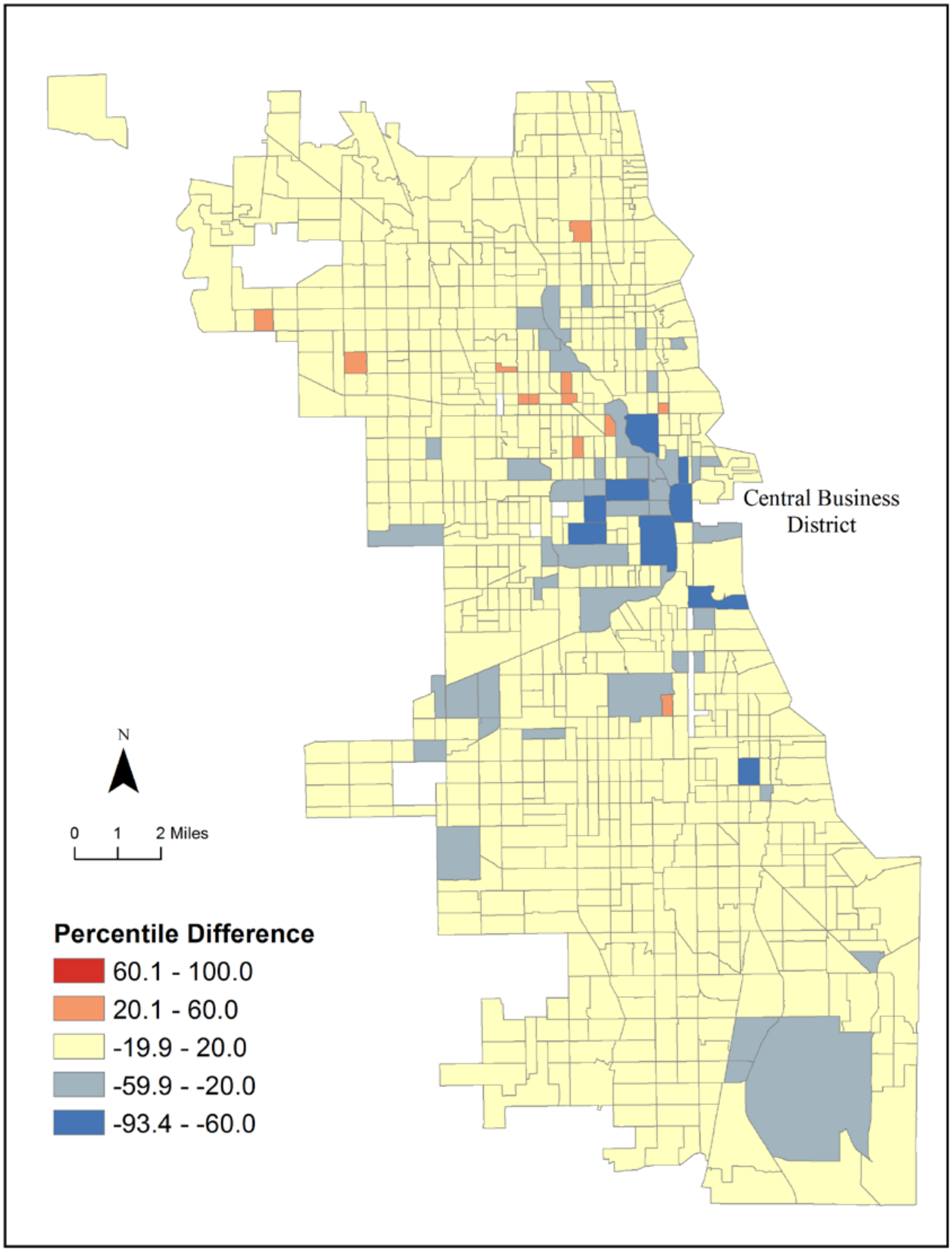

Figure 24
Percentile differences in motor vehicle theft rates when the daily population replaces the residential population as the denominator in Chicago census tracts (n = 787), 2008-2010 averages

