COMPARING METHODS FOR ESTIMATION OF DAYTIME POPULATION IN DOWNTOWN INDIANAPOLIS, INDIANA

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LIST OF ABBREVIATIONS

ACS	American Community Survey
AEGL	Acute Exposure Guideline Levels
CTPP	Census Transportation Planning Products
FSSA	Family & Social Services Administration
IPS	Indianapolis Public Schools
ITE	Institute of Transportation Engineers
SANDAG	San Diego Association of Governments
TAZ	Transportation Analysis Zone (also known as Traffic Analysis Zone)
SF3	Summary File 3

I. INTRODUCTION

Public safety departments and emergency management agencies have always had a need for accurate population counts in order to prepare for, and respond to, incidents threatening the citizenry. In the 1950s, it was noted that there was a need for daytime population estimates for civil defense purposes, specifically for determining the size and location of bomb shelters, estimating casualties from atomic attacks, and evacuation routing (Schmitt, 1956). Today, the threats to the homeland are different but just as devastating, with the need to prepare for both manmade and natural disasters.

Population statistics have historically provided information regarding the place of residence of the population, resulting in an estimate of the number of people present at any given location at nighttime. The United States Census Bureau provided daytime population estimates with the 2000 decennial census, but these data were aggregated at the county or metropolitan area levels. Data aggregated at this scale, however, does not provide estimates for smaller geographic areas within cities, such as individual city blocks. Access to finer-scale daytime population estimates could potentially improve emergency planning and response.

This paper compares two new methods for estimating daytime population against two existing models within downtown Indianapolis in Marion County, Indiana. The two existing models consist of the 2009 USA Daytime Population model created by ESRI and the LandScan Global Population Project developed by the Oak Ridge National Laboratory. A parking study of downtown Indianapolis, as prepared by the City of Indianapolis, Division of Metropolitan Development, is the basis of the first new method of estimating daytime population. The second method is a direct count of the daytime population using a methodology previously developed (Garb, Cromley, & Wait, 2007; Sleeter & Wood, 2006). Additionally, these four population estimates will be compared when applied to a scenario involving a hypothetical toxic gas plume. The goal of this research is to provide guidance to the City of Indianapolis, Division of Homeland Security on the advantages and disadvantages of each type of estimate.

II. BACKGROUND

The United States Census Bureau

As required by law, the United States Census Bureau provides multiple types of population data at different temporal and spatial resolutions. Geographically, the census block is the smallest census statistical area and is bounded by governmental jurisdictional lines (such as city or county limits) and visible features (e.g. streams, railroad tracks, and streets). In urban areas, the census block often corresponds with individual city blocks. In suburban and rural areas, a census block may be irregularly shaped and include several square miles. Population counts associated with census blocks are 100-percent data, meaning data are collected about every inhabitant and housing unit. The next smallest enumeration unit is the block group, consisting of several census blocks that are located within the same census tract and county. The block group is the smallest geographic area in which the Bureau tabulates sample data (information collected on the census or American Community Survey "long form" from an average of one in six households). Block groups typically contain between 600 and 3,000 people. The census tract is a statistical subdivision of the county and consists of several block groups that are most often contiguous. The spatial size of the census tract is dependent upon the population density. Ideally, a census tract will consist of 4,000 people; however, the population varies between 1,200 and 8,000 (U.S. Census Bureau, 2008).

The Census Bureau conducts a nationwide population census every 10 years; the last census with a full dataset available was conducted in the year 2000. Due to the need for more current information between the decennial censuses, the Bureau also estimates population and conducts the American Community Survey (ACS). The ACS provides two types of estimates related to demographic, economic, social, and housing characteristics. The three-year estimate (based upon data collected over a three-year period) is available for communities with populations greater than 20,000. The one-year estimate is available for geographic areas with a population greater than 65,000; it is more current than the three-year estimate, but uses a smaller sample size. Both estimates are provided for larger geographic areas, rather than at the block, block group, or census tract level. The smallest geographic unit for which data are available from the 2008 ACS and the 2006-2008 ACS for Marion County, Indiana is the township.

The 2000 Census provides population counts at the block level based upon the place of residence of the citizenry and represents a nighttime population distribution. Since much of the population is located away from their residence during normal business hours, the 2000 Census also provides a daytime population distribution based upon travel to work information collected in the sample data. It is based solely upon workers and the daytime residential population and does not account for any other type of travel during the day. The Census Bureau computes daytime population by two different methods, both of which provide the same result (U.S. Census Bureau, n.d.-b):

Method 1: Estimated daytime population = Total resident population + Incommuters – Outcommuters, where Incommuters = Total workers working in an area minus workers who lived and worked in the same area, and Outcommuters = Total workers living in an area minus workers who lived and worked in the same area

Method 2: Estimated daytime population = Total resident population + Total workers working in the area – Total workers living in the area

Note that there is no differentiation as to the time of day an individual worked; thus, this method of estimating daytime population includes those who worked in the evening or night. While the place of work is collected in the sample data at the block group level, it is compiled at the county or metropolitan area level (U.S. Census Bureau, n.d.-a).

The Census Bureau also generates county-to-county worker flow files. Two files are available: one provides data regarding where the workers within each county reside; the other lists where the residents within each county work. These data are readily available from 1990 and 2000. Additionally, the U.S. Department of Transportation has developed the Census Transportation Planning Products (CTPP) based upon data provided by the Census Bureau. The CTPP 2000 Part 3 data provide commuter flow information for the number of workers in each census tract of work by census tract of residence. These data are also available at the county level. The 1990 CTPP tabulated the commuter flow between residence and work for the county and census place (areas over 2,500 people). County-to-county flows are also available based upon the 2006-2008 ACS.

Garb, Cromley, & Wait (2007) proposed utilizing more current ACS population data by estimating block populations based upon the proportional relationship between the census block and tract from the prior Census and the current ACS estimate for the tract. (Note that tract data through the ACS is currently not available for Marion County, Indiana). Sleeter & Wood (2006) presented a method of determining the residential daytime population at the block group level by utilizing Summary File 3 data from the 2000 decennial census, wherein the total number of people remaining in their homes during the day is equal to the total population less those who depart for work and school.

Prior research regarding daytime population estimation

During the 30-year period prior to World War II, governmental statistical agencies in Germany, France, and Great Britain conducted daytime population research by focusing upon commuter flow. Larger cities, such as Hamburg, were subdivided into districts which were cross-tabulated to reference the places of residence and work. Within the United States, however, the 1960 census was the first to compile data regarding the place of work. Prior to this, most empirical data related to daytime population originated from highway research conducted by traffic engineers (Foley, 1954).

Foley (1952) studied the population movement into the central business districts of metropolitan areas during the daytime. Origin-destination studies (involving interviews of a sample group) and cordon counts (which count all vehicles entering the district with no regard to final destination) were evaluated to determine the number of people entering the district during the 12-hour period between 7:00 a.m. and 7:00 p.m. Using data from 63 cities, Foley found that for a metropolitan area of approximately one million people, the maximum accumulation of people within the district was between 9% and 12% of the total metropolitan population. The ratio of persons entering the district to those with destinations within the district to the maximum accumulation of persons at any one time during the day was 4:2:1.

An origin-destination traffic study, which included the purpose of each trip, was performed in Flint, Michigan in 1950 by the Michigan State Highway Department. The results were analyzed by Sharp (1955) to determine the movement and purpose of the non-residential population within the central business district during both a typical 24-hour period and eight time frames throughout the day. While work, shopping, and recreation accounted for 73% of activity for all commuters during the entire 24-hour period, the percentage of persons partaking in these activities varied throughout the day, resulting in a temporal community structure.

Origin-destination studies continue to be utilized in the estimation of daytime populations. For example, The San Diego Association of Governments (SANDAG, 2000) combined the 1995 Travel Behavior Survey (which collected origin-destination and trip purpose data for a 24-hour period) with trip generation data from the SANDAG transportation model. The final product was a population estimate for each Master Geographic Reference Area (which is similar to a census block) between 10:00 a.m. and 11:00 a.m. on a weekday. Results were utilized to compare daytime and nighttime populations of different jurisdictions within the San Diego metropolitan area.

Another example is the study of the movement of population within the greater metropolitan area of Sydney, Australia, utilizing the Sydney Household Travel Survey (Collins & Greaves, 2007). This survey consisted of residents completing a one-day continuous travel diary. Five years of data (1998-2002) were evaluated to create dynamic population models at 11:00 a.m., 4:00 p.m., and 8:00 p.m. These models were utilized in the planning of evacuation routes within the central business district. At 11:00 a.m., 47% of the zones delineated in the study had a daytime population which was at least 75% less than the residential population. The central business district and several regional business districts had a dramatic increase in daytime population, which was partially maintained by some, but not all of these districts in the evening. It was further noted that evacuation routes which are effective for one time frame of the day may not be the most efficient during a different time frame. Other studies utilizing travel surveys include Lau (2009) and Marquez, et al. (2001).

Schmidt (1956) proposed four methods of calculating daytime population. The first, being the "proration method", used symptomatic data, such as the assessed value of real estate or the number of phone calls originating within an entire metropolitan area; the percentage of the chosen symptomatic data in an individual census tract would then be considered equivalent to the percentage of daytime population present. The second method was the "censal ratio method". This method required having a daytime population for a previous year and adjusting the population values assigned to each census tract based upon the ratio of the current and previous year's assessed real estate values (or other type of symptomatic data). The third method was the "correlation method" that utilized a regression equation in which the symptomatic data were the independent variables and the daytime population was the dependent variable. The final method was the "component method", which consisted of adding up each component of the daytime population (being number of employees, school enrollment, and daytime residential population).

Schmitt (1959) found a relatively high zero-order correlation between the assessed value of real estate in Honolulu and the place of work densities, but a much lower correlation between the place of residence densities and the assessed values. Additionally, there was a very high coefficient of multiple correlation between the total assessed value and density by both the place of work and place of residence.

McPherson, et al. (2004) created day/night – indoor/outdoor population maps at 250 meter resolution for the continental United States. Block group data from the 2000 Census were utilized for the nighttime population and modified to locate the population evenly along roads rather than distributed evenly throughout the enumeration unit. The daytime population was determined based upon employment information provided by the American Business Directory, Inc., the Census County-to-County Journey to Work data (to ensure the total number of employees matched the Census count of workers per county), and the daytime residential population (based upon the non-working population in each block group). After producing the daytime and nighttime population models, the National Human Activity Pattern Study (created by the Environmental Protection Agency) was utilized to determine fractions of indoor versus outdoor activity. Noted areas for future improvement include modeling the spatial and temporal distribution of population in traffic, at educational institutions, and in retail areas.

McPherson, et al. (2006) performed an analysis of the commuting patterns of the population in the Chicago area utilizing the 2000 Census Transportation Planning Package Part 3 in conjunction with a 250 meter resolution raster daytime/nighttime - indoor/outdoor population model (McPherson, et al., 2004). A case study was presented wherein a hypothetical colorless and odorless chemical release is unnoticed for 12 hours, at which time the population requires medical attention. While the population was localized at their place of work at the time of the release, the population is subsequently dispersed over hundreds of kilometers at the time medical response is required. McPherson noted that future versions of the model need a finer temporal resolution in the sense of capturing the element of shift work, as well as a finer spatial resolution in order to include schools and retail shopping.

Sleeter & Wood (2006) created daytime and nighttime dasymetric population density maps at 10 meter resolution based upon census block populations and real estate tax parcel databases for Clatsop County, Oregon, a coastal county vulnerable to a Cascadia Subduction Zone tsunami. The daytime population estimation utilized employment data for businesses, parcel data, and school student counts along with census data (for determining the residential daytime population present). Employment point data were spatially joined to the nearest parcel; this resulted in 24% of the daytime parcels falsely classified as having zero population. The study also found that the net daytime populations of Astoria and Seaside decreased by almost 50% of the residential population; however, the study noted it did not include tourists, who can number in the tens of thousands each day.

Garb, et al. (2007) discussed different methods of determining the daytime population. These include LandScan, U.S. Census Bureau data, and obtaining counts for specific subsets of the population from local sources, such as the number of workers, students, hospital patients, and prisoners present in the area. Also emphasized is the need to compute population distribution estimates for different times of the day in order to fully prepare for an incident, as well as examining the population distributions in the vicinity of critical infrastructure considered as potential targets such as government and financial districts; electrical substations, power plants, and other utility installations; along rivers, lakes, and streams; and along traffic corridors providing access to population areas.

Bhaduri (2008) defined daytime population as the "distribution of population at times other than when they are expected to be at their residences at night which extends the duration from business hours to include the evening hours as well" (p. 880), and expressed it conceptually as:

Daytime Population = Workers + school children + tourists + business travelers + that portion of the residential population which is present during the daytime

In order to generate an estimate, businesses, schools, recreational areas, and other static daytime activity locations must be identified, along with the distribution of the mobile population at these locations. It was further elaborated that the calculation of daytime population is more complex than this, and future work will need to account for: the influx of visitors and the large number of people who are commuting or travelling through the area on the road network; individuals within the area performing activities unrelated to work or place of residence; and the temporal impact, wherein population varies based upon weekday, weekend, or holiday, the time of year (such as school not in session during the summer) and inclement weather conditions.

