People, Planet, Profit and Parking:

Mapping the Effect Autonomous Vehicles Will Have on Cities

GEOG 596 Summary Report

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Abstract

The adoption of autonomous vehicles will have an impact on the constructed environment in many areas, particularly in cities. If car-sharing become widely adopted, the need for parking storage could reduce drastically. A reduction in parking will affect the environment, economy and people. The urban heat island effect, driven substantially by the heat retention of pavement, will be lessened. The transformation of surplus parking into other uses, such as parks and buildings, will change land values. Potential implications of these effects are mapped by combining publicly available data with Geographic Information Systems (GIS). This case study analyzes current and projected automobile and transit usage, parking storage, urban heat island effects, and property values in the city of Minneapolis. Each aspect of this project maps current conditions and forecasts various scenarios if autonomous vehicle were adopted. This study hopes to assist planners, engineers, policymakers, etc., in visualizing the impact self-driving cars could have to help in making decisions for the future.

Introduction

This capstone project explores the effect widespread autonomous vehicle may have on the urban form. It supposes the ownership of personal vehicles would decrease and make existing parking facilities mostly superfluous through the widespread adoption of autonomous vehicles and some form of car sharing (Fagnant, 2014). Using the city of Minneapolis as case study, this projects seeks to answer the question: How will the projected reduction of parking from autonomous vehicles impact environmental, social and economic sectors in an American city? Minneapolis developed in the 19th century before auto-oriented planning, but through the last century has—as many American cities—focused its infrastructure on the car in the form of hierarchical streets networks, wide roads, and ample amounts of land devoted to parking. This project relies on publicly available data and GIS technology as tools to model future scenarios in which land devoted to parking is decreased and also reused. This report narrows down the broader topic into specific sectors, reviews the current literature, identifies common themes, and delves into the metrics, methods, outputs, results and limitations of such projections. Using the approach introduced by Ian McHarg in *Design By Nature* (1969), this project is viewed through the lens of three sectors: economic, environmental and social. McHarg, a landscape architect and early practitioner of GIS, looked at the different uses land can have and also how data and maps can inform decisions made about the built environment.

For each sector, factors were investigated to measure the reduction of surface parking and parking garages in the city. For the economic sector, this project looked at how property values and future development were affected if parking were replaced. In the environmental sector, urban heat islands were studied and also how transforming parking storage into parks could change surface temperatures in the city. For the social sector, the project shows how automobile usage and transit usage may change with the adoption of this new technology.

Literature Review

A central idea found in the literature is that self-driving vehicles—if widely adopted—could become more like autonomous taxis, where one could order a car for pickup and drop off, instead of owning a personal vehicle (Greenblatt, 2015). With the typical car parked 95% of the time, autonomous taxis could make more efficient use of the automobile supply. A reduction in parking would also have a drastic effect on the urban environment, potentially reducing the 31% of the total area American downtowns currently devote to parking (Shoup, 2005).

This could allow the emergence of adaptive reuses of parking, such as garages as “accessory dwelling units”, or empty parking lots turning back to nature, or wide thoroughfares shrinking. This may necessitate changes in car-oriented cities, but may be slightly easier in “cities laid out and built before the automobile, where much of the street grid can be retrofitted to disallow high-speed traffic”. Levinson’s *Mount Next: The Effects of Autonomous Vehicles on Society* article explores many of the facets of how AVs (autonomous vehicles) will be a paradigm shift, including on the urban form:

- parking will be repurposed
- any parking storage will not need to be near valuable urban areas
- on street parking will not be needed at all

(Levinson, 2015).

There is uncertainty on whether this new trend will densify or disperse the urban form. Urban development could become less dense, due to the ease and comfort of future AVs and continuing the trend of the late 20th century, or “in contrast... AV technology could also lead to greater density in core urban areas (Anderson, 2014).

Economic

Reducing parking could greatly drive down annual maintenance costs of $3300 - 5600 per parking space in central cities, and each AV will amount to $250 in parking savings. Also, the economic benefit is estimated at $196 billion in the US with a 90% market penetration rate (Fagnant, 2015). These savings and earnings could be put towards future development.

Environmental

One study shows that over 29% of the urban fabric is covered by pavement with 36-45% of that parking, which plays a “very determinant role on the overall thermal balance” by causing high temperatures especially during summer months (Santamouris, 2013). Different strategies attempt to mitigate the heat island effect, such as greening roofs and parking lots (Onishi, 2010). Many studies have attempted to quantify the urban heat island effect using GIS, including various methods incorporating satellite data, crowdsourced data collection, and statistical modeling (Smoliak, 2015)

Social

Generally speaking, parking and driving are correlated. If parking supply increases in a city, more people will use their car to drive (McCahill, 2015). Consequently, a reduction in parking would cause more people to use other modes of transportation. A correlation exists between the reduction of parking in Canadian downtowns and automobile usage as well as a reduction in parking and transit usage in American cities (Morrall, 1996). While this may not be true in the case of AVs, which could significantly disrupt the traditional model of driving/parking, there currently exists a connection between parking supply and mode share. This correlation would still apply in the transition between personally-owned vehicles that rely on parking to self-driving cars.

Factors

Economic

This project looks at how property values change when parking storage is reduced. It theorizes the value of a new building on a converted parking lot will have a similar value to existing buildings nearby. The project presents how these land values are influenced spatially—which areas of town have higher values, and what are the characteristics of these neighborhoods. The general expectation is that urban building and land values would increase as parking storage decreases. A specific hypothesis is an increase of $100,000 per acre for new buildings or when parking is replaced by buildings, and an increase of $100,000 per property for buildings near parks.

Environmental

Continuing on the idea of heat islands, the surface temperature of a city was calculated before and after parking lot reduction events. This then showed how the surface temperature of a city would change if portions of the city were converted into parks. Many methods exist to determine heat island through a GIS. Researchers have devised methods that incorporate varieties of surfaces, seasonal variation, diurnal patterns, shadows, weather, etc.; however this project simply finds a typical surface temperature of pavement, buildings, and grass during the hottest part of a summer day. In these conditions, the surface temperature of pavement and buildings are approximately 65˚ Celsius and the surface temperature of grass around 25˚ Celsius (Guan, 2011). Generally, the hypothesis is that urban heat island effect would decrease as parking storage decreased. Specifically, the hypothesis is to find an overall decrease of 1-2° Celsius in all of Minneapolis in a 100% parking lot reduction scenario.

Social

A theme found through research focused on how self-driving cars will revolutionize car usage, such as showing how an increase in AV market penetration in general will lessen automobile usage. Using a formula from McCahill, auto mode share was calculated related to parking. Also using a formula from Morrall, transit mode share is projected in relation to parking. Generally, these formulas indicate that auto mode share would decrease and transit mode share would increase. In a 100% reduced parking scenario, the specific hypothesis is that auto mode share would go down 50% and transit mode share up 25%.