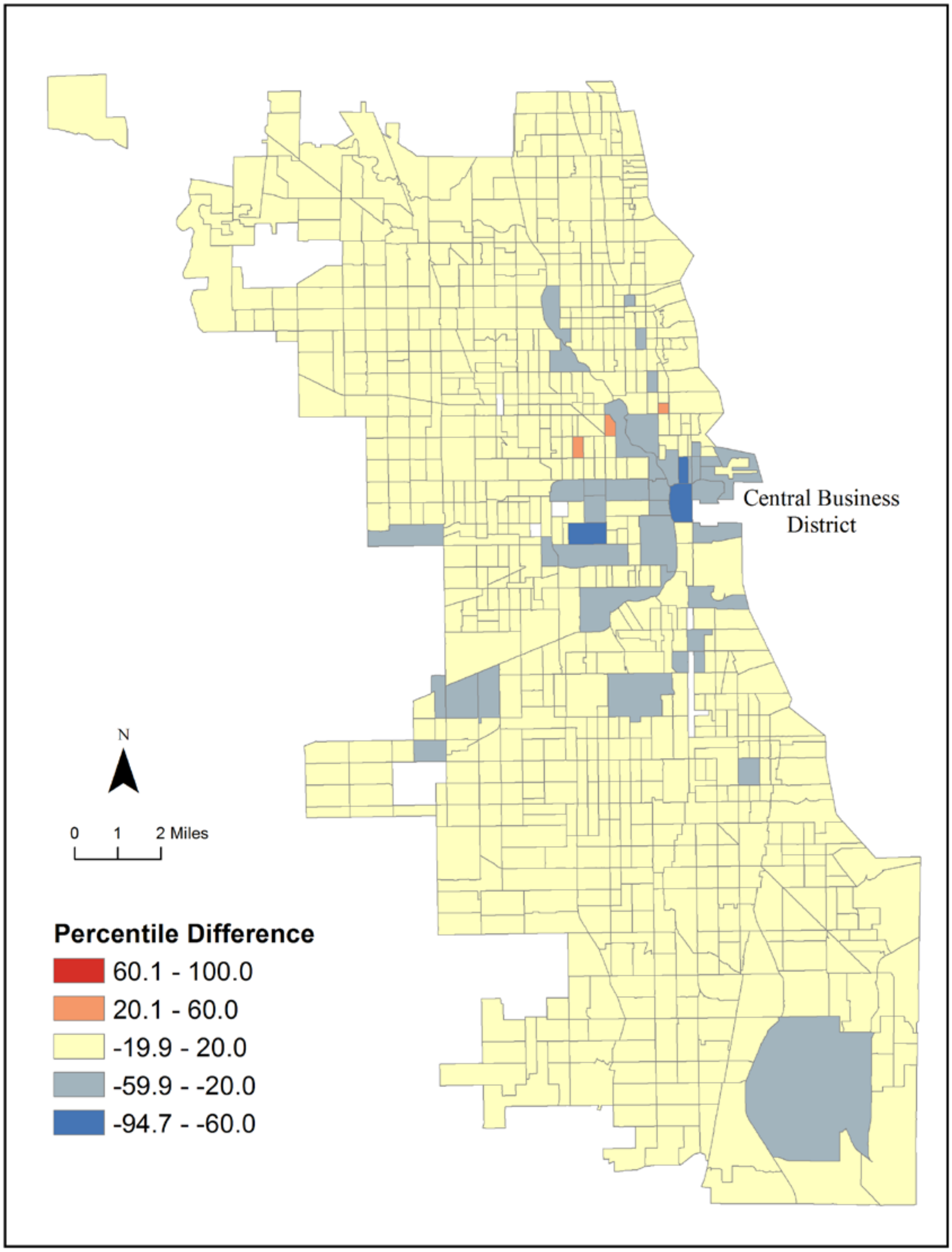

Figure 25
Percentile differences in robbery rates when the daily population replaces the residential population as the denominator in Chicago census tracts (n = 787), 2008-2010 averages

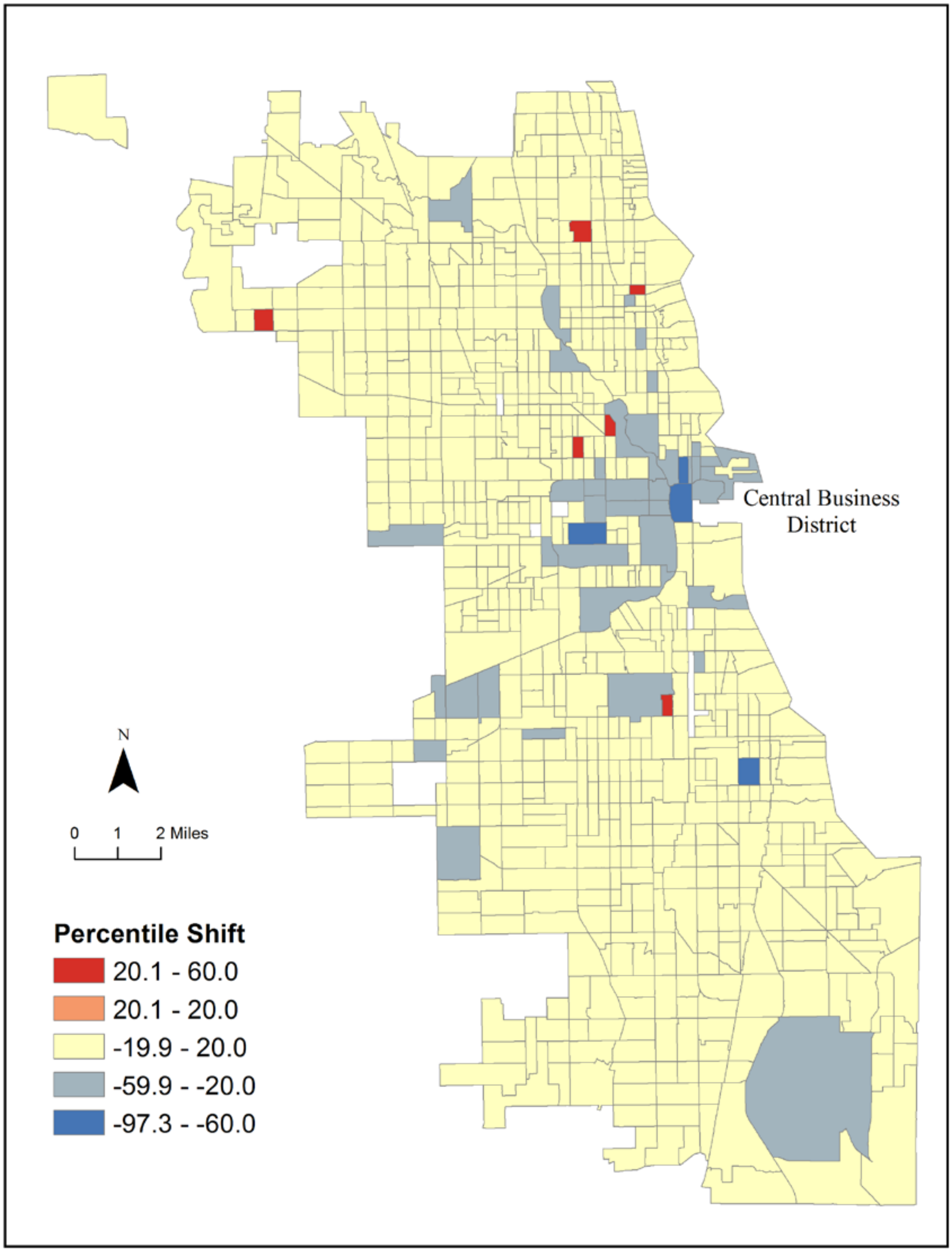

Figure 26
Percentile differences in assault rates when the daily population replaces the residential population as the denominator in Chicago census tracts (n = 787), 2008-2010 averages