Existing daytime population model #1: ESRI 2009 USA Daytime Population

ESRI prepared a thematic map entitled "USA Daytime Population," last modified July 1, 2009. Data are provided at the state, county, census tract, and census block group levels as a ratio of the number of workers employed in an area during the day per 100 area resident population. The ESRI 2009 Business Locations database provided the number of workers. The ESRI 2009 total population variable (being the household and group quarters population) is an estimate ESRI derived as outlined in the White Paper *ESRI Demographic Update Methodology: 2009/2014* (ESRI, 2009).

Existing daytime population model #2: LandScan

The Oak Ridge National Laboratory first created LandScan, a global population distribution model, in 1998 for use in emergency response to natural disasters; biological, chemical, and nuclear accidents; humanitarian relief; and other demographic and environmental applications. The raster model has a spatial distribution of 30 arc-seconds, or approximately 1 km^2 at the equator, with the width of the cells decreasing as latitude increases. A probability coefficient based upon land cover, slope, proximity to roads, nighttime lights, and an urban density factor is assigned to each raster cell and applied to census counts. The timing of population movements was not distinguished in this model. The resulting value is an "ambient population", which represents the average number of people who are likely to be present at any given time during a

24-hour period for typical days, weeks, and seasons (Dobson, Bright, Coleman, Durfee, & Worley, 2000). The algorithm for the assignment of population counts to each raster cell does not appear to be publicly available.

New daytime population estimation method #1: Indianapolis parking study

The City of Indianapolis prepared a parking study in 2006 discussing parking needs within a one mile square area of Indianapolis (bounded by North Street, East Street, South Street, and West Street). The parking supply and demand for each city block within this area was determined based upon the Indianapolis downtown average demand ratio of 1.74 parking spaces per 1,000 gross square feet of buildings (regardless of type of land use), excluding vacant space. Note that this demand is for a typical weekday and does not apply when special events are held at Lucas Oil Stadium, the Convention Center, or Conseco Fieldhouse (Department of Metropolitan Development, 2007). Utilizing an average number of people per vehicle and the square footages of buildings, the population in each city block can be estimated.

New daytime population estimation method #2: direct count

Schmitt (1956) suggested, and Sleeter & Wood (2006) estimated the daytime population utilizing counts of employees at each business location, school student counts, and U.S. Census data. In addition to these categories, Garb, et al. (2007) included exact counts (or estimates) of hospital patients and prisoners.

III. METHODOLOGY

Study Area

The study area is located in downtown Indianapolis, which is within Center Township, Marion County, Indiana, and covers an area of approximately 1,629 acres (2.55 square miles). The study area is composed of 23 Census block groups (Figure 1); Interstate 65 is the northern and eastern boundary, Interstate 70 is the southern boundary, and West Street is the westernmost boundary of the study area. The primary zoning classification within the study area is Central Business District, which includes sub-districts designed specifically for the downtown. Table 1 lists the area and percentage of zoning classifications within the study area (Figure 2). The diverse land use contributes to the variety in times when people are present within this area. Currently, the Division of Homeland Security does not have a daytime population model for the City of Indianapolis, and has only an estimate of the number of people who may be present within the entire downtown study area.

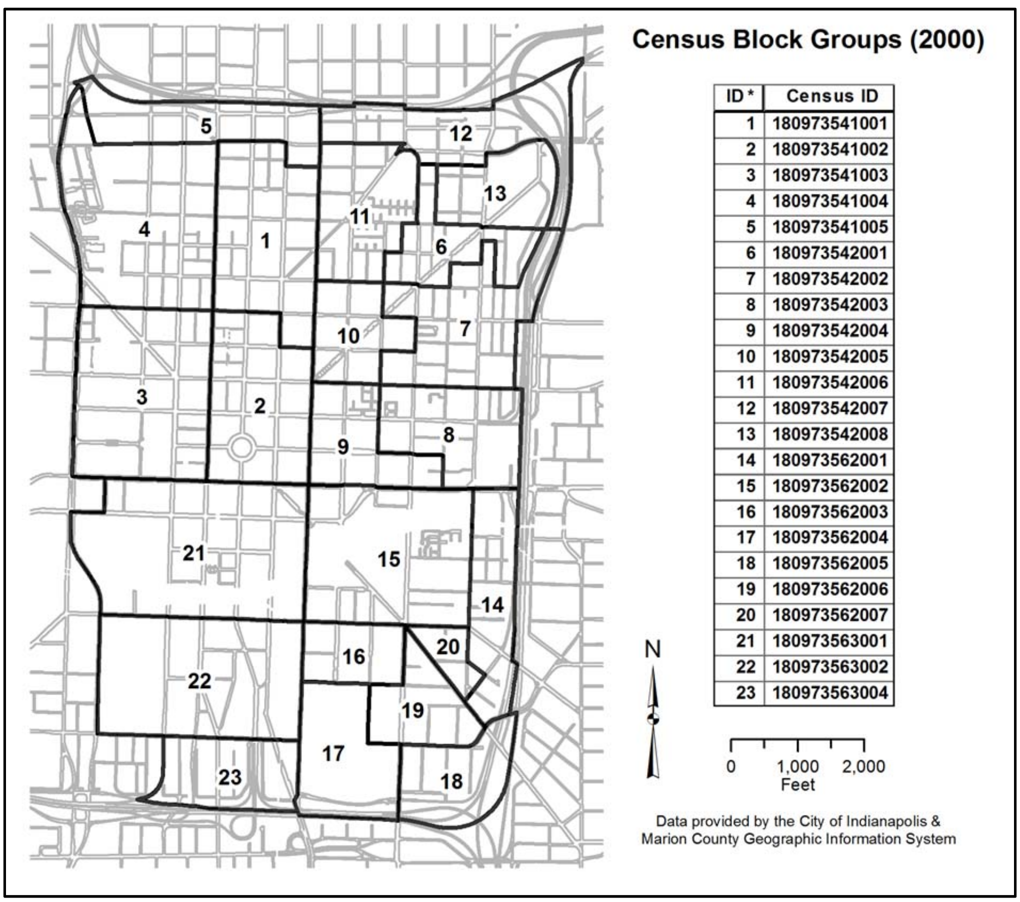

Figure 1. Census block groups within study area

Table 1. Zoning classification statistics for study area

Zoning Classification	Area (acres)	Percent
Central Business District	940.5	57.7%
Commercial District	118.4	7.3%
Dwelling District	140.5	8.6%
Historic Preservation District	21.4	1.3%
Industrial District	350.8	21.5%
Park District	10.2	0.6%
Special Use District	46.5	2.9%
University Quarter District	0.6	0.1%
Total	1628.9	100.0%

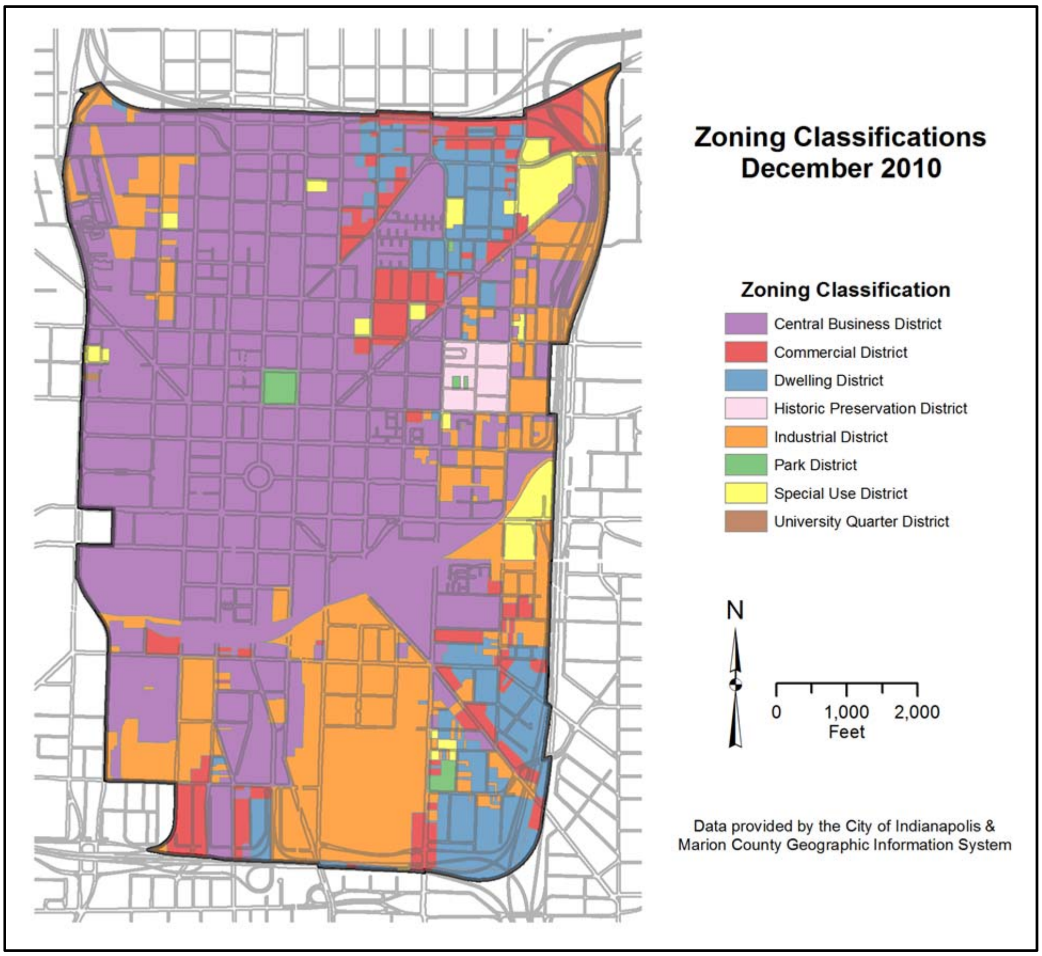

Figure 2. City of Indianapolis zoning classifications within study area

GIS Layers

The base layers utilized for this study were obtained from the City of Indianapolis and Marion County Geographic Information System. They consist of the 2000 census blocks, buildings, pavement, real estate parcels, street centerlines, and zoning. All GIS work was performed within ArcGIS 9.3.1.

Center Township Assessor building square footages

The Center Township Assessor provided data for the entire Township listing the real estate parcel number, property sub-class, and gross square footage for each type of improvement upon each parcel. These data are current as of April 2010. The square footage of each building within the study area (excluding uninhabitable space such as crawl spaces and attics, parking garages, open porches, and balconies) was extracted and joined to the land parcel database. These data are utilized with the new daytime population estimation method #1 (Indianapolis parking study).

Employment data

A list of employers located within the zip codes included in the study area, as collected by Infogroup (a company in Omaha, Nebraska), was obtained from the Department of Workforce Development for the State of Indiana. These data were from the Infogroup Employer Database 2010 v.2, and included the business name, address, type of business, and number of employees. The list of businesses was manually reviewed; street addresses were not provided for 308 businesses, and 159 duplicate listings were removed, resulting in a total of 3,242 businesses within the study area. Additionally, there were a total of 86,632 employees within the study area, with an average of 26.7 employees per business. Business locations were geocoded using standard address matching procedures and the resulting points were located at the centroid of the appropriate building footprint. These data were utilized with the new daytime population estimation method #2 (direct count).

Daytime population remaining in their residence

The population that remains in their residence during the daytime (and referred to as the “daytime residential population”) is determined by subtracting the total number of people leaving their home from the total residential population. This was calculated at the block group level using the Census 2000 Summary File 3 (SF3) tables (Table 2) as follows:

Daytime residential population	=	Total residential population (P3)	-	Population enrolled in school (P36)	-	Civilian population employed (P43)	-	Active duty population (P43)	+	Worked at home (P30)

Table 2. Census 2000 Summary File 3 tables

SF3 Table	Table Description
P3	100-Percent Count of the Population
P30	Means of Transportation to Work for Workers 16 Years and Older
P36	Sex by School Enrollment by Level of School By Type of School for the Population 3 Years and Older [nursery school through high school)
P43	Sex by Employment Status for the Population 16 Years and Over

The Census Bureau does not include active military or those institutionalized in the tabulation of employed civilian population; thus, active duty military are excluded since they are assumed to be located at their military post rather than at their permanent place of residence. The civilian employed population is assumed to be working away from their homes during the day; thus, those that do work at home are added back. This methodology is adopted from the research of Sleeter & Wood (2006).

This daytime residential block group population is utilized with the new daytime population estimation method #2 (direct count).

Existing daytime population model #1: ESRI 2009 USA Daytime Population

The ESRI 2009 Residential Population and ESRI 2009 Daytime Population Ratio for each block group was obtained from the ESRI ArcGIS webmap server. The Daytime Population Ratio is the number of workers per 100 residents. The daytime population within each block group was then calculated based upon these data using the formula:

ESRI Daytime Population = ESRI 2009 residential population * ESRI 2009 Daytime Population Ratio ÷ 100

The daytime population based upon this method is depicted in Figure 3.