Input Data

Datasets from various sources were used to determine economic, environmental and social factors.

- MetroGIS parcels from Hennepin County is a polygon shapefile feature class that contains every parcel in Hennepin County, which includes the city of Minneapolis (http://www.hennepin.us/your-government/open-government/gis-open-data, 2016). This layer was valuable in the economic sector, because it shows the estimated property value and building value for each parcel in the city. The shape of the parcels was also useful for the environmental study to put together the various layers that makeup a city for the surface temperature estimates.

- A building footprint layer from MNGeo helped in the processing of data for the economic and environmental sectors of the project. It also helped in the creation of a figure-ground map, which shows buildings and void areas in the city (http://www.mngeo.state.mn.us/).
- Census data was used for the social sector to determine people and jobs per census block group, as well as general population numbers and comparative commuting mode shares (https://www.census.gov/programs-surveys/acs/).
- Roads and parks layers were used to assist in the environmental modeling, as well as to determine the influence park values had on property values.
- To digitize the parking lots, the default ESRI aerial basemap was used, which was determined to be the best available at the highest resolution for use in GIS software. There was a tradeoff between the most recent imagery accessible and the quality of the imagery. The ESRI imagery was not the most recent (2012) but high resolution photos were needed to be able to digitize parking, and the 9-inch pixel size suited well for digitizing.

Metrics

Before delving into each sector of the project, metrics were devised on the existing conditions, which informed the data for the three sectors and their factors. From aerial photography, the acreage set aside for parking storage in present-day Minneapolis was determined, and then from this number the number of parking stalls in the city was extrapolated. New layers were created that show randomly reduced parking in 25%, 50%, 75%, and 100% scenarios, where 25% of the parking is reduced, etc. These four basic scenarios played into each metric.

Economic

For the economic sector, the metric used was property value in dollars per acre. This was calculated for the baseline scenario, and also for each scenario where parking is reduced. The difference if the parking lots were replaced with parks or buildings is also shown.

Environmental

The environmental sector showing the urban heat island effect used degrees Celsius per acre (surface temperature) as units. This calculated for the baseline (current day) scenario, and also the 25/50/75/100 parking lot reduction scenarios. Like the economic sector, the effect property value will have if parking is replaced with parks or buildings is shown.

Social

The metric for the social sector is automobile and transit mode share per acre. The project projected how many people would take their automobile or transit to work under current conditions and also how many would under future scenarios.

Method

The current parking supply was digitized to begin the study of existing conditions. Although some of the research showed automated methods based on imagery interpretation (Wang, 1998), this study follows the example of other studies digitized from aerial photography (Davis, 2009). While this was a more laborious process—taking roughly 35 hours—it was appropriate for the project. The studies that used automated methods to calculate roads and parking storage were too complex and beyond the scope of the project. Parking garages were investigated from public sites like the city of Minneapolis website (http://minneapolismn.gov/parking/ramps/index.htm), private parking websites (http://www.alliedparkinginc.com/find-parking), and Google's Street View (https://www.google.com/maps/streetview/). A new feature class was created, storing information like shape size and number of levels. From the total size, this project supposed a 9' x 18' size stall (Minneapolis Code of Ordinances, 2016), after taking away 50% of the space which is used for vehicle ingress and egress. The 50% was derived from a sampling of counted vs. calculated spaces to extrapolate the number of spaces from the digitized parking areas. A figure-ground map was created showing areas of the city which contain buildings, and the void areas between them (including parking). This map used the digitized parking feature class and the building footprints layer. A random number between 0 and 1 was assigned to each polygon to randomly reduce the parking in 25/50/75/100 scenarios. A python expression was used to calculate this number (http://gis.stackexchange.com/questions/78251/how-to-randomly-subset-x-of-selected-points). This random number was used as input for all three sectors.

Economic

Using the parking lot feature class, all parcels were selected that had parking lots to begin the economic sector method. An IDW (inverse distance weighted) interpolation tool using ESRI's Geostatistical Analyst determined the value of new buildings that would be built on the parking lot. IDW values nearby parcels and buildings more than distant features and determines a new value based on proximity. These new values were then added to the database. This feature class determined the four reduction scenarios. For parks, the value of all parcels within 500' of a park were calculated and compared to all parcels further away. The result was a 27.4% increase in land value, which was then applied to each scenario where parking is converted to parks.

Environmental

To measure the urban heat island effect, a surface temperature was assigned to certain datasets—65˚ for buildings and pavement and 25˚ for grass and other impervious surfaces. The current urban heat island effect in Minneapolis was calculated by combining parking, buildings, parks, roads and impervious sections of parcels in a single layer. The randomized parking reductions were incorporated and the new values for surface temperature were plugged in for parking replaced by parks. These new numbers were used to determine new surface temperatures in each of the parking lot reduction scenarios.

Social

The automobile mode share was driven by this formula from McCahill (2015): $y = .77x + .45$, where y equals automobile mode share percentage, and x = parking spaces per resident and employee. Census data comprising population and employees per census block group was joined to parking data to determine the *x* value for each reduction scenario, which then gave the mode share. The mode share per acre was calculated and the number of commuters per acre using that mode. For transit mode share the formula was $y = 3.6 - 32.97 \ln(x)$, where x = parking spaces per employee and y = percentage of transit mode share, from Morrall and Bolger's research (1996). The employee data per census block group was joined together with parking data to determine how much transit would be used for each scenario.

Outputs

Each factor has three or four outputs. The existing conditions metric has a map and polygon geodatabase feature class to show parking storage, as well as a polygon figure-ground map. Key statistics are also displayed in tables. The environmental sector has a baseline heat island map, and projected heat island maps for each scenario, as well as statistics. The social sector also shows a baseline auto mode share and transit mode share map, a projected scenarios map, and statistics. Similarly, the economic sector shows a baseline property values map, a projected property values map, as well as statistics.

The maps were made in ArcMap for a 2D representation and some in 3D ArcScene where records were extruded based on the key unit for each sector. These 3D maps are useful for multivariate display, where height can be one attribute and color of the record another. These maps show by height the key unit (degrees Celsius, mode share, and property value per acre) and then by color the amount of parking for each baseline and projected scenario so relationships can be drawn between parking and the key metric (see Figures 11-12 for examples).

Results

The first task involved digitizing the parking supply of Minneapolis, creating maps and calculating statistics. As of 2012 (the year of the aerial photography) there were 261,917 parking spaces comprising 1,560 acres in Minneapolis (Figure 1, Figure 2). This amounts to 7.1 spaces per acre, and 0.6 spaces per person (using 2013 population estimates) (Figures 3-4).