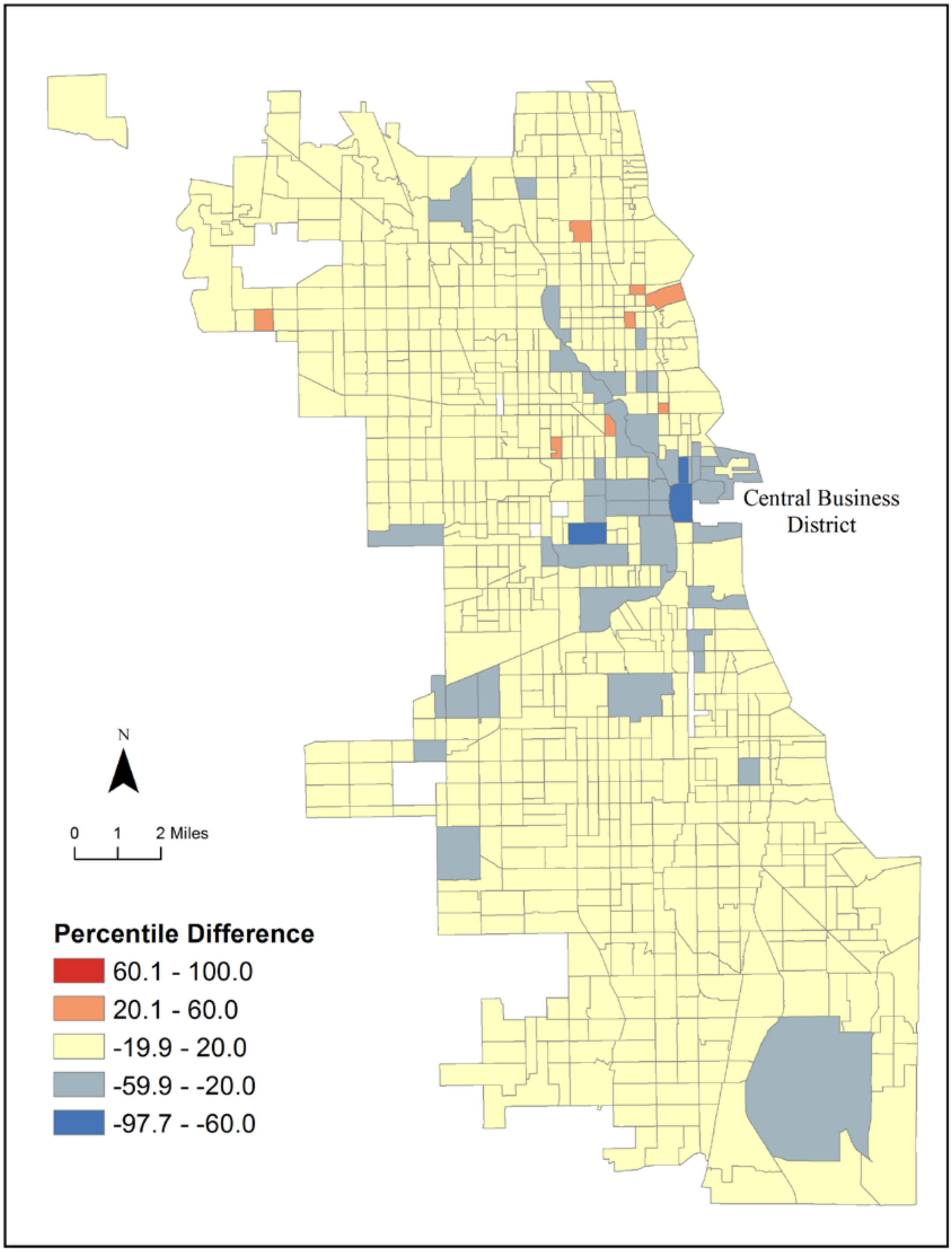

Figure 27
Percentile differences in battery rates when the daily population replaces the residential population as the denominator in Chicago census tracts (n = 787), 2008-2010 averages

A similar, but more concentrated, pattern of percentile changes is seen for motor vehicle theft rates calculated using the daily population denominator as compared to the residential population denominator. Shown in Figure 24, a cluster of decreasing risk percentiles is seen just west of the central business district in Chicago. Compared to theft, fewer census tracts display motor vehicle theft risk percentile increases greater than 20 percent.

The maps for robbery (Figure 25), assault (Figure 26), and battery (Figure 27) each show a similar pattern in percentile changes. The central business district displays decreased risk percentile rankings, while percentile increases are scattered north of the central business district. Notably, the map showing assaults (Figure 26) displays several census tracts where the assault risk increased by greater than 20 risk percentiles when the daily population denominator was used to calculate the crime rate.

Percentile differences between square mile-based crime rates and residential population-based rates were also mapped. However, only the theft map (Figure 28) is presented here, because each crime type displayed a very similar pattern to that seen for thefts. Because square area-based risk is sensitive to the spatial area of census tracts, the patterns correspond closely with the size of tracts. Large census tracts in the southern region of Chicago display decreased percentile rankings, and very small tracts in the north display increased crime risk percentile rankings when using the square mile denominator. Employing the square area of census tract as the denominator appears to create the greatest number of crime rate percentile absolute differences exceeding 20 across the city, as shown by the higher number of census tracts that are not yellow in Figure 28.