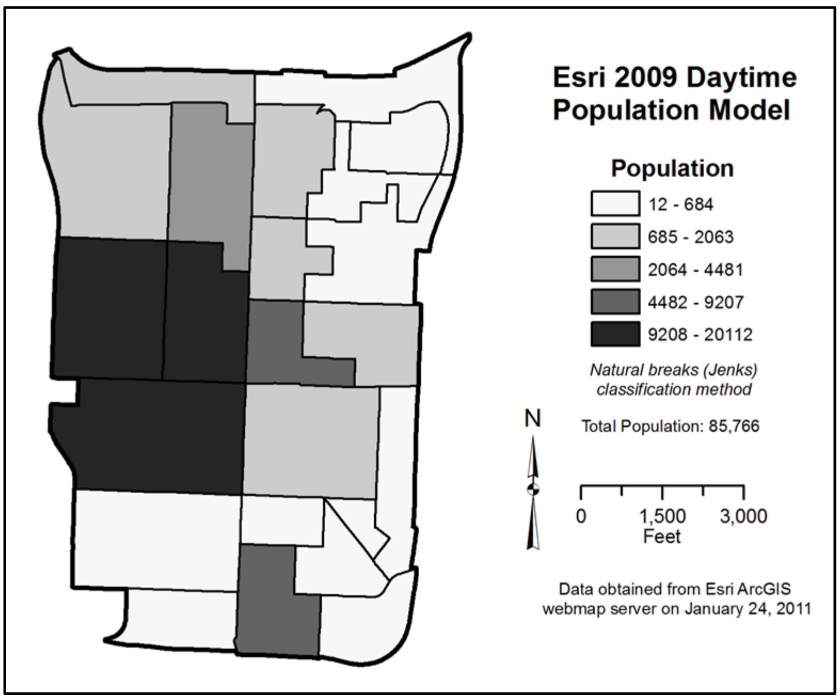

Figure 3. ESRI 2009 USA Daytime Population

Existing daytime population model #2: LandScan

The Oak Ridge National Laboratory provided the 2008 High Resolution Global Population Data Set in a raster file using the Geographic, WGS84 projection. This raster was converted to polygon features and re-projected to the NAD 1983 Indiana East State Plane coordinate system (US feet). The grid cells have an average size of 3035.56 feet (north/south) by 2342.45 feet (east/west) within the study area. Figure 4 represents the original LandScan data superimposed over the study area. Figure 5 represents the estimated LandScan population per block group based upon areal interpolation.

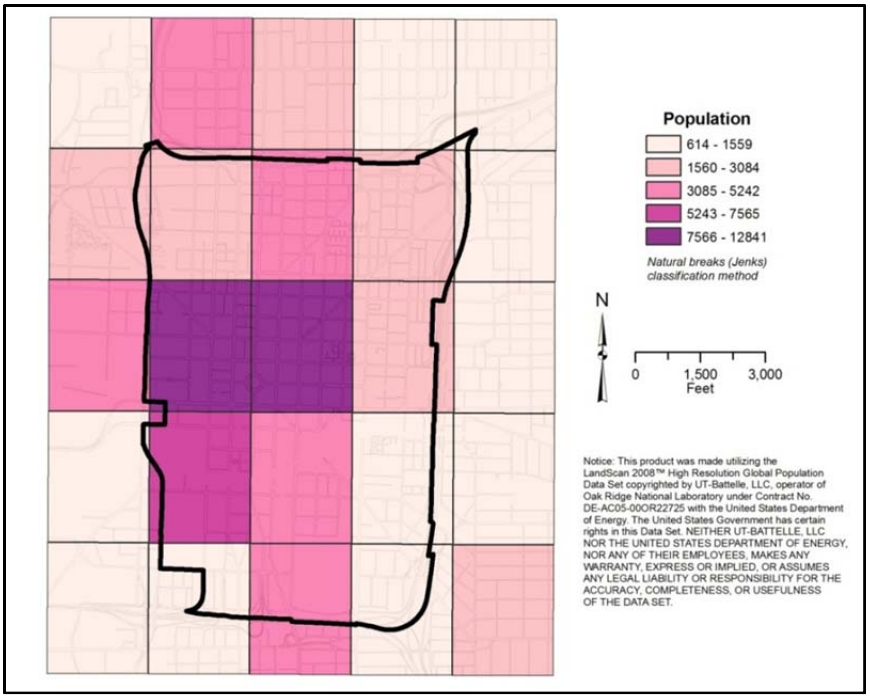

Figure 4. 2008 LandScan High Resolution Global Population Data Set

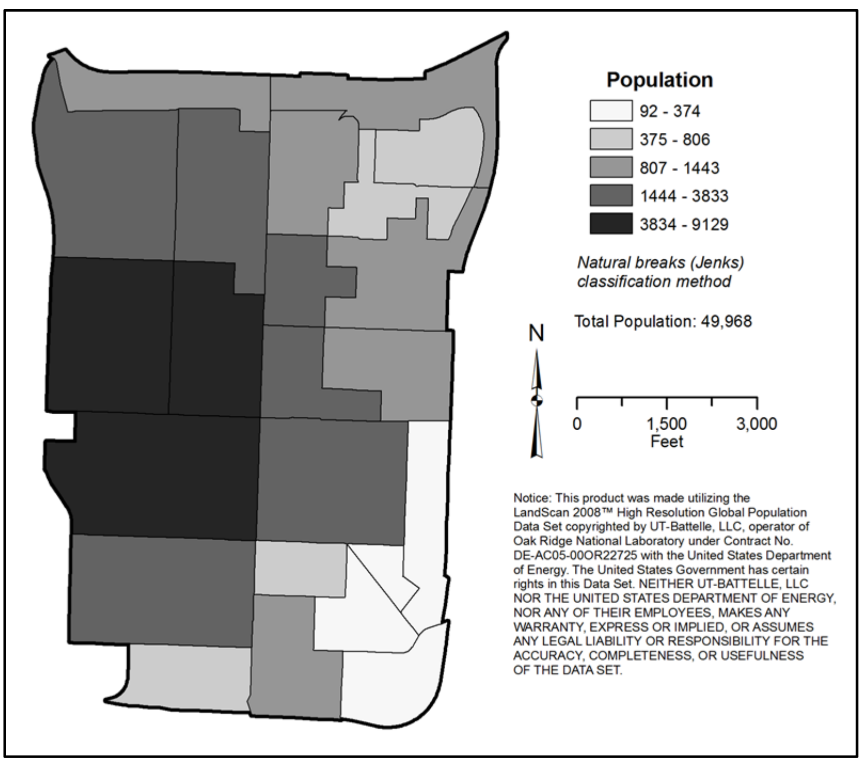

Figure 5. 2008 LandScan Population proportioned to Census block groups

New daytime population estimation method #1: Indianapolis parking study

As discussed previously, the downtown average demand ratio for parking is 1.74 parking spaces per 1,000 gross square feet of buildings (regardless of type of land use), excluding vacant space. The gross square footage of each building is based upon the parcel information provided by the Center Township Assessor. The average number of passengers per vehicle is 1.7 (Davis, Diegel, & Boundy, 2010). The daytime population for each land parcel is calculated using the formula:

Daytime population = gross square footage *(1.74 parking spaces ÷ 1,000 square feet) * (1.7 people ÷ 1 parking space)

The population is aggregated at the census block group level (Figure 6) based upon the location of the centroid of the parcels.

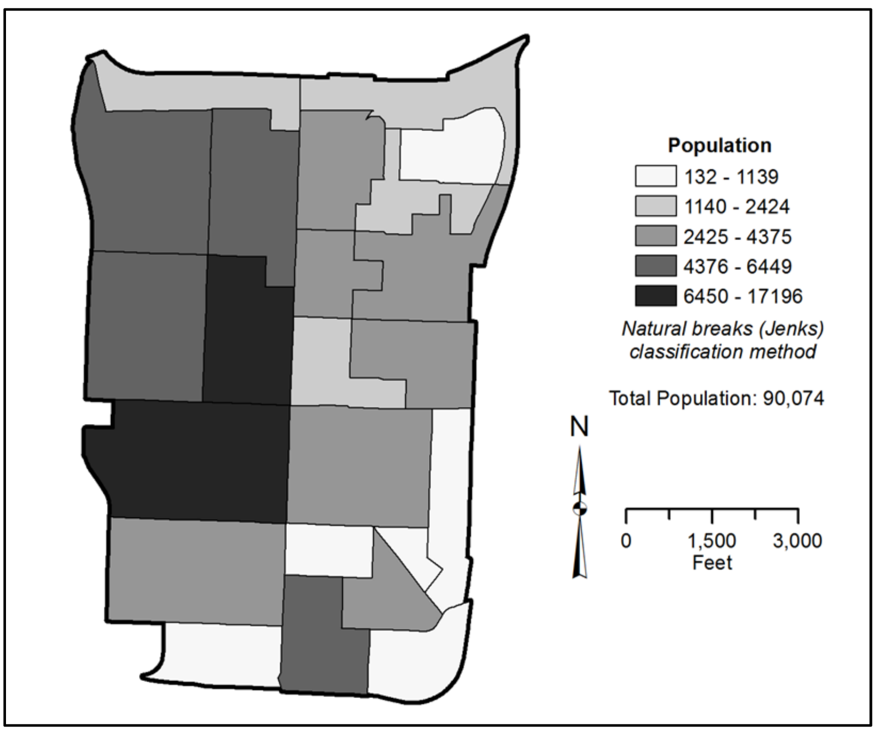

Figure 6. New daytime population estimation #1 based upon parking demand

New daytime population estimation method #2: direct count

The daytime population is directly counted at locations where a fixed number of people are present throughout the day. Business employment data and the daytime population remaining in their residence (both discussed previously) are included in this method. Other data utilized are as follows:

Daycare centers: a list of all licensed child care centers, licensed child care homes, and unlicensed registered child care ministries within Marion County was obtained from the State of Indiana Family & Social Services Administration (FSSA). The number of children licensed for each center (as provided by FSSA) has been added to the population count.

Jails: the 2006 Census of Jail Facilities (United States Department of Justice, et al., 2006) along with the information on the Community Education Centers, Inc. website (being the corporation contracted to run Liberty Hall correctional facility) were utilized to include jail population where prisoners are not included in the 2000 decennial census.

School student count: enrollment for primary and secondary schools is shown per information obtained from the U.S. Department of Education National Center for Education Statistics, the State of Indiana Department of Education, and school websites.

Hospitals: there are no hospitals within the study area.

These data are aggregated at the census block group levels (Figure 7).

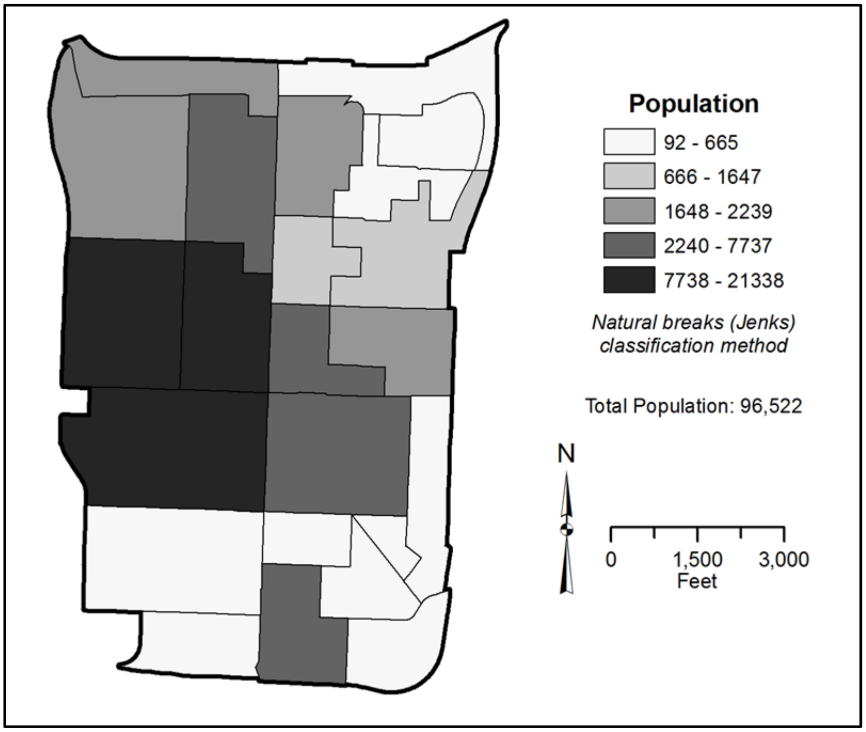

Figure 7. New daytime population estimation #2 by direct count

Toxic gas plume scenario

A simulated toxic gas plume was modeled in ALOHA 5.4.1.2 for demonstration purposes using weather conditions in Indianapolis on March 9, 2011 at 17:47 EST. The plume was imported into MARPLOT version 4.1.2 in order to set the source point of the plume (being the south lawn of the Indiana State Capitol grounds) and display the threat zones on a map of the City. Two Acute Exposure Guideline Levels (AEGL) are included in this study. The area within the AEGL-3 level has an airborne concentration of the substance which could cause life-threatening health effects or death in the general population. Areas within the AEGL-2 level have an airborne concentration where the general population is at risk of an impaired ability to escape or serious, long-lasting adverse health effects. The AEGL-2 confidence line delineates the area the plume is expected to remain 95% of the time. The AEGL-1 level, where the effects of the substance are transient and reversible, has not been included in this study (U.S. Environmental Protection Agency & National Oceanic and Atmospheric Administration, 2007). A KML file of the resulting zones and confidence line was generated within MARPLOT for import into ArcGIS. The threat zones, along with the affected block groups are depicted in Figure 8.