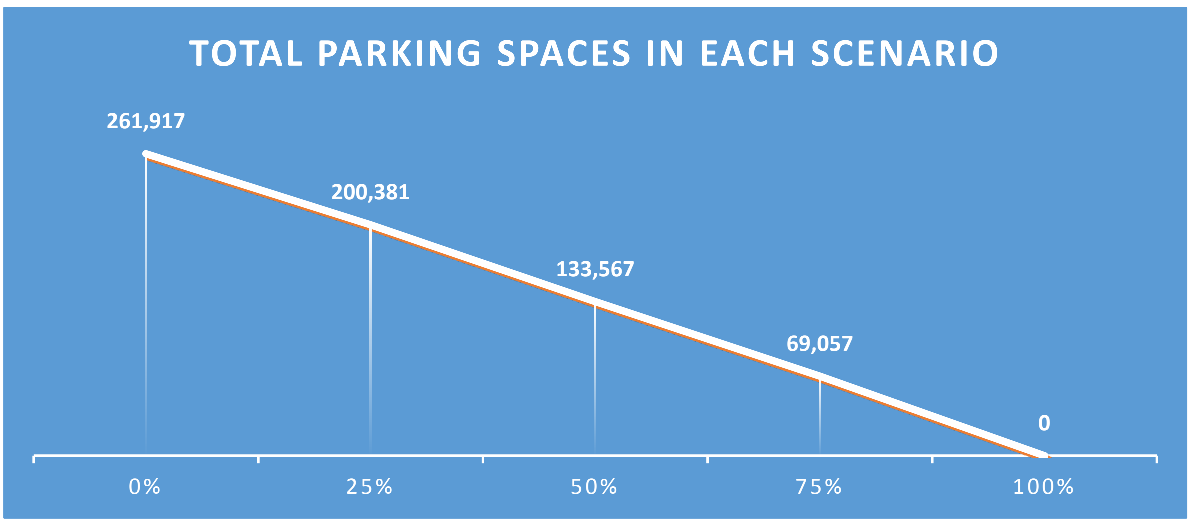

Figure 1. Total parking spaces for each scenario

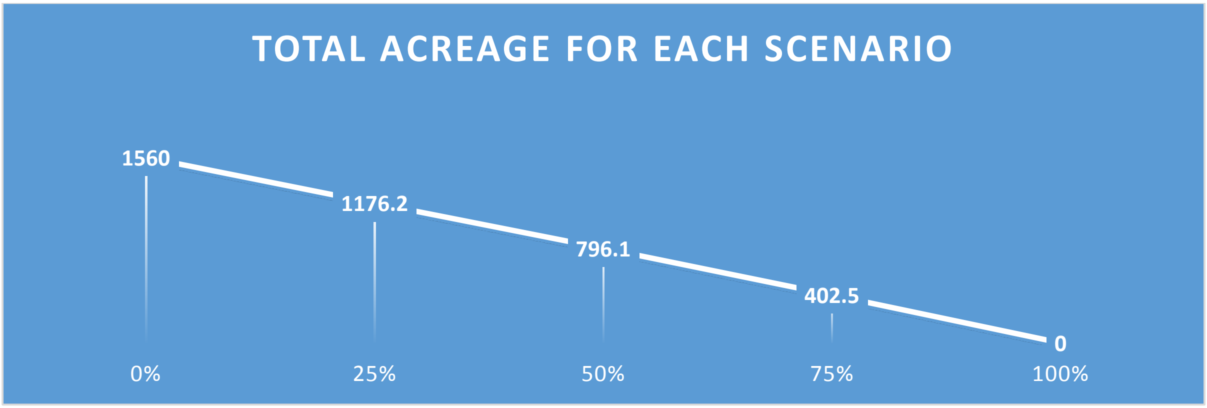

Figure 2. Total acreage for each scenario

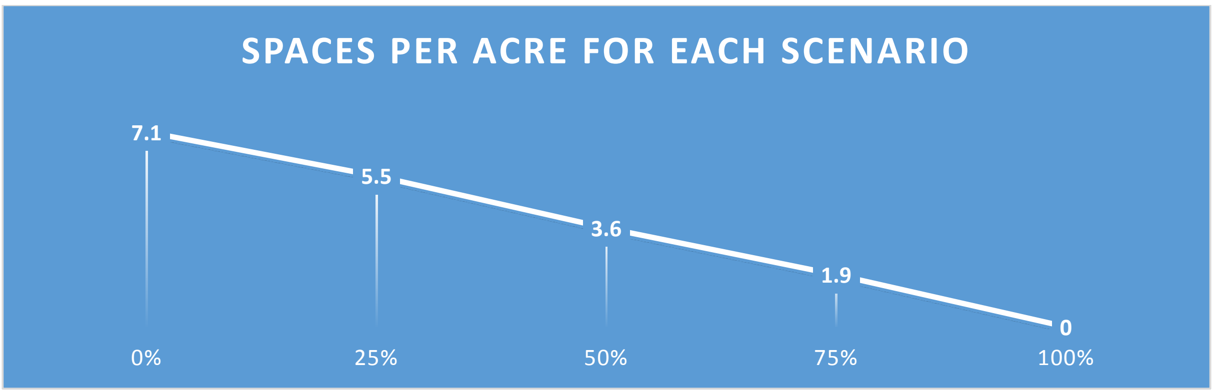

Figure 3. Spaces per acre for each scenario

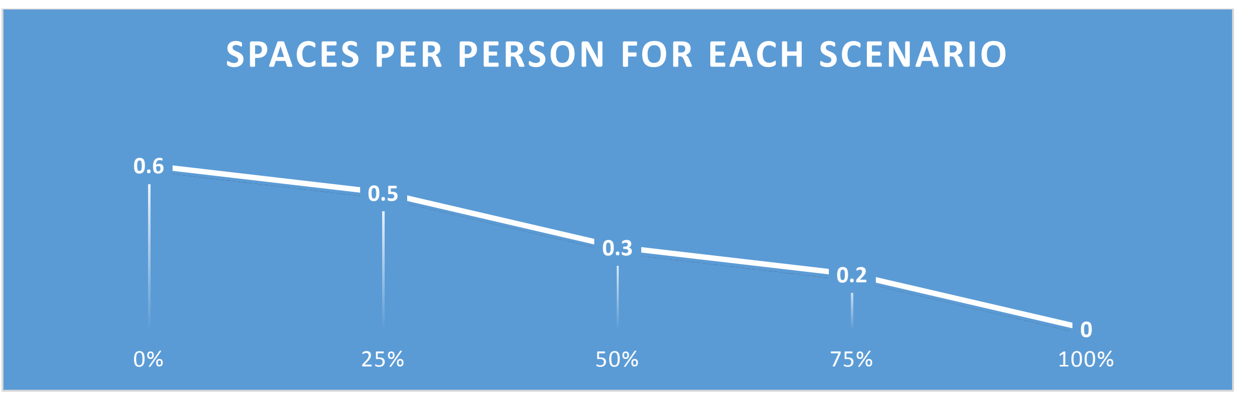

Figure 4. Spaces per person for each scenario

Also shown are maps of downtown Minneapolis with parking reduced (Figure 5). The combination of all of the surface lots and predominately parking garages in downtown shows an abundant supply.