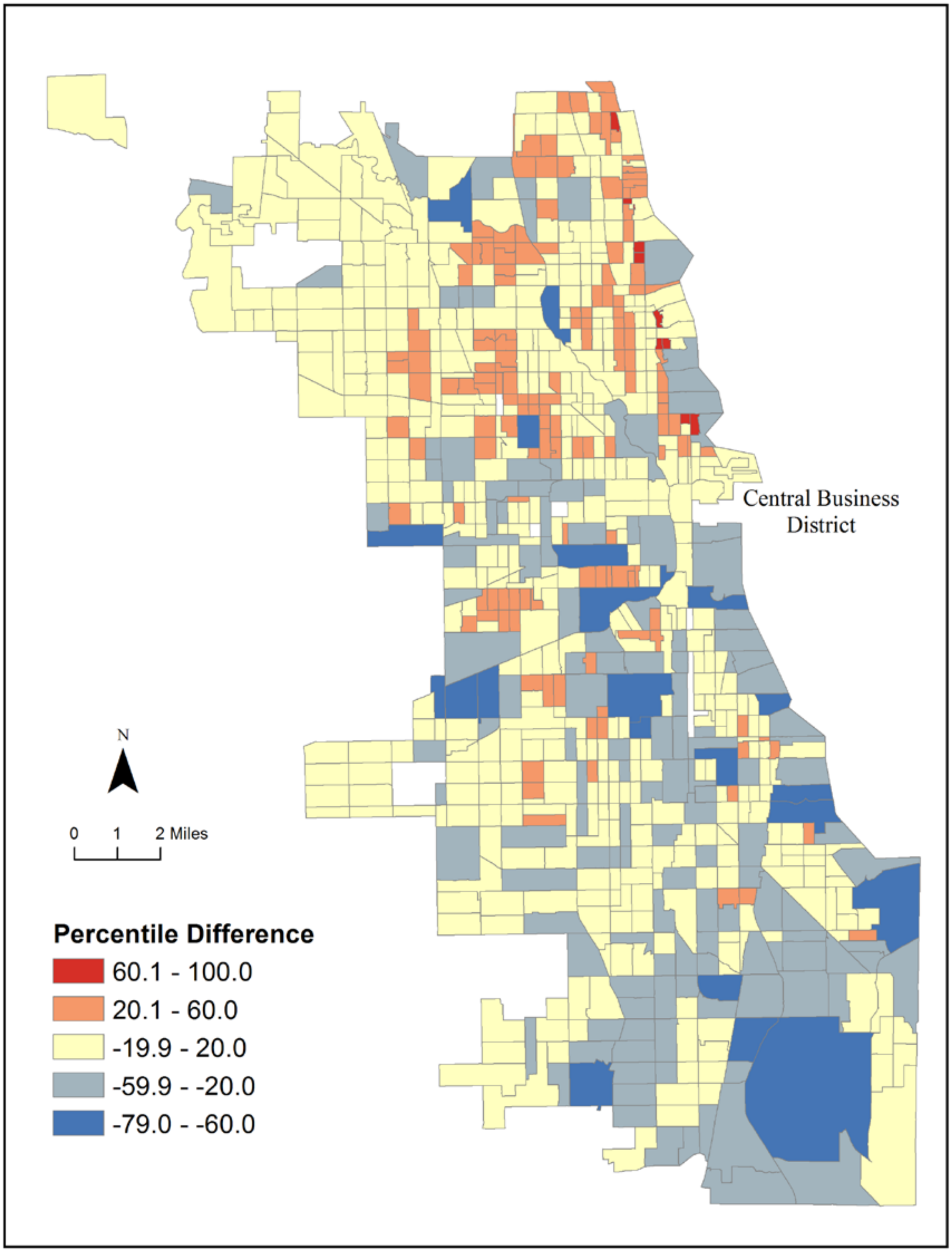

Figure 28
Percentile differences in theft rates when square area replaces the residential population as the denominator in Chicago census tracts (n = 787), 2008-2010 averages

Crime Rate Correlations

Table 5 displays the Spearman's correlation matrix of each crime type. This nonparametric measure of association suggests fairly high correlations among the various denominator-based crime rates. For example, almost 68 percent of the variation in thefts per daily population is shared with thefts per residents. Although anticipated, the highest correlations are seen with the average daily population crime rates. This is likely due to the average daily population being the average of the residential and daily populations. The lowest correlations are seen with the per square mile crime rates. In the case of theft, less than 37 percent of the variation in thefts per square mile is shared with all other measures of theft risk. Among all crime types, theft and motor vehicle theft have the lowest correlations among the various risk measures, while the violent crimes of robbery, assault, and battery have the highest correlations among their various risk measures.

Crime Count Correlations with Alternative Denominators

The final analysis is performed to potentially identify the most suitable population at risk for each crime type in this dataset. The matrix presented in Table 6 shows the Spearman's rank-ordered correlation coefficients measuring association between crime counts and the alternative denominators employed above.

Correlations between theft counts and each denominator range from 0.363 for square miles, to 0.544 for the daily population; said in another way, the percentage of shared variance between theft and the various denominators ranges from 13.1 percent to 29.6 percent (squared coefficients). Correlations with thefts are the highest seen in this dataset, followed by motor vehicle thefts, assault, battery, and robbery. Correlations of crime types other than theft range from 0.183 between robberies and the residential population, to 0.396 between motor vehicle thefts and square miles. In general, property crimes are more closely associated with the denominators considered here, than are the violent crimes. Robbery has the lowest correlations, with less than five percent of shared variance with all denominators.

If one needed to choose the most appropriate denominator for each crime type, the daily population would be preferred due to its higher correlation than other denominators with each crime type in this dataset, other than for motor vehicle theft. The square miles denominator is most closely associated with motor vehicle thefts. However, it should be noted that differences in the degree of association between crime counts and alternative denominators shown in Table 6 are not especially large, and these correlation coefficients are sample specific; therefore, these comparisons of association may not hold up in other cities or at other times.

Table 5

Spearman's Rho correlation coefficients measuring association among crime rates in Chicago census tracts

Thefts per..	**Residents**	**Daily population**	**Average daily pop.**
Residential pop.	–		
Daily population	0.824	–	
Average daily pop.	0.947	0.955	–
Square miles	0.581	0.592	0.604
MVTs per..			
Residential pop.	–		
Daily population	0.877	–	
Average daily pop.	0.946	0.979	–
Square miles	0.589	0.683	0.653
Robberies per..			
Residential pop.	–		
Daily population	0.920	–	
Average daily pop.	0.962	0.988	–
Square miles	0.792	0.809	0.807
Assaults per..			
Residential pop.	–		
Daily population	0.911	–	
Average daily pop.	0.956	0.987	–
Square miles	0.732	0.756	0.752
Batteries per..			
Residential pop.	–		
Daily population	0.910	–	
Average daily pop.	0.958	0.985	–
Square miles	0.757	0.780	0.777

ABBREVIATIONS: Pop. = population; MVT = motor vehicle thefts.