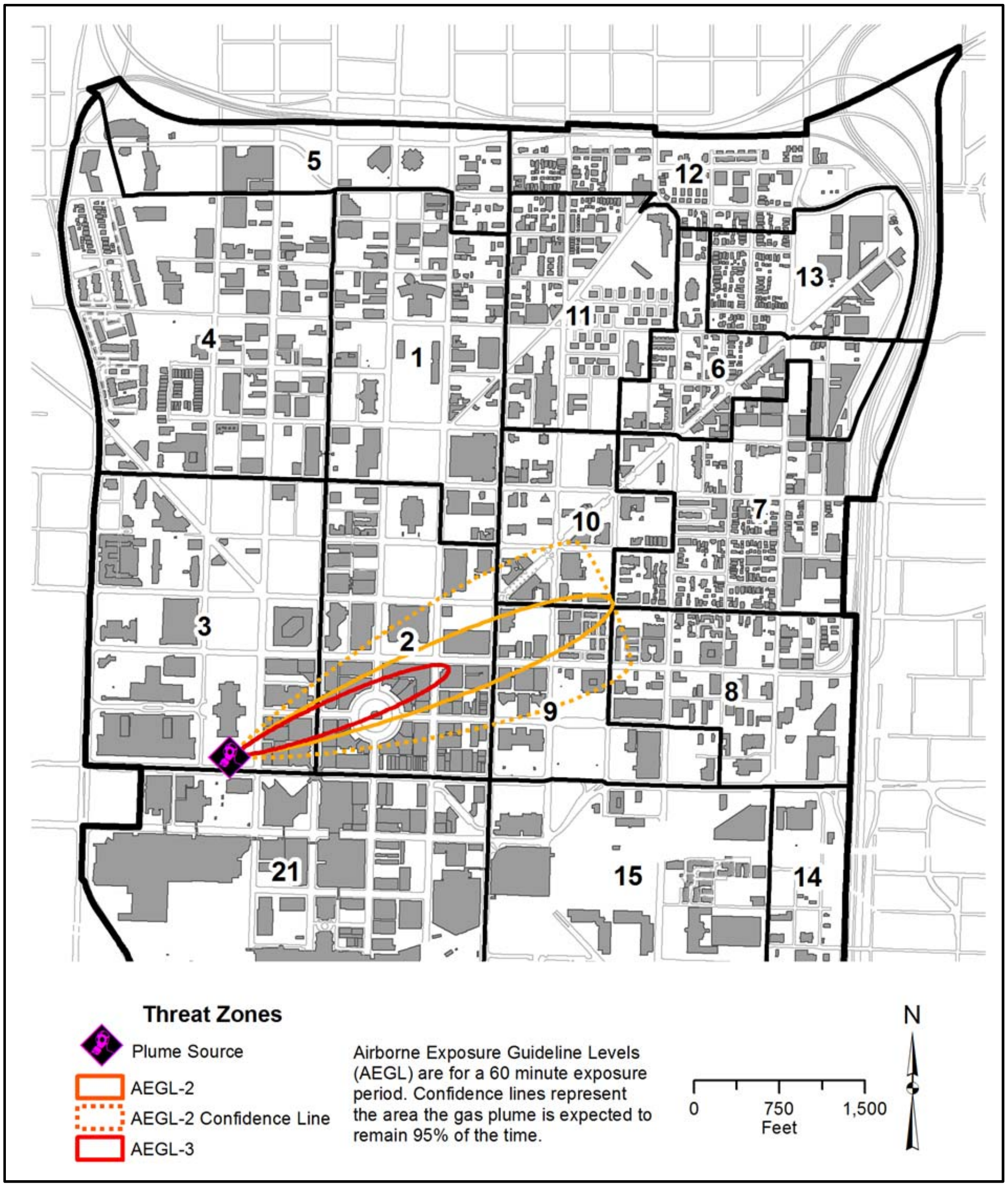

Figure 8. Simulated threat zones

Data analysis

The population affected by the simulated gas plume is calculated for each of the four estimation techniques by applying the areal weighting method outlined by Garb, et al. (2007). The population count within the AEGL-2 confidence line includes those within the AEGL-2 and AEGL-3 zones. The results are provided in Table 4.

The estimated population for the four methods is tabulated within each land zoning classification (Table 5). These data are analyzed to determine whether there is a relationship between the land zoning classification and the population estimates.

The deviation between the methods is analyzed to determine the differences between each technique. Data are aggregated at the Census block group level. Table 3 outlines each analysis to be performed, along with the corresponding figure and table number for each result. Table 6 reflects the population counts for each block group for the two population models and two estimation methods. Comparison between different methods were conducted both in aggregate form (i.e. comparing estimates for the total study area) and spatially (i.e. comparing geographic variation in agreement within the different methods by overlaying the maps with map algebra). This latter approach may identify areas of good and poor agreement between the different methods and highlight areas that help to enhance understanding of the strength and weakness of different approaches. This approach may lead to identification of study region sub-areas that could inform further refinement of the methods.

Table 3. Deviation analyses performed

Deviation Calculation			Figure No.	Table No.
LandScan	-	ESRI Daytime Pop.	13	7
LandScan	-	Parking Study	14	7
LandScan	-	Direct Count	9,12,15	7-8
ESRI Daytime Pop.	-	Direct Count	10,12,16	7-10
ESRI Daytime Pop.	-	Parking Study	17	7
Direct Count	-	Parking Study	11,12,18	7- 8

IV. RESULTS AND DISCUSSION

Comparisons between the four methods of population estimation

Population affected by the simulated plume

The ESRI model and the direct count method had very similar results, with the population estimate varying by 154 within the AEGL-2 confidence line. The LandScan model had the lowest estimate of population affected by the plume, being 49% less than the parking study method and 64% less than the direct count and ESRI methods. The parking study method also underestimated the affected population by 29%-30% relative to the ESRI model and direct count method (Table 4).

Table 4. Estimated population affected by simulated gas plume

Threat Zone	ESRI Model	LandScan Model	Parking Study Method	Direct Count Method
AEGL-3	2,018	713	1,545	2,177
AEGL-2	4,491	1,438	2,822	4,277
AEGL-2 Confidence Line	14,232	5,066	9,988	14,078

Population estimates based upon zoning classification

The LandScan model corresponded with the direct count method in the commercial, dwelling, and historic preservation districts, but severely underestimated the population within the central business district. The LandScan model also underestimated the population within the other districts relative to the other methods. The ESRI model was within at least 80% of the direct count estimate within the central business, commercial, industrial, park, and university quarter districts; in each instance, the ESRI model was less than the direct count estimate. The ESRI model was within 80% of the parking study estimate only within the central business and park districts. The parking study estimate was within 80% of the direct count estimate in the central business, industrial, and park districts (Table 5).

Population counts for each block group

Table 6 provides population estimates for each method at the block group level. Table 7 provides the deviations between the estimates, also at the block group level. Table 8 and Figures 9 through 11 are regression analyses of the ESRI, LandScan, and parking study estimates with respect to the direct count population estimate.

Table 5. Population estimates for each zoning classification

Type of Zoning	ESRI Model	LandScan Model	Parking Study Method	Direct Count Method
Central Business District	69,588	37,184	62,273	76,734
Commercial District	2,064	2,281	4,517	2,577
Dwelling District	854	1,511	4,111	1,429
Historic Preservation District	164	315	978	318
Industrial District	10,814	7,338	14,923	12,767
Park District	1,445	478	1,498	1,555
Special Use District	757	816	1,742	1,049
University Quarter District	80	45	32	93
Total	85,766	49,968	90,074	96,522

Table 6. Population estimate for each block group

ID	CensusID	ESRI Daytime Population Model	LandScan Population Model	Parking Study Method	Direct Count Method
1	180973541001	4,481	2,956	5,564	5,743
2	180973541002	20,112	6,100	17,196	21,338
3	180973541003	16,260	9,129	6,449	18,735
4	180973541004	1,540	2,890	5,619	2,239
5	180973541005	2,063	1,071	1,724	2,102
6	180973542001	342	521	2,062	524
7	180973542002	627	1,204	3,735	1,214
8	180973542003	922	1,060	3,152	2,065
9	180973542004	9,207	2,824	2,424	7,143
10	180973542005	1,477	2,548	3,456	1,647
11	180973542006	1,043	1,441	2,789	1,917
12	180973542007	367	1,005	1,840	385
13	180973542008	354	519	882	378
14	180973562001	151	339	1,139	244
15	180973562002	842	2,228	4,375	4,599
16	180973562003	12	806	132	231
17	180973562004	7,879	1,443	4,695	7,737
18	180973562005	12	278	640	134
19	180973562006	203	374	2,975	409
20	180973562007	44	92	491	92
21	180973563001	16,916	6,566	14,476	16,677
22	180973563002	684	3,833	3,448	665
23	180973563004	228	741	811	304
Total Population		85,766	49,968	90,074	96,522

Table 7. Results of deviation calculations

ID	CensusID	LandScan - ESRI	LandScan - Parking Study	LandScan - Direct Count	ESRI - Parking Study	ESRI - Direct Count	Direct Count - Parking Study
1	180973541001	-1,525	-2,608	-2,787	-1,083	-1,262	179
2	180973541002	-14,012	-11,096	-15,238	2,916	-1,226	4,142
3	180973541003	-7,131	2,680	-9,606	9,811	-2,475	12,286
4	180973541004	1,350	-2,729	651	-4,079	-699	-3,380
5	180973541005	-992	-653	-1,031	339	-39	378
6	180973542001	179	-1,541	-3	-1,720	-182	-1,538
7	180973542002	577	-2,531	-10	-3,108	-587	-2,521
8	180973542003	138	-2,092	-1,005	-2,230	-1,143	-1,087
9	180973542004	-6,383	400	-4,319	6,783	2,064	4,719
10	180973542005	1,071	-908	901	-1,979	-170	-1,809
11	180973542006	398	-1,348	-476	-1,746	-874	-872
12	180973542007	638	-835	620	-1,473	-18	-1,455
13	180973542008	165	-363	141	-528	-24	-504
14	180973562001	188	-800	95	-988	-93	-895
15	180973562002	1,386	-2,147	-2,371	-3,533	-3,757	224
16	180973562003	794	674	575	-120	-219	99
17	180973562004	-6,436	-3,252	-6,294	3,184	142	3,042
18	180973562005	266	-362	144	-628	-122	-506
19	180973562006	171	-2,601	-35	-2,772	-206	-2,566
20	180973562007	48	-399	0	-447	-48	-399
21	180973563001	-10,350	-7,910	-10,111	2,440	239	2,201
22	180973563002	3,149	385	3,168	-2,764	19	-2,783
23	180973563004	513	-70	437	-583	-76	-507
Standard Deviation		4,175	2,781	4,266	3,235	1,058	3,273

Table 8. Comparison of deviations from direct count method for each block group

ID	Direct Count Method Population	ESRI Daytime Population Model Population	Mean	ESRI Model Deviation from Direct Count Method		Direct Count Method Population	LandScan Population Model Population	Mean	LandScan Model Deviation from Direct Count Method		Direct Count Method Population	Parking Study Method Population	Mean	Parking Study Deviation from Direct Count Method
1	5,743	4,481	5,112	1,262		5,743	2,956	4,350	2,787		5,743	5,564	5,654	179
2	21,338	20,112	20,725	1,226		21,338	6,100	-9,138	15,238		21,338	17,196	19,267	4,142
3	18,735	16,260	17,498	2,475		18,735	9,129	-477	9,606		18,735	6,449	12,592	12,286
4	2,239	1,540	1,890	699		2,239	2,890	3,541	-651		2,239	5,619	3,929	-3,380
5	2,102	2,063	2,083	39		2,102	1,071	40	1,031		2,102	1,724	1,913	378
6	524	342	433	182		524	521	518	3		524	2,062	1,293	-1,538
7	1,214	627	921	587		1,214	1,204	1,194	10		1,214	3,735	2,475	-2,521
8	2,065	922	1,494	1,143		2,065	1,060	55	1,005		2,065	3,152	2,609	-1,087
9	7,143	9,207	8,175	-2,064		7,143	2,824	-1,495	4,319		7,143	2,424	4,784	4,719
10	1,647	1,477	1,562	170		1,647	2,548	3,449	-901		1,647	3,456	2,552	-1,809
11	1,917	1,043	1,480	874		1,917	1,441	965	476		1,917	2,789	2,353	-872
12	385	367	376	18		385	1,005	1,625	-620		385	1,840	1,113	-1,455
13	378	354	366	24		378	519	660	-141		378	882	630	-504
14	244	151	198	93		244	339	434	-95		244	1,139	692	-895
15	4,599	842	2,721	3,757		4,599	2,228	-143	2,371		4,599	4,375	4,487	224
16	231	12	122	219		231	806	1,381	-575		231	132	182	99
17	7,737	7,879	7,808	-142		7,737	1,443	-4,851	6,294		7,737	4,695	6,216	3,042
18	134	12	73	122		134	278	422	-144		134	640	387	-506
19	409	203	306	206		409	374	339	35		409	2,975	1,692	-2,566
20	92	44	68	48		92	92	92	0		92	491	292	-399
21	16,677	16,916	16,797	-239		16,677	6,566	-3,545	10,111		16,677	14,476	15,577	2,201
22	665	684	675	-19		665	3,833	7,001	-3,168		665	3,448	2,057	-2,783
23	304	228	266	76		304	741	1,178	-437		304	811	558	-507