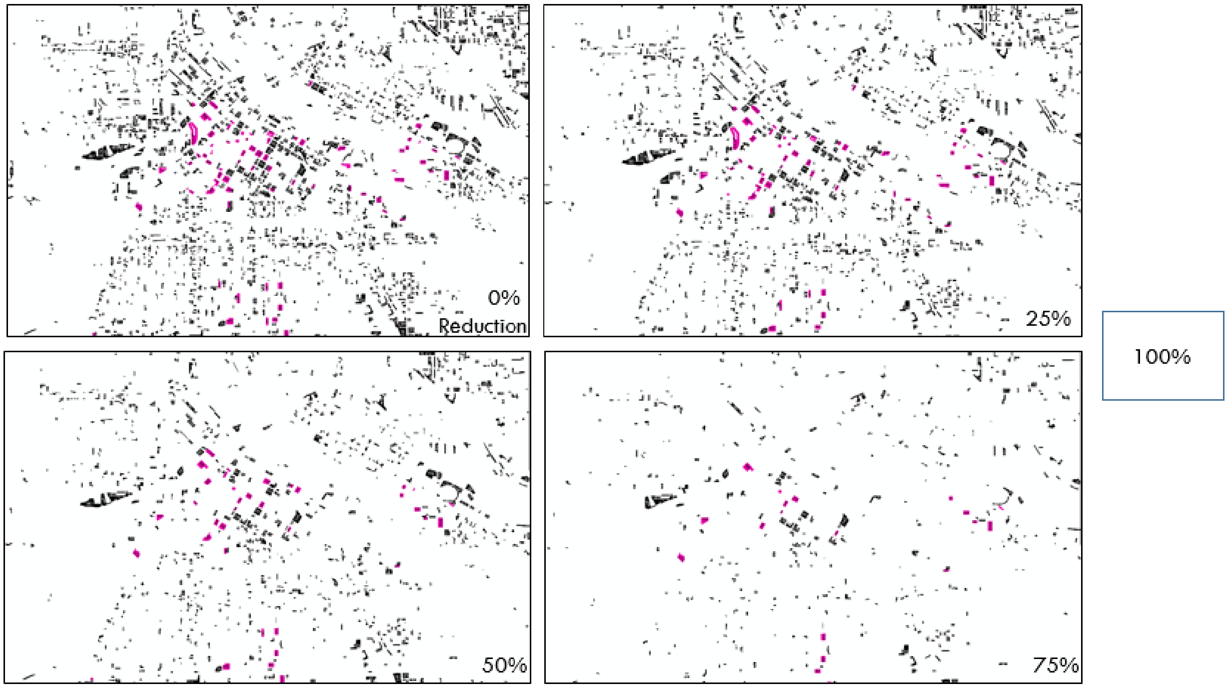

Figure 5. Downtown parking in Minneapolis in each random reduction scenario.

Figure 6 shows a representation of a figure ground map, showing the built up areas (buildings are brown) and the void areas in between (parks are green) plus existing parking (gray).

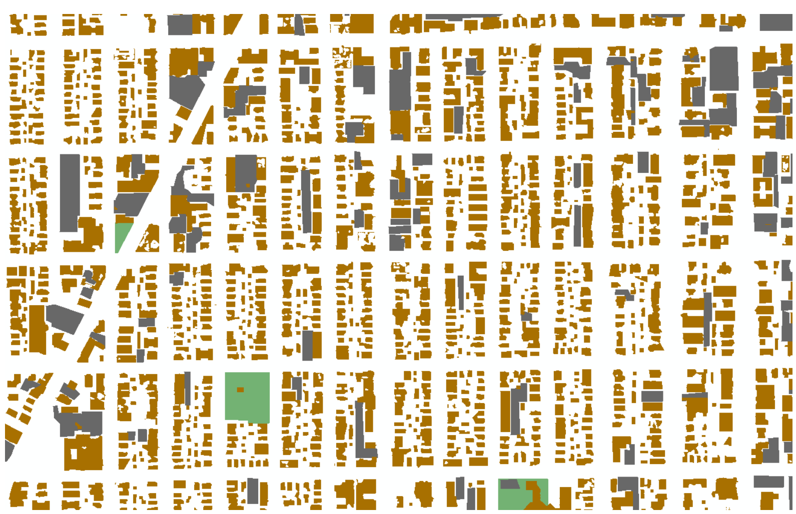

Figure 6. Figure Ground map example in South Minneapolis

Economic

The results of replacing parking with buildings reveal gains in the billions of dollars in different parking reduction scenarios, from $794 million in new building value in a 25% parking storage reduction scenario to $3.11 billion if buildings were built on all parking (Figure 7). The key metric—building value per acre—ranged from $21,628 to $84,620 (Figure 8). The new building value per person went from $1,978 to $7,775 (Figure 9). In each scenario, there was an average increase of nearly $1 million per building (Figure 10).