Table 6

Spearman's Rho correlation coefficients measuring association between crime counts and demographics in Chicago census tracts

Independent Variable	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
1. Theft	–							
2. MVT	0.586	–						
3. Robbery	0.640	0.769	–					
4. Assault	0.529	0.759	0.834	–				
5. Battery	0.544	0.770	0.861	0.956	–			
6. Residential population	0.378	0.369	0.184	0.248	0.242	–		
7. Daily population	0.544	0.383	0.217	0.283	0.279	0.813	–	
8.Average daily population	0.502	0.388	0.205	0.270	0.265	0.921	0.963	–
9. Square miles	0.363	0.396	0.200	0.343	0.296	0.515	0.611	0.586

VI: DISCUSSION

The results reported above address several research questions related to the impact of using alternative denominators when measuring crime risk. Commuter data from American Community Survey were used to estimate two alternative measures of the population at risk. These two measures, along with a measure of square area, were used to calculate crime rates and draw comparisons with traditional, per capita crime rates in Chicago.

Shifting Crime Risk

Two series of maps were first created to visually depict differences in crime risk measurements that depend on the denominator employed for calculating crime rates. The first series of figures mapped alternative crime rates to compare general patterns of crime risk across the city. Although some of the maps displayed large-scale similarities, subtle differences in the patterns of crime risk were apparent for each crime type examined. It is most clear from this first map series that property crimes display the starkest differences in spatial distribution of crime risk. Most notably, calculating thefts per 10,000 daily population and thefts per 10,000 average daily population seem to disperse theft risk to other areas of the city, while the other crime rates illustrate higher values of theft risk exclusively in or near the central business district.

The second map series, showing hot and cold spot clustering, displays a clear shift in high and low risk areas between per capita crime rates and per daily population rates. The central business district and surrounding area is substantially affected for each crime type. In each case, hot spot clusters of per capita crime rates are reduced when the daily population is used to calculate crime rates. From this descriptive analysis it is clear that hot spots can turn to cold spots (or areas without substantial clustering), and vice versa, depending on which denominator is used to calculate the crime rate. In both this map series and the previous, Boggs' (1965) initial hypothesis regarding inflated crime rates in the central business district is supported in Chicago.

This thesis also found that crime risk percentile ranking of census tracts can change by as much as 97 percent if an alternative denominator is employed. The average shift in percentile ranking ranged from as low as a four percent (using the most conservative population estimate) to as much as 20 percent. These percentile shifts suggest that standardized census tract rankings can be substantially impacted with the use of an alternative denominator as opposed to the traditional residential population to measure crime risk. In the most extreme case, a census tract can shift from being among the riskiest tracts, to the least risky. These results are comparable with Stults and Hasbrouck (2015) who also compared crime rate rankings across cities using alternative commuter-based crime rate denominators. As discussed, these researchers compared city crime rankings, finding that rank shifts ranged from roughly 2.7 percent to 5.3 percent.

It is shown here that the average shift in percentile ranking for the daily population-based crime rates exceeded seven percent for all crime types and was as high as 10 percent for theft rates. Although not directly comparable to Stults and Hasbrouck's (2015) findings, it seems that intra-city crime rates may be impacted to a greater degree than across city crime rates. It is possible that all commuting measured within cities is different than commuting only from the outside the city. This thesis captures a large range of movement within the city. A person who commutes to the neighboring census tract for work is counted as both and inflow and an outflow. Looking across cities, as done by Stults and Hasbrouck (2015), only considers commuters that come from outside the city. This difference in spatial resolution could be important for understanding how the population shifts throughout the day, and how this shift affects crime risk.

Relationships Among Crimes, Crime Risk, and Denominators

Some research discussed in the literature review has found lower (or even negative) crime rate correlations than those seen in this thesis, but others have also found higher correlations as well. For example, Pyle et al. (1974) reported correlation coefficients that did not exceed 0.4 for a variety of burglary and robbery alternative denominator-based rates. Phillips (1973) showed negative relationships between employee-based and residential population-based crime rates. On the other hand, Boggs (1965) calculated rank-order correlations between "crime-specific" and standard crime rates that ranged from -0.107 for grand larceny, to 0.997 for criminal homicide and aggravated assault. Property crime rate correlations found in Chicago are lower than those for violent crime types, but not nearly as low as what Boggs' (1965) reported.

It is possible that the higher correlations found in Chicago are simply due to the inclusion of the residential population in the calculation of both the daily population and the average daily population. To some extent, it could be argued that combining relevant denominators together, as was done here, is better than considering different denominators independently. For example, had commuter inflows alone been used as the denominator to calculate crime rates, it is likely that correlations would have been much lower. But this does not mean necessarily make either denominator a better measure of the population at risk. When potential denominators can be combined logically, it may provide a more accurate measure of the population at risk. In the case of the daily population used here, this denominator had the highest correlation with four of the five crime types (e.g., $r^2 > 0.54$ for theft), whereas the correlations between the residential population and each crime type did not exceed 0.38. Therefore, it may be advantageous for future research to consider combining denominators (in a meaningful way) to provide a better approximation of the crime-specific population at risk, rather than relying each measure independently. Here, the residential population is combined with commuter inflows and outflows. Other examples might be to combine residential and commercial units for a global analysis of burglary, or several public transportation nodes (e.g., bus stops, train stations) for street robbery analysis rather than relying on one type in isolation.

In summary, the descriptive techniques employed in this thesis provide additional evidence to the importance of considering alternative denominators in the calculation of crime rates. The findings support previous research on this topic, as well as more generally support the routine activities approach and environmental criminology as theoretical lenses for understanding crime. More specifically, commuters are shown to be an important factor in how crime risk is described, especially in the central business district.

Limitations

Generally speaking, this thesis is a descriptive analysis of crime risk in Chicago. As such, none of the findings were tested for statistical significance and should not be generalized to other cities or contexts. In addition, the unit of analysis used in this study is a potential limiting factor. The census tract unit (as with any imposed unit of analysis) could suffer from aggregation bias. As discussed above, smaller units of analysis have been more popular in contemporary crime research, but others also suggest that processes at larger scales may also be important for understanding crime (see Boessen & Hipp, 2015). The census tract unit was used here, but other units of analysis could impact the findings as well.