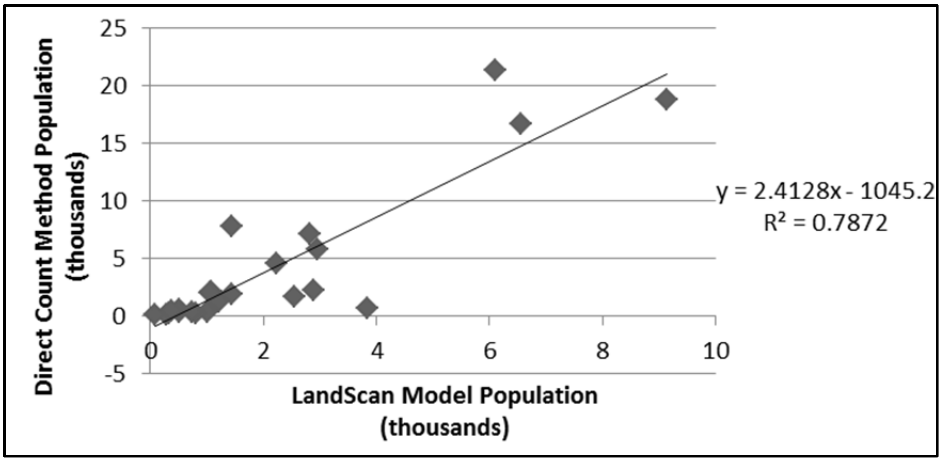

Figure 9. Regression Analysis: direct count method vs. LandScan model

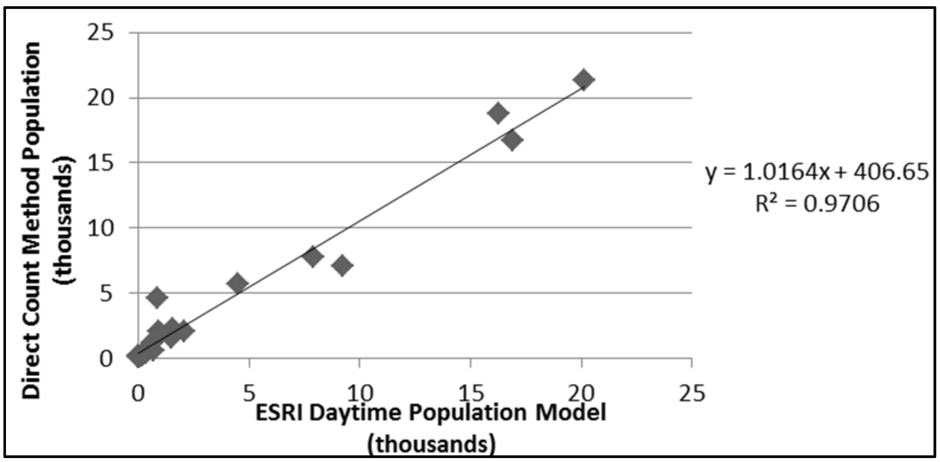

Figure 10. Regression Analysis: direct count method vs. ESRI model

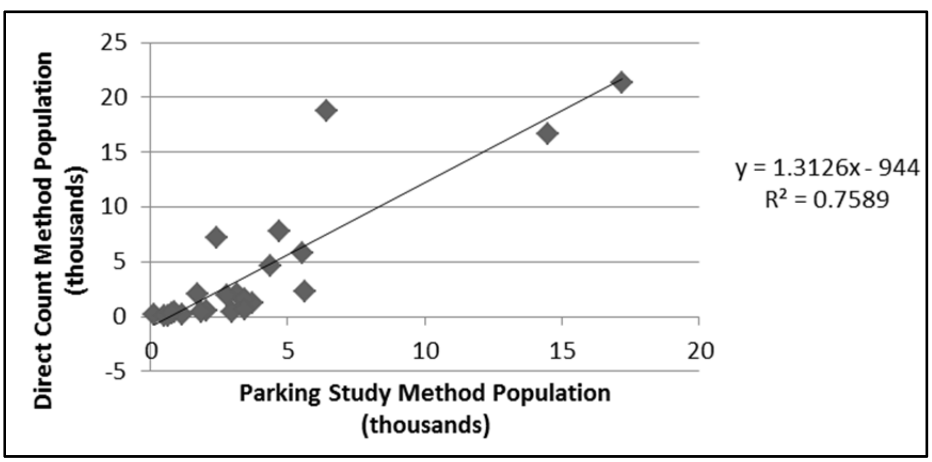

Figure 11. Regression Analysis: direct count method vs. parking study method

Analysis of LandScan data

LandScan is a global population model which represents an ambient population over a 24-hour period. The model reflected a total population of 49,968 for the study area. This model does account for population influx into the downtown area, as the study area has a 2000 Census population of 10,095 (which represents the residential population); however, the LandScan population estimate is 35,798 to 46,554 less than the three other methods for the study area. A review of Tables 5 through 8 along with Figures 9, 12, 13, and 14 indicates that the LandScan model severely underestimated the population in the dense urban areas of the central business district within block groups 2, 3, 9, and 21. The LandScan model also underestimated the population at the Eli Lilly complex in block group 17. The LandScan model provides more reasonable population estimates within lower density areas, such as residential, historic preservation, and commercial zoned areas.

At a smaller scale, the LandScan model reflects a population of 883,775 for all of Marion County, whereas the 2000 Census county population is 860,454 and the 2010 Census county population is 903,393. While the LandScan model is too coarse for use at the scale of this study, the Census data indicates it may be more applicable for a regional area of several counties.

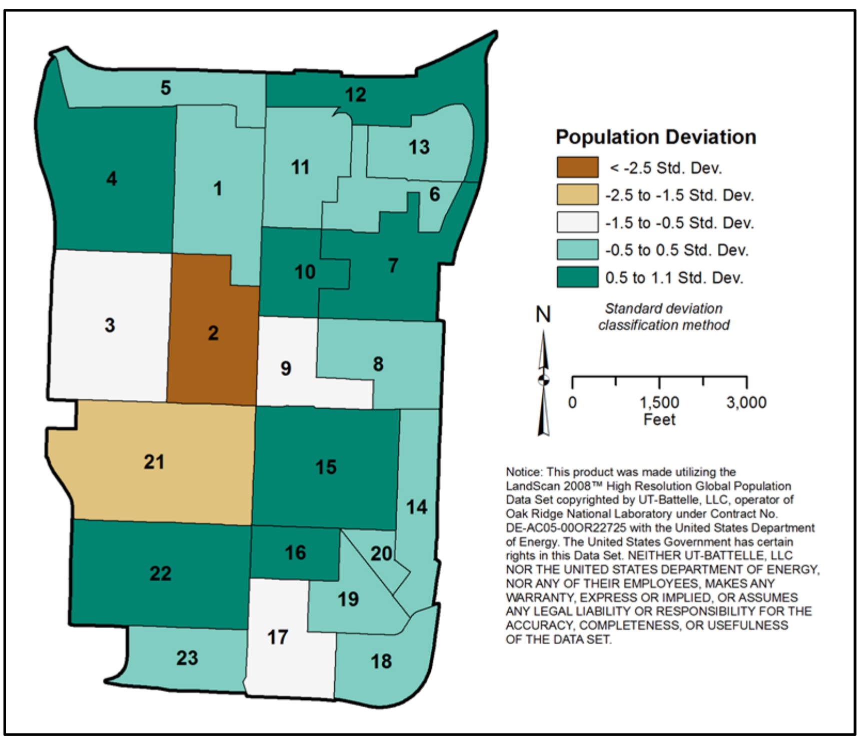

Figure 12. Analysis: LandScan - ESRI daytime population deviation calculation

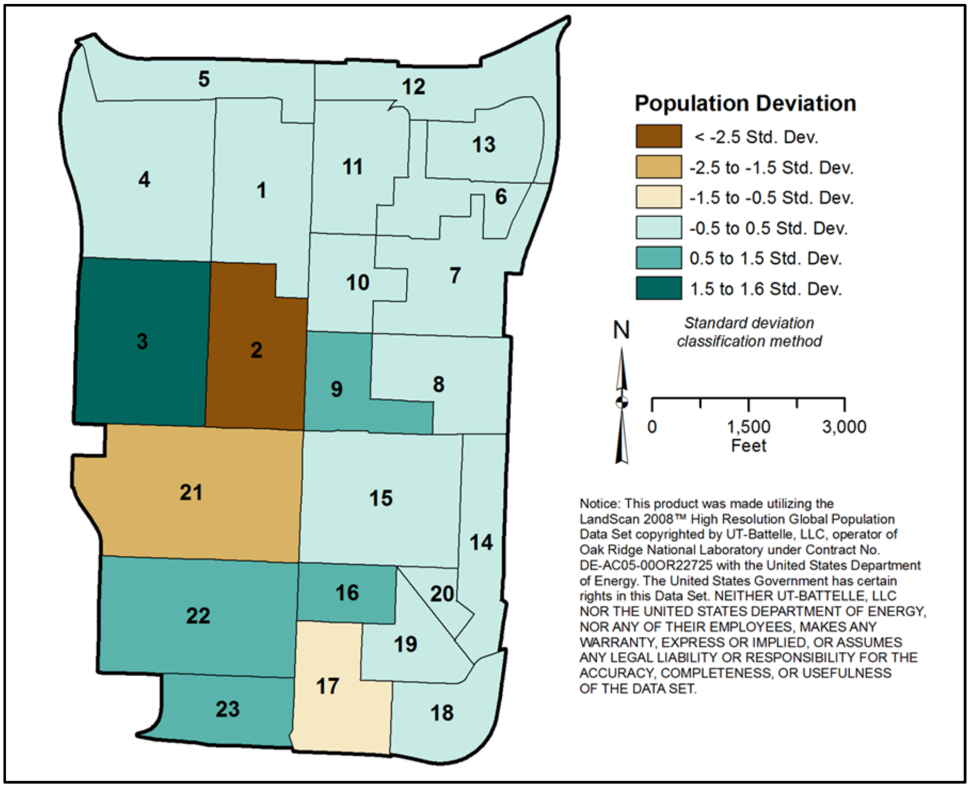

Figure 13. Analysis: LandScan - parking study estimate deviation calculation

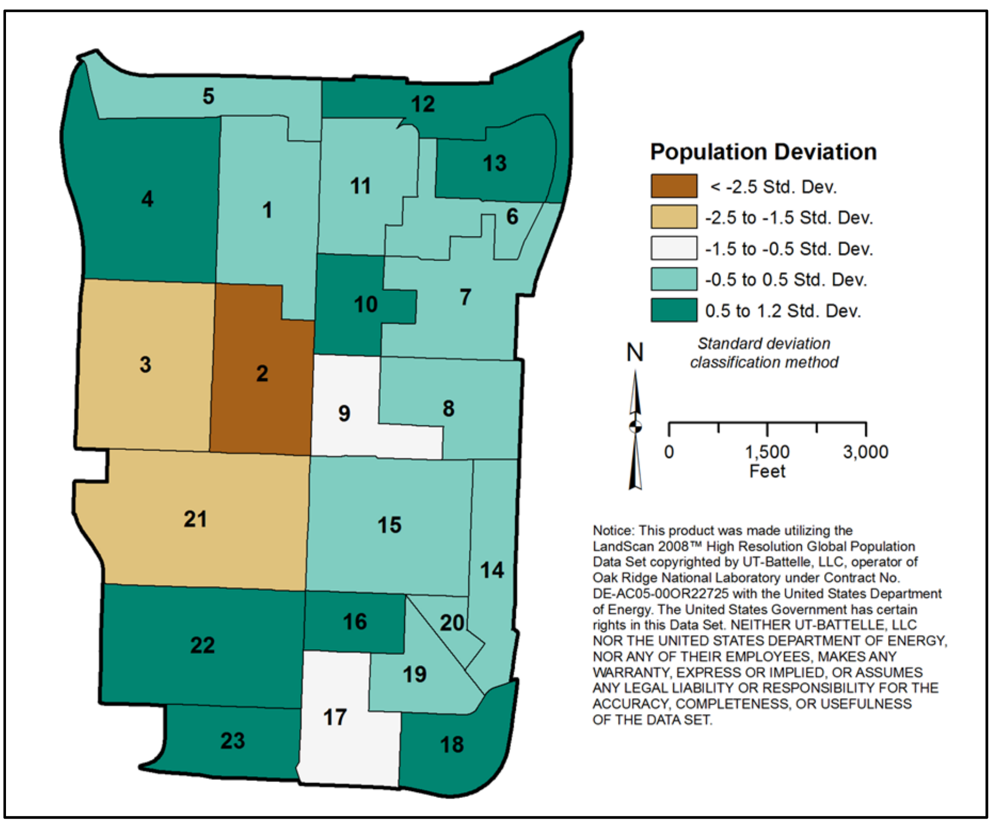

Figure 14. Analysis: LandScan - direct count estimate deviation calculation

Analysis of ESRI Daytime Population model and direct count method

Data at the block group level comparing the ESRI and direct count methods are provided in Tables 5 through 9. A regression analysis of the ESRI model and the direct count population estimate is depicted in Figure 10, and the deviations between these two models are depicted in Figure 15.