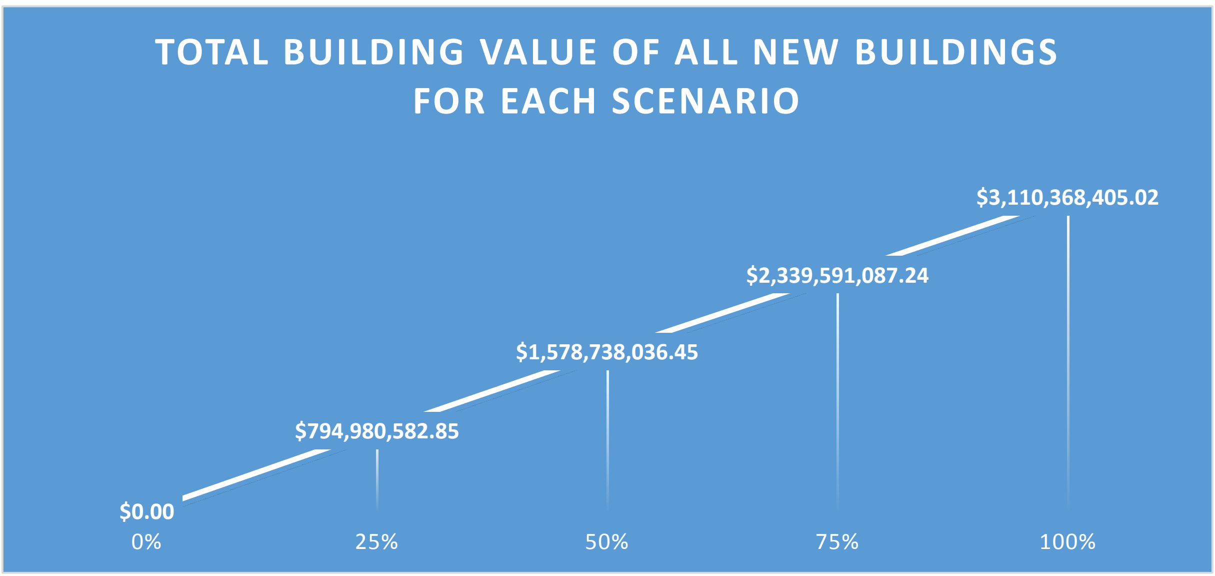

Figure 7. Total building value of all new buildings for each scenario

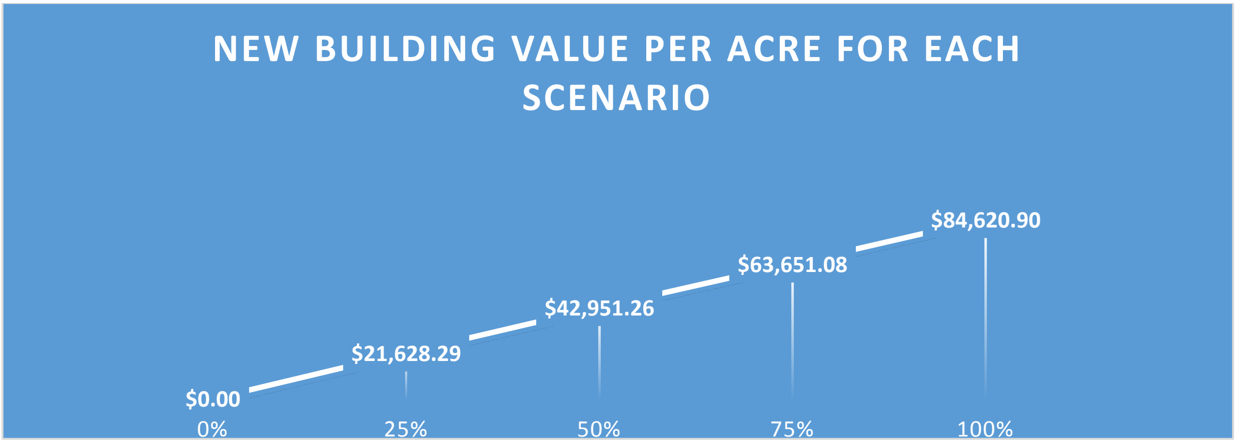

Figure 8. New building value per acre for each scenario

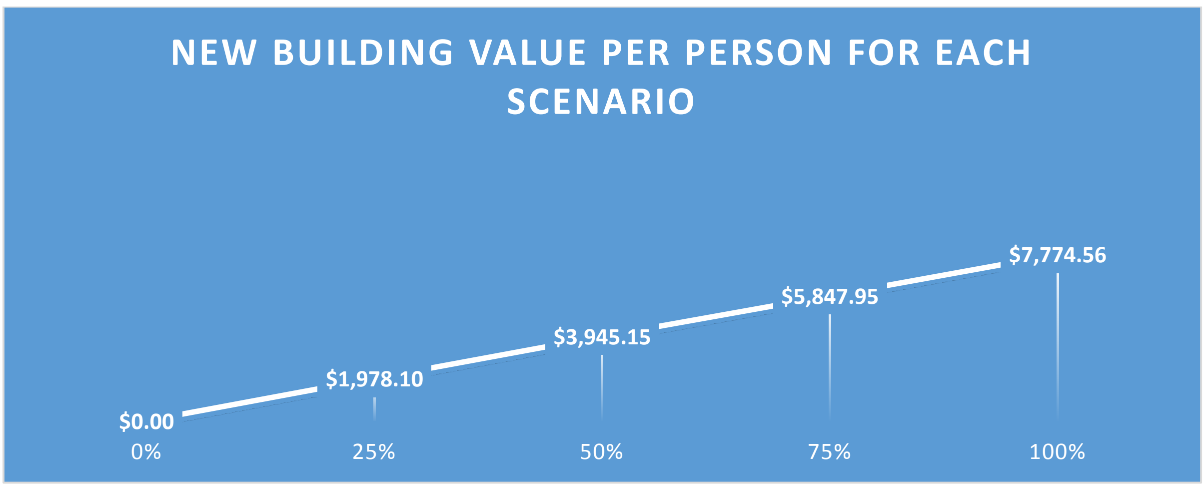

Figure 9. New building value per person for each scenario.

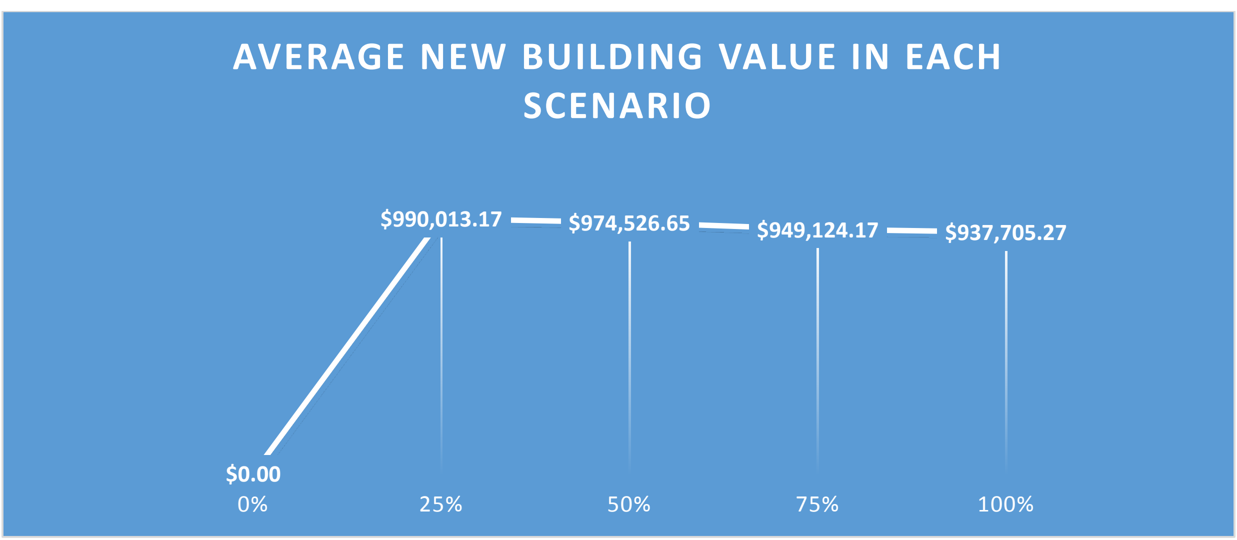

Figure 10. Average new building value in each scenario.

The maps in Figure 11-12 represent the new buildings that would be built on old parking lots. The height of the building show the new building value, while the color indicates the amount of parking spaces per acre.