Commuters were the only true measure of population movement examined in this thesis. The population shifts throughout the day for many other reasons (e.g., shopping, leisure, school) that were not measured here. Other studies have attempted to capture a greater range of movements (Felson & Boivin, 2015), but these data are not currently available for Chicago. As a result, several key population movements are likely missing from the analysis. Using other approximations of population movements, such as public transit, entertainment district visitors, or employee counts, could assist in sharpening measurement of the population at risk. Also, the analytic strategy of this thesis did not allow for comparing the relative utility of alternative denominators. Rather than determining the "best" denominator, it is instead suggested that considerations be made regarding which denominator is most appropriate, given the intended measurement and data available.

Future Research

Despite the limitations, this thesis provides a valuable foundation for further study regarding the measurement of crime risk. Most clearly, future studies should seek to determine if the differences reported in this thesis matter on a broader level. In other words, to what extent do these differences in crime risk measurement impact understanding and prediction of crime more generally? It is possible that an understanding of the distinctions in the population at risk is vitally important for describing crime, but less important for testing crime theory or improving prediction. Subsequent work might therefore include alternative denominators (e.g., commuters) as explanatory factors in multivariate crime models. For example, commuter inflows may be important predictors of property crime, as evidenced by Felson and Boivin (2015) and might therefore have confounding influence on other independent variable effects. In addition, the daily population computed here could replace the residential population commonly used in multivariate models as an alternative measure of the population at risk. Differences between residential population and daily population estimates may increase as the unit of analysis decreases in size; as commuter data become accessible at smaller units of analysis, research can begin to apply these concepts at smaller spatial scales to sharpen measurement. The study by Malleson and Andresen (2015) represents the potential for using alternative sources of data for estimating high-resolution population movements.

Other research should also consider the potential processes associated with commuting, and how these processes might relate to crime. For instance, only commuter inflow and outflow estimates were used here to supplement measurements of the population at risk. Additional factors could also be incorporated to examine contextual factors that may provide insight. An example of this may be how the distance of commuting or time of day could provide important information for creating crime-specific denominators that are sensitive to certain situational contexts (e.g., daytime versus nighttime). Other data sets may also provide more detailed information, such as method of transit (e.g., car, bus, walk, bicycle) that would also sharpen measurement.

Beyond commuting, the movement of the population over the course of the day has been shown by Andresen and colleagues (Andresen, 2006; Andresen & Jenion, 2010; Malleson & Andresen, 2015) to change measures of crime risk. Although explicit measures of other population "flows" (such as entertainment visitors or shoppers) might become available, such as the transportation survey utilized by Felson and Boivin (2015), other proximate measures could also be considered. This might include using the number of liquor licenses in an area to approximate entertainment visitors or the number of museums to approximate tourists flows. Although these variables may be crude, they may provide the initial steps towards increasing understanding of these processes.

Finally, descriptive maps created in this thesis revealed the stark concentration of commuter inflows. While both commuter inflows and outflows represent population movement, it may also be important to investigate places where population movement is extremely low. Pockets of few commuter inflows and outflows are seen in the southern and western regions of Chicago where risk of violent crime is also high. Something about this seemingly stationary population appears to relate with violence. Further inquiry into positive and negative associations of population movement with crime could uncover other important ecological antecedents for crime events.

VII: CONCLUSION

The use of rates for measuring crime risk is a popular tool for the police and citizens alike. Crime researchers also utilize crime rates to measure crime in a way that explicitly controls for the number of potential victims and offenders in the area. However, the residential population is most commonly used as a denominator to deflate the crime count. Since Boggs (1965) discussed this issue years ago, a relatively narrow line of research continues to suggest that greater consideration be given to how crime risk is measured.

This thesis addressed a variety of research questions regarding crime risk measurement, focusing on the role of the denominator used to calculate crime rates. More specifically, three alternative denominators were compared with the traditional, residential population denominator when calculating crime rates in Chicago census tracts. Previous research has examined the impact of commuters on crime between cities (Stults & Hasbrouck, 2015) and several Canadian studies have estimated the effects of population movements on crime (Andresen, 2006; 2010; Malleson & Andresen, 2015; Felson & Boivin, 2015); yet, a census tract-level analysis of daily population movements and crime had not been conducted in the United States prior to this thesis.

It was shown here that spatial patterns and clusters of crime risk change with the denominator used to represent the population at risk. The ranking of census tracts using percentiles was also dependent on the denominator used, and these differences were most prevalent in the central business district of Chicago. Finally, rank-order correlations were calculated between various crime rates, and between crime counts and denominators to measure paired-association among these variables. Results suggest that the alternative denominator-based crime rates are moderately to highly correlated with the residential population-based crime rates. Secondly, supplementing the residential population with commuter flows improves the relationship between the crime rate numerator and crime rate denominator.

As discussed, the police and the public tend to rely on residential population-based crime rates to interpret relative risk of areas. Although the “best” denominator is not identified here, it is clear in this thesis that the denominator decision can certainly lead to conflicting descriptions of crime risk. Relying solely on the residential population as a means for controlling for the number of potential victims and offenders can overestimate crime risk in some areas, and underestimate crime in others. This issue is especially important for the central business district, where commuters can vastly change the number of people in an area over the course of one day. Future research should consider that population movement has an important role in measuring crime risk.

REFERENCES

Akers, R.L. (1977). *Deviant behavior: a social learning approach* (2nd ed.). Belmont: Wadsworth Publishing Co.

Andresen, M.A. (2006). Crime measures and the spatial analysis of criminal activity. *The British Journal of Criminology*, *46*(2), 258-285.

Andresen, M.A., Frank, R., & Felson, M. (2013). Age and the distance to crime. *Criminology and Criminal Justice*, *14*, 1748895813494870.

Andresen, M.A., & Jenion, G.W. (2010). Ambient populations and the calculation of crime rates and risk. *Security Journal*, *23*, 114-133.