Table 9. Comparison of ESRI Daytime Population Model & Direct Count Estimate

			Direct Count Estimate			
ID	CensusID	ESRI Daytime Population Model	Employees	Residential Daytime Pop.	Additional Population	Total
1	180973541001	4,481	5,468	183	92	5,743
2	180973541002	20,112	21,322	16	0	21,338
3	180973541003	16,260	18,376	182	177	18,735
4	180973541004	1,540	1,763	386	90	2,239
5	180973541005	2,063	1,837	265	0	2,102
6	180973542001	342	429	95	0	524
7	180973542002	627	794	408	12	1,214
8	180973542003	922	974	99	992	2,065
9	180973542004	9,207	7,124	19	0	7,143
10	180973542005	1,477	1,559	88	0	1,647
11	180973542006	1,043	1,048	539	330	1,917
12	180973542007	367	216	120	49	385
13	180973542008	354	315	63	0	378
14	180973562001	151	190	54	0	244
15	180973562002	842	915	2,074	1,610	4,599
16	180973562003	12	0	7	224	231
17	180973562004	7,879	7,725	12	0	7,737
18	180973562005	12	17	117	0	134
19	180973562006	203	211	123	75	409
20	180973562007	44	33	59	0	92
21	180973563001	16,916	15,628	657	392	16,677
22	180973563002	684	437	15	213	665
23	180973563004	228	251	53	0	304
Total Population		85,766	86,632	5,634	4,256	96,522

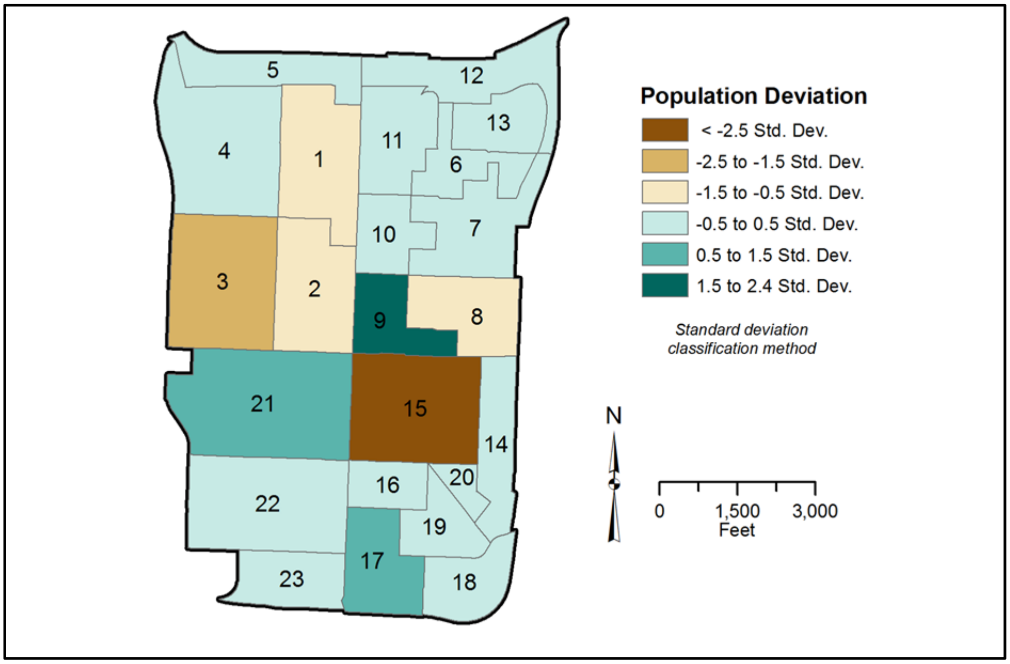

Figure 15. Analysis: ESRI daytime population - direct count estimate deviation calculation

Analysis of employment data

The ESRI 2009 USA Daytime Population model and the direct count estimate both utilized employment data provided by Infogroup, Inc. The ESRI model data is from the 2009 InfoUSA database (ESRI, 2009), whereas the direct count data is from the Infogroup Employer Database 2010 v.2, which had 98.9% of its data updated between January 2009 and January 2010. The 2010 dataset included the business address, the Census tract and block group, and the latitude and longitude as methods of spatially locating the business data. The direct count method spatially located the businesses based upon street address. It is unknown how ESRI spatially placed the business locations. Table 10 compares the employee counts between the ESRI model (2009 InfoUSA data), the raw 2010 Infogroup data, and the direct count estimate. Infogroup does not provide any information regarding the accuracy of their data, other than the addresses are 90% to 95% accurate when utilized for mailing purposes.

The direct count employee estimate is 3,585 people less than the raw employee count due to businesses having multiple listings. As an example, the law firm of Barnes & Thornburg LLP (within block group 21) is listed in the Infogroup database as having 500 employees, which corresponded with information on their website; however, 68 of the attorneys were also individually listed as separate business entities, resulting in employees being counted more than once. In this instance, there was an over-count of 1597 employees in the raw data. The direct count employee estimate is greater than the raw data count in two block groups due to businesses having incorrect addresses which erroneously placed them within the study area.

Table 10. Comparison of employee populations with ESRI model and Direct Count method

ID	CensusID	Unedited (raw) Infogroup 2010 data	Direct Count Employee Estimate	Difference between unedited data & Direct Count estimate	ESRI Employee Population	Direct Count Employee Estimate	Difference between ESRI population & Direct Count estimate
1	180973541001	5,483	5,468	15	4,481	5,468	-987
2	180973541002	21,815	21,322	493	20,112	21,322	-1,210
3	180973541003	18,474	18,376	98	16,260	18,376	-2,116
4	180973541004	1,740	1,763	-23	1,540	1,763	-223
5	180973541005	2,328	1,837	491	2,063	1,837	226
6	180973542001	447	429	18	342	429	-87
7	180973542002	801	794	7	627	794	-167
8	180973542003	1,053	974	79	922	974	-52
9	180973542004	7,168	7,124	44	9,207	7,124	2,083
10	180973542005	1,575	1,559	16	1,477	1,559	-82
11	180973542006	1,094	1,048	46	1,043	1,048	-5
12	180973542007	216	216	0	367	216	151
13	180973542008	315	315	0	354	315	39
14	180973562001	190	190	0	151	190	-39
15	180973562002	925	915	10	842	915	-73
16	180973562003	1	0	1	12	0	12
17	180973562004	7,725	7,725	0	7,879	7,725	154
18	180973562005	21	17	4	12	17	-5
19	180973562006	211	211	0	203	211	-8
20	180973562007	33	33	0	44	33	11
21	180973563001	17,888	15,628	2,260	16,916	15,628	1,288
22	180973563002	417	437	-20	684	437	247
23	180973563004	297	251	46	228	251	-23
Total Population		90,217	86,632	3,585	85,766	86,632	-866

The direct count employee estimate may still be over-inflated, as there were several businesses which appeared to count employees twice; however, there was insufficient information to confirm multiple counting. For example, the City-County Building (within block group 9) has

3,999 employees in the raw dataset, with 2,100 of these having the employer “City-County Building”, while the remaining 1,899 are listed with 84 specific governmental agencies or private business entities. The direct count estimate included all 3,999 employees. Note that the ESRI employee count was 2,083 higher than the direct count employee estimate for block group 9; if the employee count within the City-County building had been adjusted, the population difference between the ESRI and direct count methods would have been approximately 4,000.

There are other issues related to the employee data which impact both the ESRI model and the direct count method. Shift work is not considered, as all employees are assumed to be present during the daytime. Further, some employee counts appear to include employees who work at a separate location. For example, the Indianapolis Public Schools (IPS) Service Center occupies four buildings within block group 13, yet Infogroup did not provide data for this location. These employees are presumed to have been included in the employee count at the IPS headquarters located within block group 1. Further, employee counts may be skewed where businesses have multiple buildings with the same mailing address. For example, the Infogroup data assigns Eli Lilly employees at the Lilly Corporate Center to two addresses; however, there are 25 buildings associated with these two addresses. Due to the data being aggregated at the block group level, this issue did not affect the study; however, this would impact studies where these data are aggregated at the building or city block level.

A comparison of the ESRI employee population with the direct count employee population revealed the total populations for the entire study area varied by only 866 employees, which may be accounted for by changes in employment; however, counts within individual block groups varied by over 2000 employees in both the positive and negative direction. The reason for this variation cannot be determined without further knowledge of the raw data used by ESRI in the creation of their model.

Advantages and disadvantages of the ESRI 2009 USA Daytime Population and direct count methods

The primary advantage of the ESRI model is that it is publicly available from the ESRI MapServer website and is updated on a yearly basis. This model could also be modified within a GIS to include additional populations present (such as school children and prisoners) within each block group.

The ESRI 2009 USA Daytime Population model has at least four disadvantages. First, unlike the direct count estimate, this model only tabulates the number of workers by place of employment. Other people present during the daytime, such as the residential population present during the daytime and those hospitalized, in school, and incarcerated are not included in this model. Second, the ESRI model aggregates the employment data at the Census block group level, which prevents utilizing these data at a higher spatial resolution (such as determining the number of workers employed within a building or a city block). Furthermore, since these data are already compiled by ESRI, they cannot be reviewed to determine whether the data issues discussed in the Employment Data section were rectified or are a part of the dataset. Finally, from the standpoint of usability, these data are provided as a ratio of the number of workers per 100 residents, rather than as a ratio based upon the area of the block group or in a non-ratio format wherein the total number of employees is provided.

The direct count method initially aggregated employment data at the building level, in contrast to the ESRI model which aggregated the employment data at the block group level. This provides the flexibility of creating additional population models (daytime versus evening and weekday versus weekend) by analyzing each business in order to estimate employee counts for evening and weekend shifts. The direct count method also has the flexibility of aggregating data at a census block or city block level, rather than at the block group level. Furthermore, as previously discussed, the direct count method includes additional non-employee population present during the daytime.

The primary disadvantage of the direct count method is the time consuming process of reviewing, geocoding, and manually placing the employment data within the proper buildings. Both the ESRI and direct count methods have the additional disadvantage of not including other population segments in their estimates. Examples of these populations include those visiting the area for shopping, business, and tourism.

Parking study analysis

The deviations between the parking study estimate and the ESRI and direct count methods are depicted in Figures 16 and 17, and the regression analysis between the parking study and direct count estimates is depicted in Figure 11.

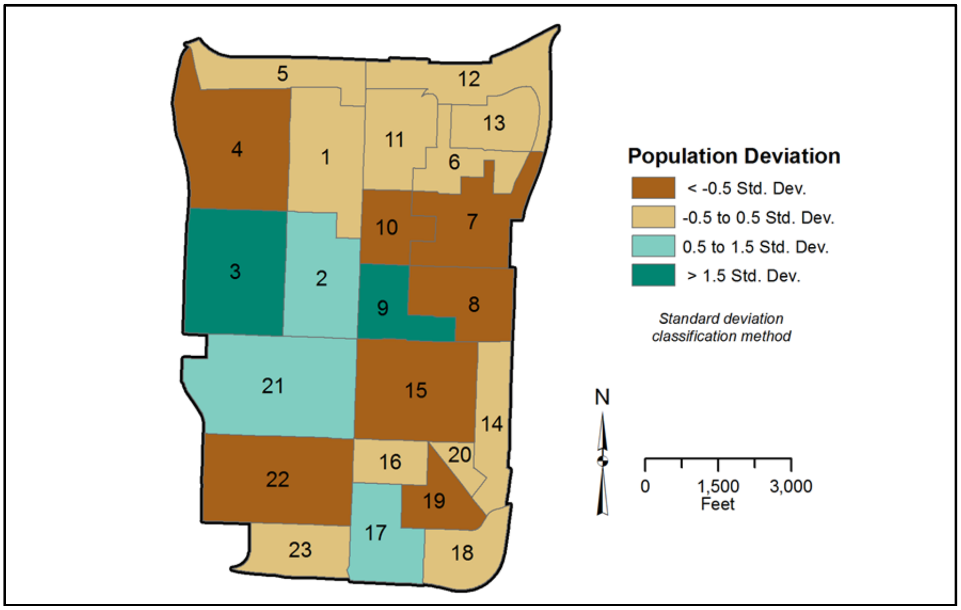

Figure 16. Analysis: ESRI daytime population - parking study estimate deviation calculation

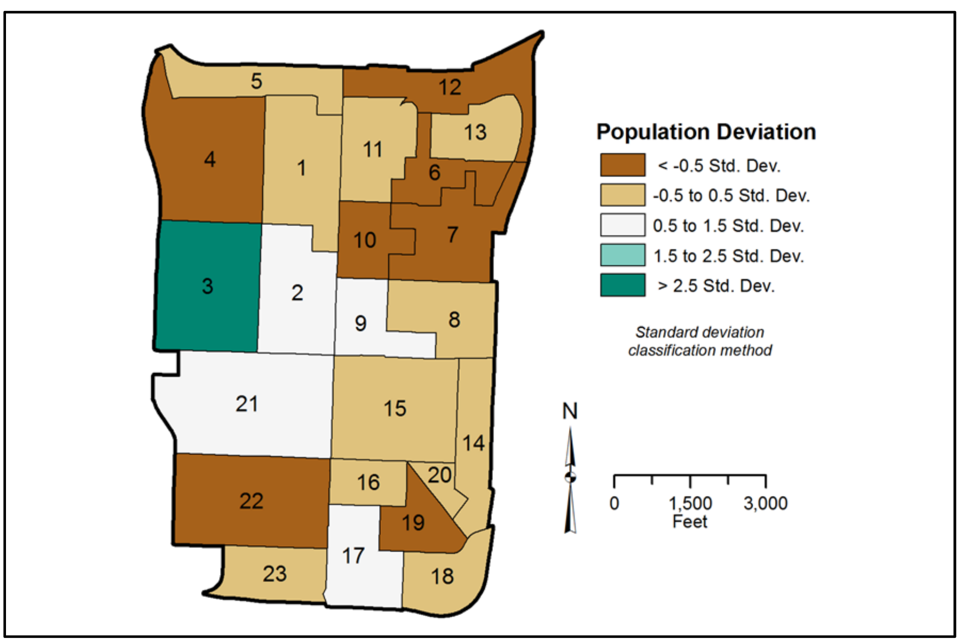

Figure 17. Analysis: direct count estimate - parking study estimate deviation calculation

The Center Township Assessor identifies and appraises all taxable land parcels within the Township, and maintains a database which includes the gross square footage of various uses within a building. There are limitations with these data; first, the Assessor does not maintain records on exempt, non-taxable real estate such as land owned by a governmental agency or not-for-profits. Thus, building square footages were not provided for buildings on these non-taxable parcels. Furthermore, many vacant and/or abandoned buildings are considered taxable properties; the square footages of these buildings are included in this estimate. Finally, new construction which has not been assessed is not included in these data.