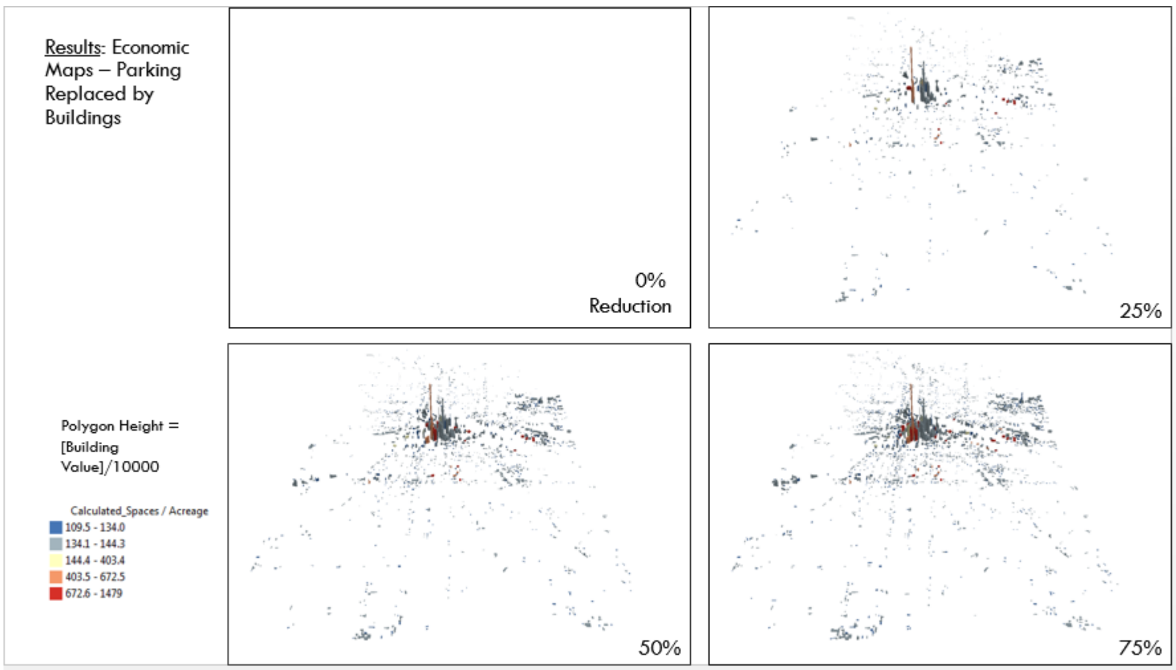

Figure 11. Parking replaced by buildings for the 25 – 75 % scenarios.

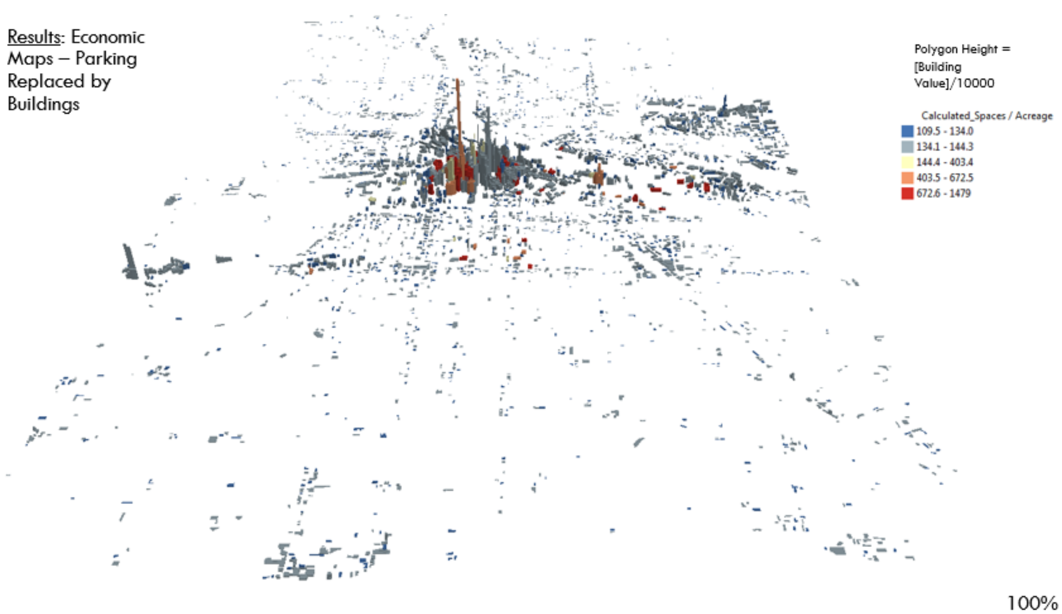

Figure 12.100% of parking replaced by buildings

Gains in land value were also projected when parking was replaced by parks. In just a 25% reduction, properties within 500' of parks in the city would increase a total of $1.06 billion in value, to a total of $4.64 billion (Figure 13). If all parking were converted to parks, these properties would be worth all together $6.25 billion. Per acre, the total value would go from $126,340 to $170,051, or in other words an increase of $28,848 to $38,828 per acre (Figure 14). Per person, this value would range from $2,650 to $3,730 (Figure 15). In each scenario the increase per property would be about $18,000 (Figure 16).