Asbury, H. (2003). *The gangs of Chicago: An informal history of the Chicago underworld*. Random House.

Bernasco, W. (2010). A sentimental journey to crime: Effects of residential history on crime location choice. *Criminology, 48*, 389-416.

Bernasco, W., & Block, R. (2011). Robberies in Chicago: A block-level analysis of the influence of crime generators, crime attractors, and offender anchor points. *Journal of Research in Crime and Delinquency*, *48*, 33-57.

Block, R. L., & Block, C. R. (1995). Space, place and crime: Hot spot areas and hot places of liquor-related crime. *Crime and Place*, *4*(2), 145-184.

Boggess, L. N., & Hipp, J. R. (2016). The spatial dimensions of gentrification and the consequences for neighborhood crime. *Justice Quarterly*, *33*(4), 584-613.

Boggs, S.L. (1965). Urban crime patterns. *American Sociological Review, 30*, 899-908.

Boivin, R. (2013). On the use of crime rates. *Canadian Journal of Criminology and Criminal Justice*, *55*(2), 263-277.

Bordua, D.J. (1959). Juvenile delinquency and ‘anomie’: An attempt at replication. *Social Problems, 6*(3), 230-238.

Boessen, A., & Hipp, J.R. (2015). Close-ups and the scale of ecology: Land uses and the geography of social context and crime. *Criminology, 53*(3), 399-426.

Brantingham, P.J., & Brantingham, P.L. (Eds.) (1981). *Environmental criminology*. Prospect Heights, IL: Waveland Press, Inc.

Brantingham, P.J., & Jeffery, C.R. (1981). Afterword: Crime, space, and criminological theory. In P.J. Brantingham & P.L. Brantingham (Eds.) *Environmental Criminology*. Prospect Heights, IL: Waveland Press, Inc.

Brantingham, P.L., & Brantingham, P.J. (1998). Mapping crime for analytic purposes: Location quotients, counts, and rates. *Crime mapping and crime prevention, 8*, 263-288.

Burgess, E.W. (1925). The growth of the city: An introduction to a research project. In R.E. Park *The City*. Chicago, IL: The University of Chicago Press.

Bursik, R. J. (1988). Social disorganization and theories of crime and delinquency: Problems and prospects. *Criminology*, *26*(4), 519-552.

Bursik, R. J., & Grasmick, H. G. (1999). *Neighborhoods & crime*. Lexington Books.

Chamlin, M.B., & Cochran, J.K. (2004). An excursus on the population size crime relationship. *Western Criminology Review, 5*, 119-130.

Chicago Police Department. (2016). CLEARMAP Crime Summary Crime Type Categories: Definitions & Description. Retrieved from: http://gis.chicagopolice.org/clearmap_crime_sums/crime_types.html.

Clarke, R.V. (1984). Opportunity-based crime rates: The difficulties of further refinement. *The British Journal of Criminology*, *24*(1), 74-83.

Cohen, L.E., & Felson, M. (1979). Social change and crime trends: A routine activity approach. *American Sociological Review*, *44*(4), 588-608.

Cohen, L.E., Kaufman, R.L., & Gottfredson, M.R. (1985). Risk-based crime statistics: A forecasting comparison for burglary and auto theft. *Journal of Criminal Justice, 13*, 445-457.

Copes, H. (1999). Routine activities and motor vehicle theft: A crime specific approach. *Journal of Criminal Justice, 22*(2), 125-146.

Dobson, J. E., Bright, E.A., Coleman, P.R., Durfee, R.C., & Worley, B.A. (2000). LandScan: A global population database for estimating populations at risk. *Photogrammetric Engineering and Remote Sensing 66*, 849–857.

Erickson, M.L., Gibbs, J.P., & Jensen, G.F. (1977). Conventional and special crime and delinquency rates. *Journal of Criminal Law and Criminology, 68*(3), 305-317.

Felson, M. (1994). *Crime and everyday life*. Thousand Oaks, CA: Pine Forge Press.

Felson, M., & Boivin, R. (2015). Daily crime flows within a city. *Crime Science, 4*(31).

Felson, M., & Eckert, M. (2016). *Crime and everyday life* (5^{th} Ed.). Thousand Oaks, CA: Sage.

Ferraro, V. (2016). Immigration and crime in the new destinations, 2000-2007: A test of the disorganizing effect of migration. *Journal of Quantitative Criminology*, *32*, 23-45.

Frank, R., Andresen, M.A., & Brantingham, P.L. (2013). Visualizing the directional bias in property crime incidents for five Canadian municipalities. *Canadian Geographer, 57*, 31-42.

Frisbie, D.W., Hintz, R., Joelson, M., & Nutter, J. (1977). *Crime in Minneapolis.* St. Paul: Governor’s Commission on Crime Prevention and Control.

Getis, A., & Ord, J.K. (1992). The analysis of spatial association by use of distance statistics. *Geographical Analysis, 24*(3), 189-206.

Gottfredson, M.R. (1981). On the etiology of criminal victimization. *Journal of Criminal Law and Criminiology*, *72*(2), 714-726.

Gottfredson, M.R., & Hirschi, T. (1990). *A general theory of crime*. Stanford, CA: Stanford University Press.

Groff, E.R., & McEwen, T. (2007). Integrating distance into mobility triangle typologies. *Social Science Computer Review, 25*, 210-238.

Hakim, S., & Rengert, G.F. (1981). *Crime spillovers.* Thousand Oaks, CA: Sage.

Harries, K.D. (1981). Alternative denominators in conventional crime rates. In P.J. Brantingham & P.L. Brantingham (Eds.) *Environmental Criminology.* Prospect Heights, IL: Waveland Press, Inc.

Hirsch, A.R. (1983). *Making the second ghetto: Race and housing in Chicago, 1940-1960*. New York, NY: Cambridge University Press.

Inter-university Consortium for Political and Social Research (ICPSR). (2016). Project on Human Development in Chicago Neighborhoods. Accessed online at: http://www.icpsr.umich.edu/icpsrweb/PHDCN/biblio/series/00206/resources.