There was one land parcel associated with the Eli Lilly Corporate Center which was located across three block groups. The centroid of this parcel (and the 1628 people associated with it) was located within block group 19, whereas the ESRI and direct count methods tabulated the population associated with this parcel in block group 17. While this was the only instance of a land parcel located across more than one block group, this may be an issue if data are aggregated at the census block level.

Many buildings were located across more than one land parcel with the tax information for these buildings associated with only one of the parcels. Likewise, there were instances of properties consisting of multiple buildings where the tax records for these buildings were associated with a parcel in which the buildings were not situated upon. Since these data were aggregated at the block group level, this issue did not impact the study; however, this may influence the results of future studies which are performed at a larger scale.

An analysis revealed there were 75 buildings which were not included in the Assessor's data (Figure 18). Table 11 outlines the building use and the corresponding number of unaccounted buildings. Thirty-nine of these buildings had an estimated population generated in the direct count method. These population estimates were aggregated at the block group level in Table 12. The substantial under-estimate in block groups 3 and 9, as compared with the ESRI model and the direct count estimate, can be attributed to the governmental office space which was not included in the population estimates.

The parking study method generated a higher population within the dwelling, commercial, historical preservation, and special use zoning districts, indicating that this method includes that portion of the residential population which is not located within the study area during the daytime.

Since this method is based upon a study which analyzed the parking requirements for the downtown area, it may account for that portion of the daytime population which is visiting the area for business, shopping, or tourism purposes. It is worth noting that this method does not include the population which utilizes a mode of transportation other than privately owned vehicle. While this method has the noted deficiencies, it may provide a better daytime population estimate if vacant buildings were excluded and square footages were available for all occupied buildings.

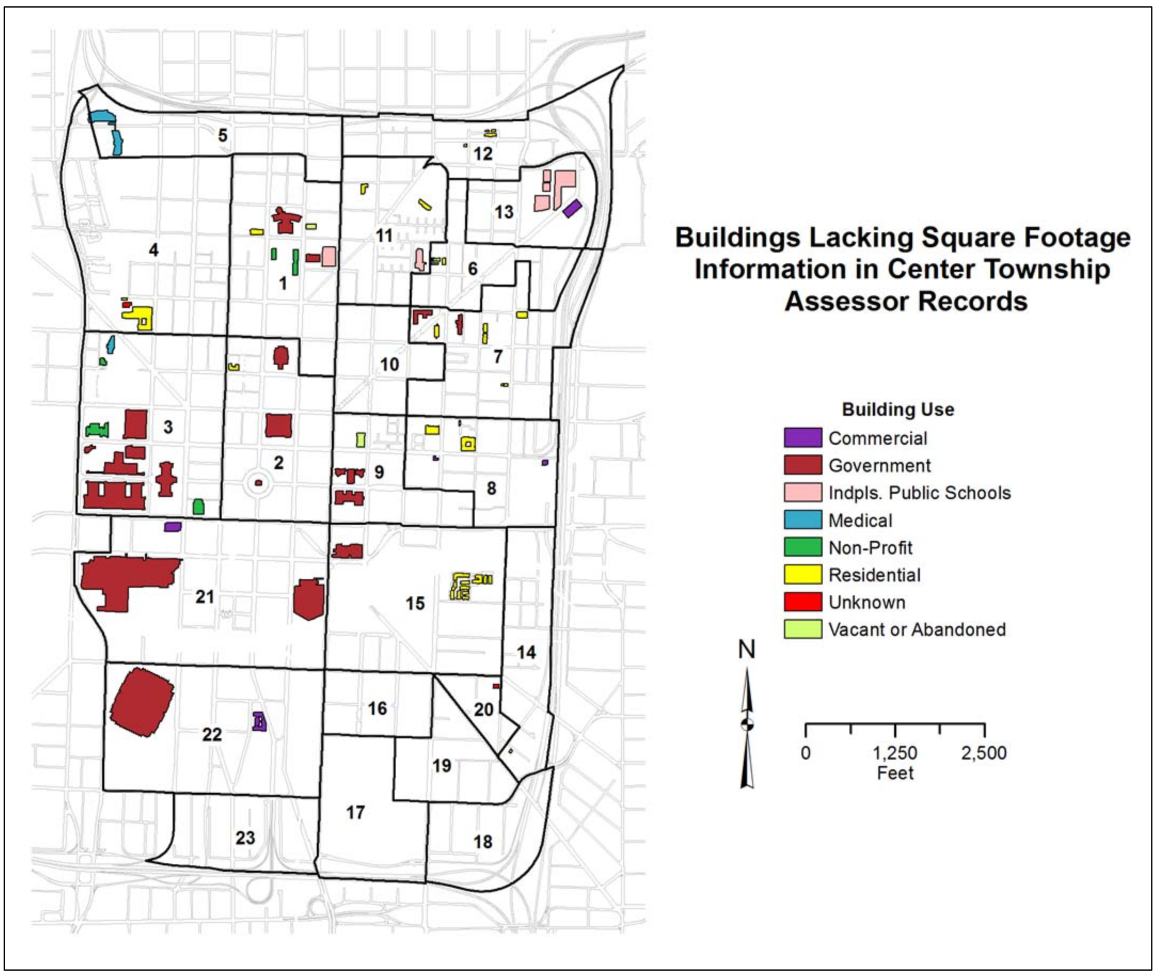

Figure 18. Buildings not included in parking study estimate

Table 11. Buildings not included in Parking Study Estimate

Building Use	Number of Buildings
Commercial	5
Government Owned	19
Indpls. Public Schools	7
Medical	2
Non-Profit	5
Residential	32
Unknown	2
Vacant or Abandoned	3
Total	75

Table 12. Estimated populations of buildings not included in Parking Study estimate

ID	CensusID	Number of Buildings	Population associated with these buildings from direct count method
1	180973541001	7	1,549
2	180973541002	4	163
3	180973541003	10	9,686
4	180973541004	3	3
5	180973541005	1	162
6	180973542001	3	0
7	180973542002	8	95
8	180973542003	5	8
9	180973542004	3	4,537
10	180973542005	0	0
11	180973542006	3	378
12	180973542007	4	1
13	180973542008	5	0
14	180973562001	1	0
15	180973562002	12	1,455
16	180973562003	0	0
17	180973562004	0	0
18	180973562005	0	0
19	180973562006	0	0
20	180973562007	1	11
21	180973563001	3	2,880
22	180973563002	2	16
23	180973563004	0	0
Total		75	20,944

Future Directions

There are several lines of research which have the potential to improve upon the population estimates developed in this study. The first is to estimate other segments of the population within the study area. The second is to evaluate the LandScan USA model. The monitoring of cellular telephone usage and the passive tracking of these phones is the third area of research, while the evaluation of traffic analysis zones is the final area.

Supplemental data to ESRI model and direct count method

As previously noted, the ESRI model and direct count method utilize employment data in the generation of their estimates. The direct count method also includes the school, daycare, prison, and daytime residential populations in its estimate; however, there are several segments of the population which are not included in either estimate. As noted in prior research, the irregular influx of visitors to an area can dramatically impact the daytime population (Sleeter & Wood, 2006). Within the study area, predictable influxes of 20,000 to 70,000 people occur for those events held at Conseco Fieldhouse, Lucas Oil Stadium, and the Convention Center. Population estimates at these locations can be added to a dynamic daytime population model.

Other visitors to the area, such as business travelers, tourists, those at retail and recreation areas, and commuters utilizing the transportation network should also be included in a population model (Bhaduri, 2008). Additional research is necessary to effectively model this transitory population. Potential avenues may include a multi-tiered approach of utilizing origin-destination studies and the Institute of Transportation Engineers' trip generation data in conjunction with the known population estimates. The results could then be compared with the parking study estimate (modified to account for the buildings erroneously included or excluded) to determine whether there is a correlation between the estimates.

LandScan USA

As discussed previously, the 2008 LandScan Global Population Model has a spatial resolution of 30 arc-seconds, which is equivalent to approximately 1 kilometer at the equator. The Oak Ridge National Laboratory has also developed the LandScan USA model, which has a spatial resolution of 3 arc-seconds (approximately 90 meters). LandScan USA Version 1.0 consists of datasets for both the nighttime residential (including prisoners) and daytime population (which includes prisoners, students, and the mobility of workers). Populations are computed at a finer 1 arc-second grid cell based upon land cover, proximity to roads and railroads, slope, landmarks (being businesses, religious institutions, and schools), parks, prisons, and airports, in conjunction with the employment data and prisoner and student counts. The census block population was utilized for control purposes in the allocation of residential population. These data were then aggregated at the 3 arc-second level (Bhaduri, Bright, Coleman, & Urban, 2007). Future versions of the model will include the seasonal population fluctuation, accounting for visitors, resulting in high/low season, daytime/nighttime grids (Kim et al., 2011). The evaluation and comparison of the LandScan USA model with the direct count method may reveal that the LandScan USA model is adequate for emergency planning and response at the local level.

Cellular telephone study

A study related to mapping the intensity of cellular telephone activity involved the collection of data from cell phone antennas in Milan, Italy over a 16 day period in 2004 (Pulselli, Ratti, & Tiezzi, 2006; Ratti, Frenchman, Pulselli, & Williams, 2006). Each cellular base station has its coverage area divided into sectors (usually three). Cellular traffic intensity is measured in erlangs, where one erlang equals one caller speaking on a phone for one hour. Hourly data, with the number of erlangs per sector, were acquired for the 1071 sectors within the 400 km^2 area around the center of Milan, with each sector covering an area approximately 400-500 meters from the base station. The intensity of cell phone usage within each sector was then analyzed, which revealed the characteristics of the neighborhood in which the base station was located. The intensity of cell phone coverage was also plotted in order to represent the spatial and temporal variations in usage of the cell base stations. It was found that the maximum intensity of calls progressed from the suburbs in the early morning to a peak at noon within the core central district. Finer resolution maps indicated a high intensity of activity during rush hour at Milan’s Stazione Centrale (a railway station).

The SENSEable City Laboratory at the Massachusetts Institute of Technology presented an exhibit at the Kunsthaus Graz (Austria) entitled “Mobile Landscapes: Graz in Real Time”, which was a part of the M-City exhibition from October 1, 2005 through January 8, 2006. It consisted of three real-time maps. The first depicted an animation of the cell phone traffic intensity for the previous 24 hours, utilizing the same concept as the research in Milan. The second map depicted the traffic migration of cellular phones throughout the network, wherein the traces between base station sectors were plotted for cellular calls which utilize more than one base station. The third map displayed the trajectories of individual cell phones throughout Graz for the previous 24 hours; these phones were “paged” every five minutes to determine the base station and corresponding geographical coordinates for the central point of the cell (Ratti, Sevtsuk, Huang, & Pailer, 2007).

The ability to locate and track individual cell phones has continued to evolve, as represented by the “Real Time Rome” project, which was a proof of concept for the Tenth International Architecture Exhibition of the Venice Biennale. Telecom Italia developed a software platform which can determine the actual location of a cellular device and its corresponding speed in order to analyze traffic flow. Real time raster traffic maps with a spatial resolution of 250 meters were generated every five minutes for an area of approximately 100 km^2; these maps were color coded to indicate areas of slow and fast moving traffic. Raster cells with an average speed greater than 40 km/h also had a proportionally sized arrow (based upon speed) depicting the direction of traffic flow (Calabrese, Colonna, Lovisolo, Parata, & Ratti, 2011).