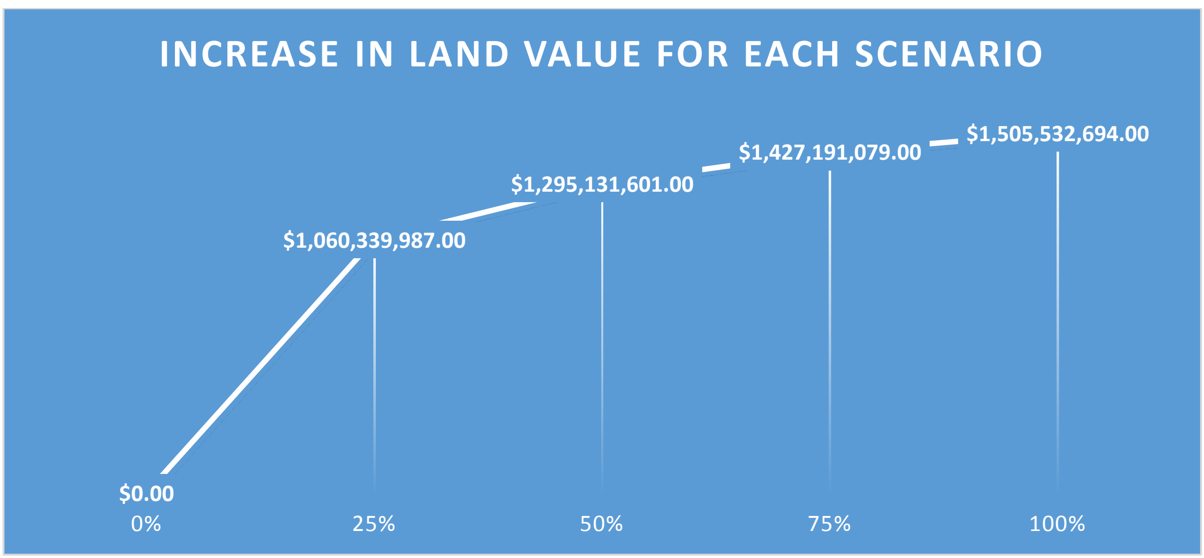

Figure 13. Increase in land value for each scenario

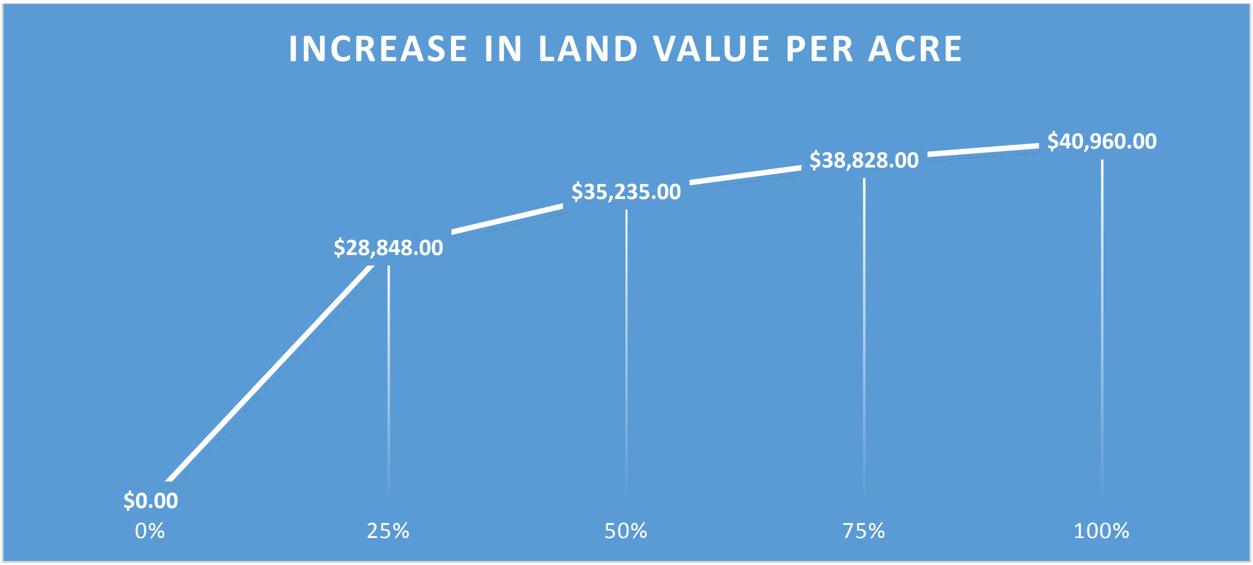

Figure 14. Increase in land value per acre

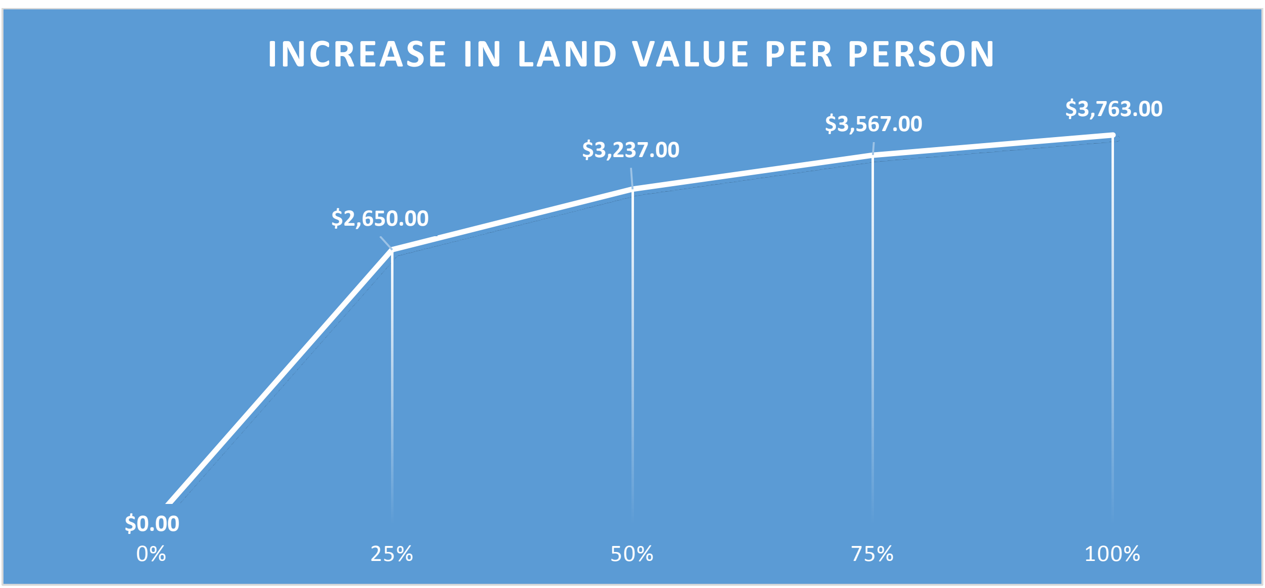

Figure 15. Increase in land value per person

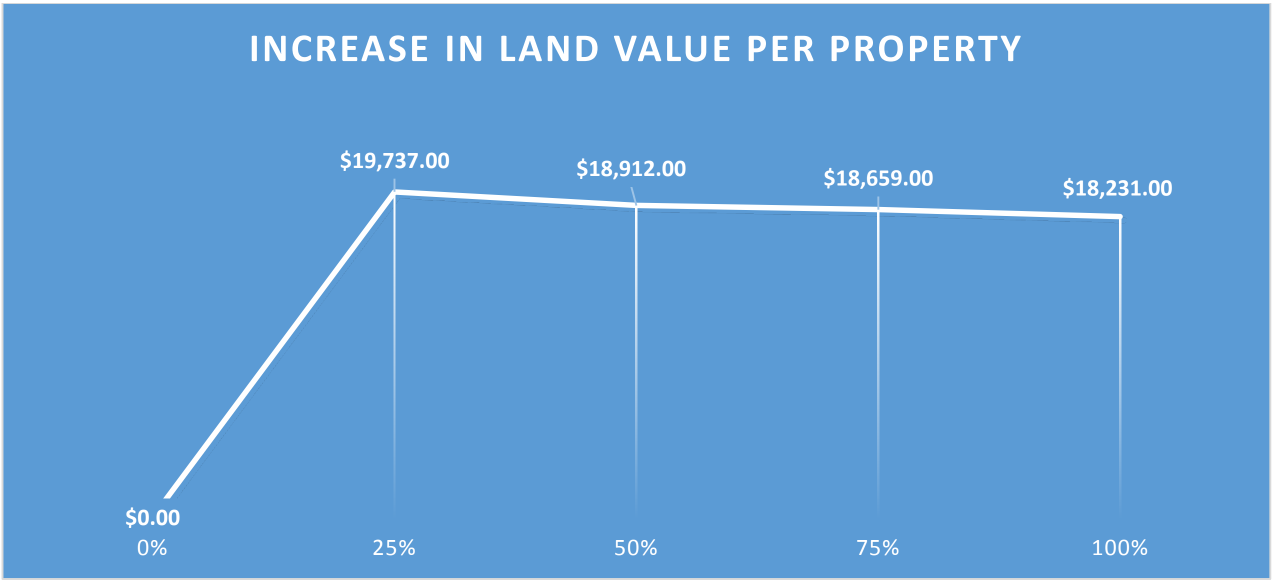

Figure 16. Increase in land value per property

Figure 17 shows parcels in the city influenced by parks as parking is converted in to parks and the corresponding increase in land value.