Jarrell, S., & Howsen, R.M. (1990). Transient crowding and crime: The more 'strangers' in an area, the more crime except for murder, assault and rape. *American Journal of Economics and Sociology, 49*(4), 483-494.

Jeffery, C.R. (1977). *Crime prevention through environmental design*. (2nd Ed). London: Sage Publications.

Jeffery, C.R. (1971). *Crime prevention through environmental design*. London: Sage Publications.

Jenks, G.F. (1967). The data model concept in statistical mapping. *International Yearbook of Cartography, 7*, 186-90.

Johnson, S.D. (2014). How do offenders choose where to offend? Perspectives from animal foraging. *Legal and Criminological Psychology, 19*, 193-210.

Lander, B. (1954). *Toward an understanding of juvenile delinquency.* New York, NY: Columbia University Press.

Landesco, J. (1929). *Organized crime in Chicago* (Vol. 3). Illinois Association for Criminal Justice.

Lemieux, A.M. (2010). *Risks of violence in major daily activities: United States, 2003-2005.* Doctoal dissertation. School of Criminal Justice, Rutgers University, Newark, NJ.

Lemieux, A.M., & Felson, M. (2012). Risk of violent crime victimization during major daily activities. *Violence and Victims, 27*(5), 635-655.

Lombardo, R.M. (2013). *Organized crime in Chicago*. Urbana: University of Illinois Press.

Malleson, N., & Andresen, M.A. (2015). The impact of using social media in crime rate calculations: Shifting hot spots and changing spatial patterns. *Cartography and Geographic Information Science, 42*(2), 112-121.

O'Brien, D.T., & Sampson, R.J. (2016). Public and private spheres of neighborhood disorder: Assessing pathways to violence using large-scale digital records. *Journal of Research in Crime and Delinquency*, *52*(4), 486-510.

Pettiway, L.E. (1985). Measures of opportunity and the calculation of the arson rate: The connection between operationalization and association. *Journal of Quantitative Criminology, 1*(3), 241-268.

Phillips, P.D. (1973). Risk-related crime rates and crime patterns. *Proceedings, Association of American Geographers, 5*, 221-224.

Pyle, G.F. (1974). *The spatial dynamics of crime.* Research Paper No. 159. Chicago, IL: University of Chicago Department of Geography.

Pyle, G.F., Hanten, E. W., Williams, P. G., Pearson, A., & Doyle, J. G. (1974). *The Spatial Dynamics of Crime* (Vol. 159). Chicago, IL: University of Chicago, Department of Geography.

Ratcliffe, J. (2010). Crime mapping: Spatial and temporal challenges. In A.R. Piquero & D. Weisburd (eds.) *Handbook of Quantitative Criminology.* New York, NY: Springer.

Reckless, W.C. (1933). *Vice in Chicago*. Chicago, IL: University of Chicago Press.

Roncek, D. W., & Faggiani, D. (1985). High schools and crime: A replication. *The Sociological Quarterly*, *26*(4), 491-505.

Roncek, D. W., & LoBosco, A. (1983). The effect of high schools on crime in their neighborhoods. *Social Science Quarterly*, *64*(3), 598-613.

Roncek, D. W., & Maier, P. A. (1991). Bars, blocks, and crimes revisited: Linking the theory of routine activities to the empiricism of “hot spots”. *Criminology*, *29*(4), 725-753.

Rosenbaum, D. P. (1988). Community crime prevention: A review and synthesis of the literature. *Justice Quarterly*, *5*(3), 323-395.

Rossmo, K.D., Lu, Y., & Fang, T.B. (2012). Spatial-temporal crime paths. In M.A. Andresen & J.B. Kinney (eds.) *Patterns, Prevention, and Geometry of Crime.* New York, NY: Routledge.

Sampson, R. J. (2012). *Great American city: Chicago and the enduring neighborhood effect*. University of Chicago Press.

Sampson, R. J., & Raudenbush, S. W. (1999). Systematic social observation of public spaces: A new look at disorder in urban neighborhoods. *American Journal of Sociology*, *105*(3), 603-651.

Sampson, R. J., Raudenbush, S. W., & Earls, F. (1997). Neighborhoods and violent crime: A multilevel study of collective efficacy. *Science, 277*(5328), 918-924.

Shaw, C.R., & McKay, H.D. (1942). *Juvenile delinquency and urban areas.* Chicago, IL: The University of Chicago Press.

Sherman, L. W., Gartin, P. R., & Buerger, M. E. (1989). Hot spots of predatory crime: Routine activities and the criminology of place. *Criminology*, *27*(1), 27-56.

Skogan, W. G. (1976). Victimization surveys and criminal justice planning. *University of Cincinnati Law Review*, *45*, 167-206.

Skogan, W. G., & Hartnett, S. M. (1997). *Community policing, Chicago style*. New York: Oxford University Press.

Skogan, W. G., & Maxfield, M. G. (1981). *Coping with crime: Individual and neighborhood reactions*. Thousand Oaks, CA: Sage.

Sparks, R.F. (1980). Criminal opportunities and crime rates. In S.E. Fienberg & A.J. Reiss (Eds.) *Indicators of Crime and Criminal Justice: Quantitative Studies*. Washington, DC: U.S. Department of Justice, Bureau of Justice Statistics.

Spear, A. H. (1967). *Black Chicago: The making of a negro ghetto, 1890-1920*. Chicago, IL: University of Chicago Press.

Stipak, B. (1988). Alternatives to population-based crime rates. *International Journal of Comparative and Applied Criminal Justice*, *12*(2), 247-260.

Stults, B.J., & Hasbrouck, M. (2015). The effect of commuting on city-level crime rates. *Journal of Quantitative Criminology, 31,* 331-350.

Townsley, M., & Sidebottom, A. (2010). All offenders are equal, but some are more equal than others: Variation in journeys to crime between offenders. *Criminology, 48*(3), 897-917.

Tuttle, W. M. (1970). *Race riot: Chicago in the red summer of 1919*. Champaign, IL: University of Illinois Press.

Weisburd, D. (2015). The law of crime concentration and the criminology of place. *Criminology, 53,*(2), 133-157.