The SENSEable City Laboratory has participated in these research projects regarding the geographic location of cell phones in order to better understand the urban landscape, with the premise that cell phone activity is correlated with the population present in an area. The Laboratory has proven the ability to map cellular telephone intensity, the migration of cellular traffic, and the real-time tracking of individual cellular phones. As this research evolves, finer spatial resolution maps may become available for both the determination of typical population distributions throughout a city (for various temporal periods) and as real time data, depicting the number of people present during an emergency situation.

Traffic analysis zones

A traffic (or transportation) analysis zone (TAZ) is utilized to tabulate traffic-related data, particularly the journey-to-work and place-of-work statistics. The area covered by each TAZ is defined at the local level to meet planning needs; thus, the geographical extents of each TAZ can vary from a single city block to several blocks. These data are compiled in the Census Transportation Planning Package (CTPP), which includes the worker flow data as well as some demographic data (Christopher, n.d.). The recommended size of a TAZ is a resident or worker population of at least 1,200 (Federal Highway Administration, 2011). Figure 19 illustrates the relationship between the 23 block groups and the 59 TAZ which are partially or entirely within the study area.

Researchers at the University of Utah and Oak Ridge National Laboratory performed a study utilizing CTPP data at the TAZ level to model the hourly urban population change in Salt Lake City, Utah during a typical workday (Kobayashi, Medina, & Cova, 2011). The population surfaces were generated utilizing a pycnophylactic method of areal interpolation, and a raster with 50 meter resolution was generated for each time frame. Three-dimensional models were generated to create the graphics for an animation depicting the changes in population throughout the day. This method also allows for the generation of static, two-dimensional population maps for each time frame, as well as three-dimensional models of change in population for a specified time interval. The model was then applied to a scenario involving a theoretical dirty bomb blast, wherein the census block data indicated 167 people would be affected, whereas the TAZ model indicated 4,679 people are impacted at the time of the initial blast.

This model is similar in concept to the ESRI and direct count methods, in that it utilizes worker data to generate the population count. The TAZ provides more spatial detail than the block group, as several TAZ within the study area are the size of a city block. The TAZ model also has a higher temporal resolution, providing population counts at an hourly level in contrast to the ESRI and direct count methods which represent the daytime in its entirety. As discussed by Kobayashi, the TAZ model includes only trips to and from workplaces, and does not include non-work travel such as shopping and recreation. Future work may involve combining aspects of the direct count method with the TAZ model; i.e. adding other fixed populations (such as school children and prisoners) to the model at the appropriate time intervals, and comparing the results to those of the direct count method.

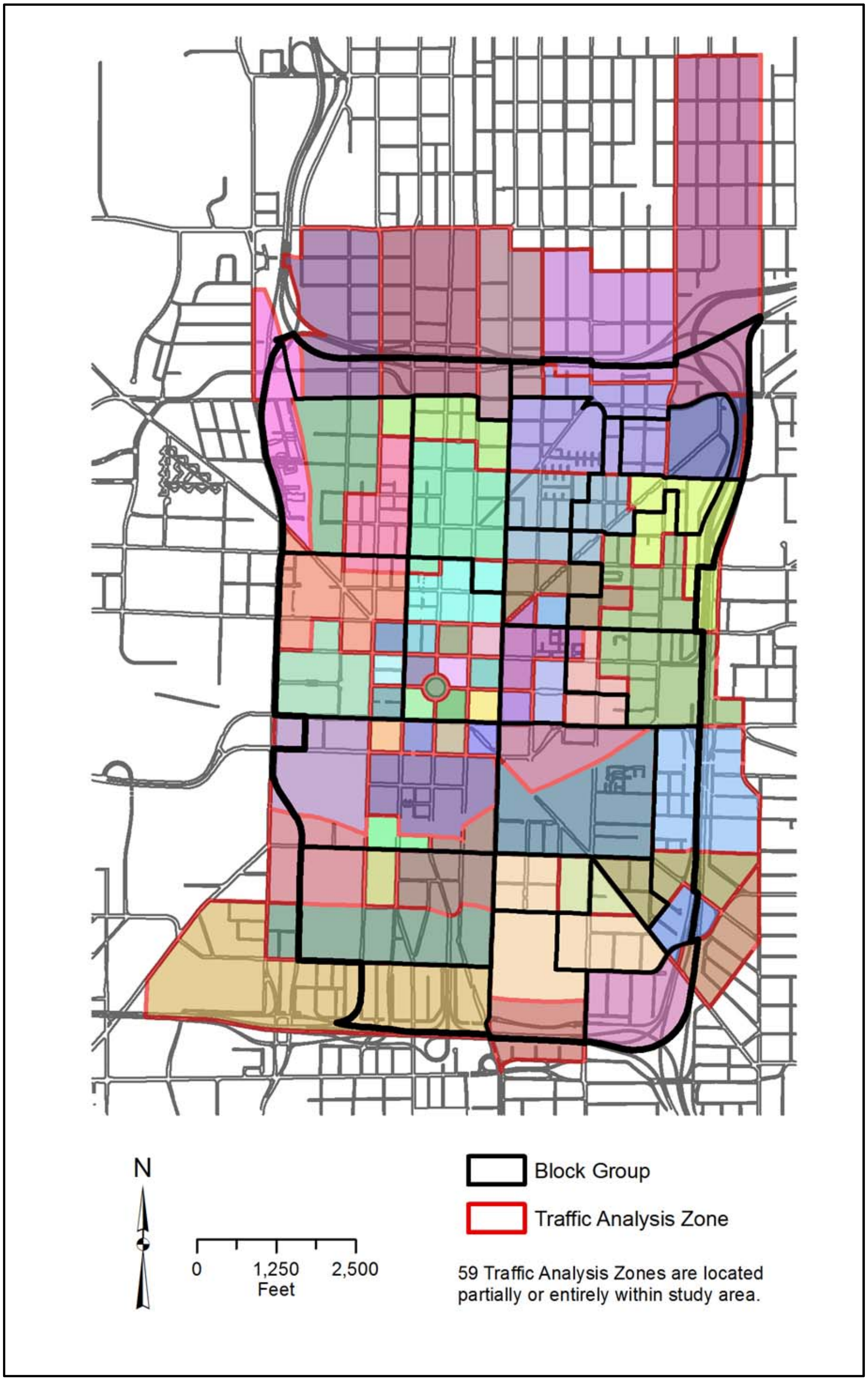

Figure 19. Traffic analysis zones within study area

V. CONCLUSIONS

Accurate population counts are necessary for an appropriate emergency response to an incident affecting the citizenry. Four types of population estimates were evaluated in this study. The direct count estimate tabulated those segments of the population considered to be at static locations throughout the day, which consisted of employees, daycare and school children, prisoners, and the daytime residential population. The ESRI 2009 USA Daytime Population model is very similar to the direct count method, but includes only the employee count. The parking study method, which is based upon the gross square footage of buildings, estimated a population within 6,448 of the direct count method; however, it did not include 75 buildings which have an employee population of 20,944. The 2008 LandScan Global Population Model was developed by the Oak Ridge National Laboratory and consists of a grid with a resolution of 30 arc-seconds. The estimated population was 48% less than the direct count estimate.

The direct count method was determined to be superior for use in emergency response at the local level, as it included more segments of the population than the ESRI model. Additionally, the data utilized in this method is initially associated with individual buildings; thus, it can be aggregated at the building or block level, rather than the block group level (as used in this study), resulting in a finer spatial resolution. This would, for example, provide emergency responders an estimate of the number of people who may need to be evacuated from a specific building or a city block. This finer resolution also allows for the population within each building to be associated with the nearest street intersection node (Figure 20), which is of particular value in the use and application of transportation planning and analysis software. The disadvantages of the direct count method include the time consuming process of collecting, evaluating, and geocoding the data; the proper allocation of employee population for businesses with multiple buildings; and the exclusion of other segments of the population within the study area, such as those visiting for shopping, recreation, tourism, and business.

The ESRI 2009 Daytime Population model is recommended for use where the spatial resolution of the block group is acceptable. The model consists of a ratio of the number of employees per 100 resident population, from which an employee population count can be generated. It is further recommended that the model be locally modified with supplemental population counts, such as school children and prisoners. The disadvantages of this model include the inability to analyze the employee data utilized by ESRI in the generation of the model and, like the direct count method, the exclusion of other segments of population within the study area.

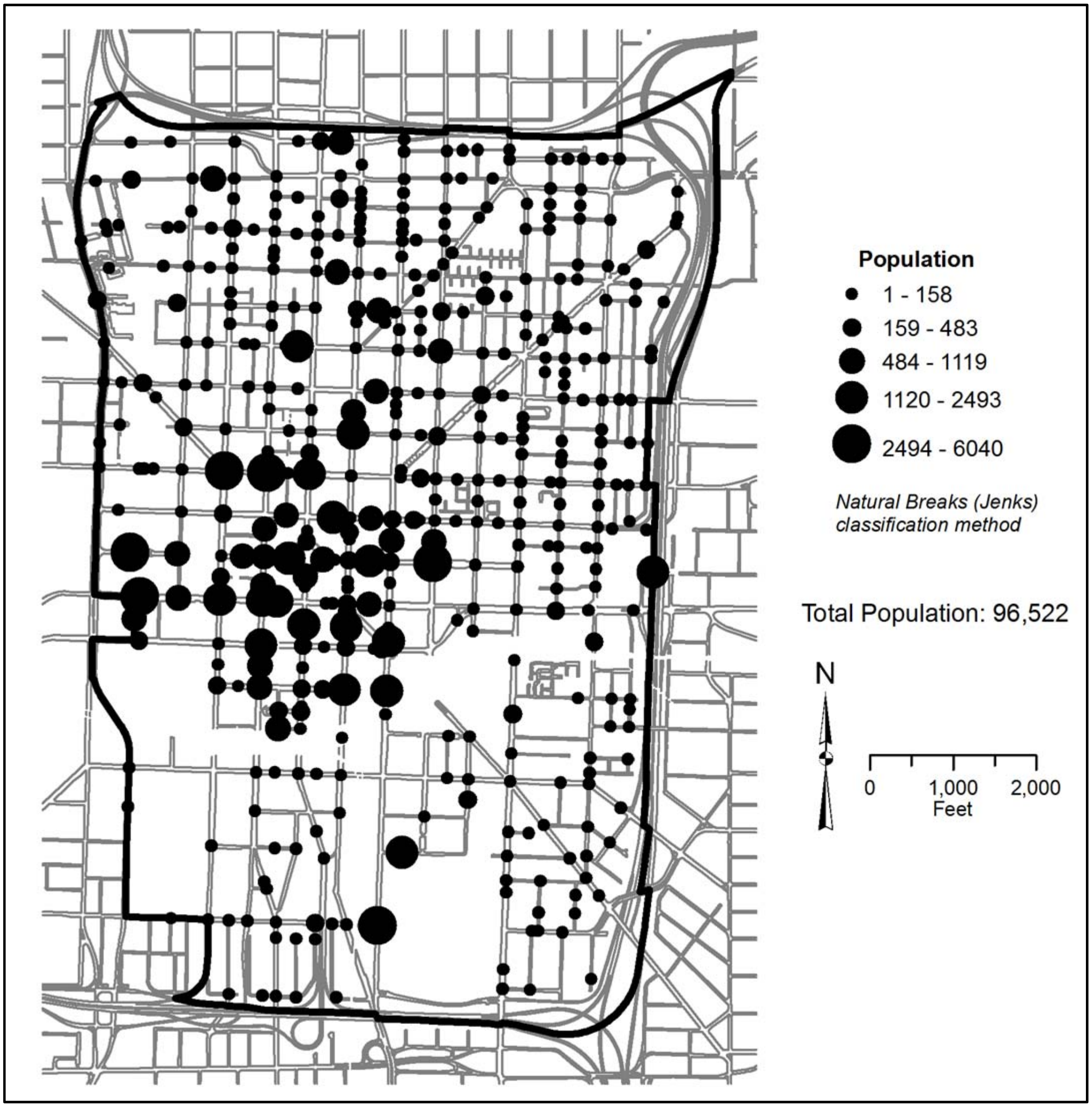

Figure 20. Direct count population placed at nearest street node

The 2008 LandScan Global Population Model is too coarse, with respect to both the population estimate and the size of the grid, for application in a local emergency response. The county-wide population estimate, however, was within 3% of the 2010 Census residential population for Marion County. It is recommended that further research be performed to determine the suitability of the LandScan model for multi-county emergency response.

The parking study estimate has the disadvantage of being dependent upon the Assessor for providing square footages of buildings; these records are incomplete with respect to new construction and land parcels which are not taxed. Furthermore, many vacant and abandoned buildings are on the tax roll, which inflates the estimated population. Further research related to this model at the building level would include determining whether there is a relationship between the land zoning classification, the number of employees, and the resulting parking study estimate.

Future directions of estimating the daytime population within the study area include analysis of the LandScan USA model, which has a spatial resolution of 3 arc-seconds; research related to the locating and tracking of individual cell phones; and the use of traffic analysis zone data in the modeling of the population. These new data, in conjunction with data from the current study, may result in further refinement of these daytime population estimates.

The population present within the study area is fluid and dynamic; however, these population models are a static representation of the location of the citizenry, providing an estimate which will assist emergency management agencies in their planning and response to incidents. Future research will continue to improve these estimates to provide more accurate population counts for different temporal periods.

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