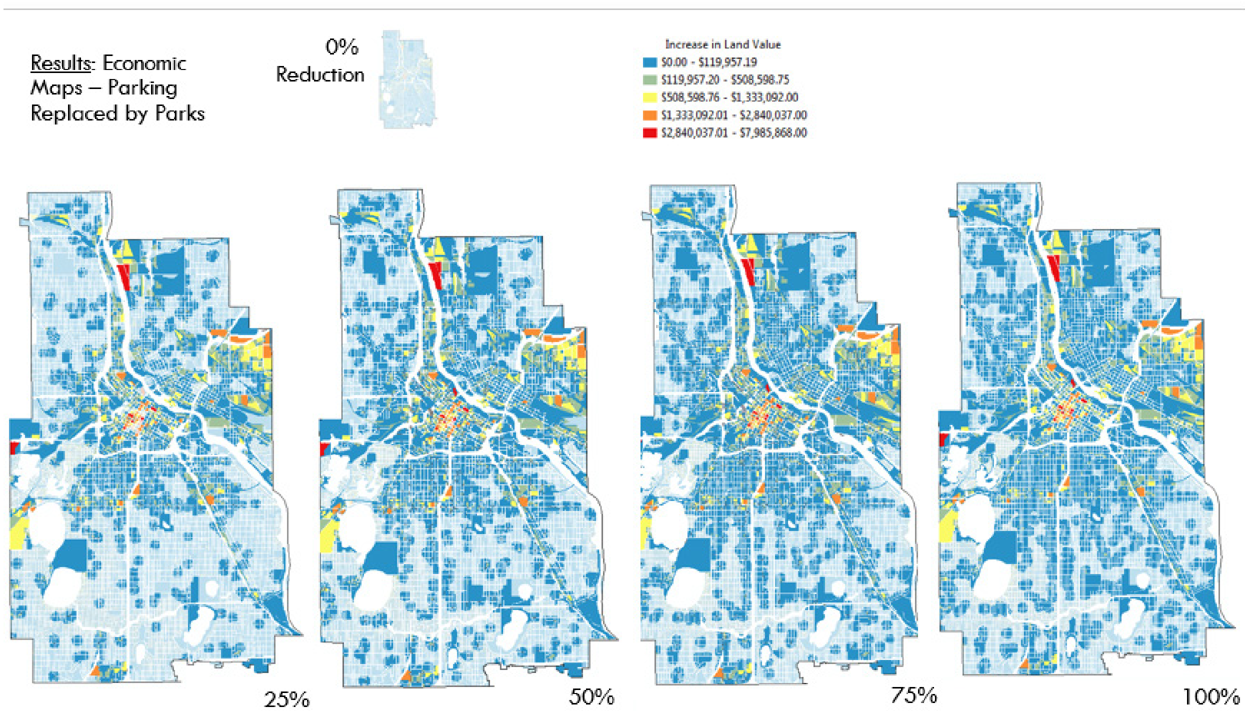

Figure 17. Parking replaced by parks for each scenario.

Environmental

Reducing parking and converting it to parks did not have a noticeable effect at a city-wide scale when looking at the urban heat island effect, or when focusing in on downtown (Figure 18).

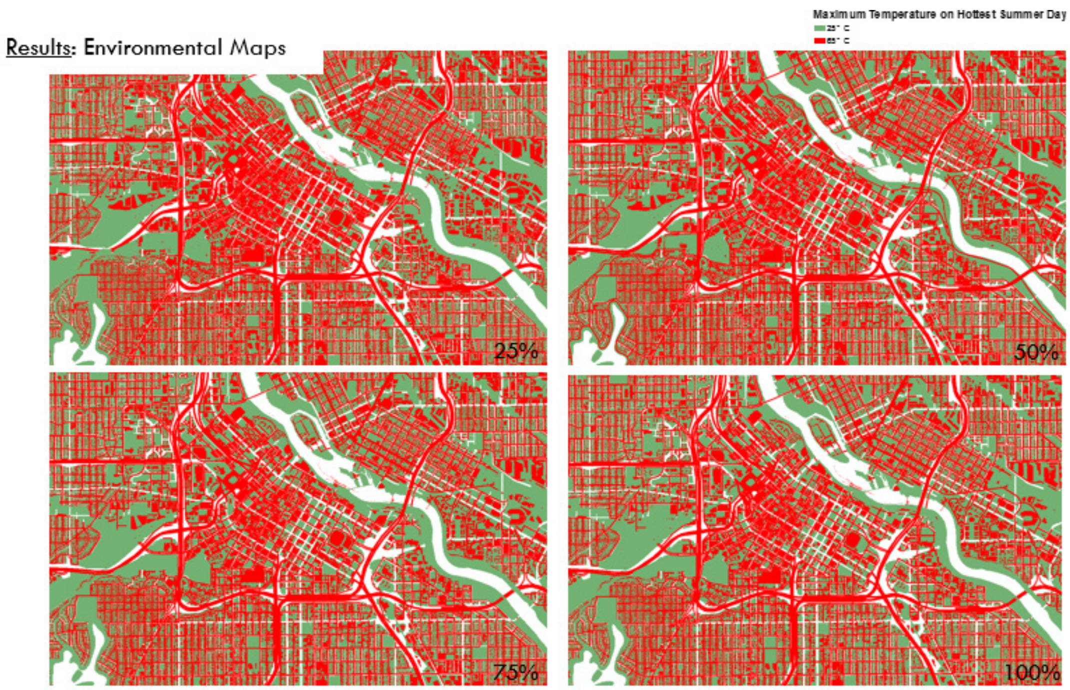

Figure 18. Environmental maps showing the urban heat island effect in downtown Minneapolis for each scenario.

At the citywide level, enough of the city is covered by the red of impervious buildings or pavement that it seems to overwhelm the green of cooler temperature. Zoom in to the block-level, however, and some of the changes are more evident (Figure 19).

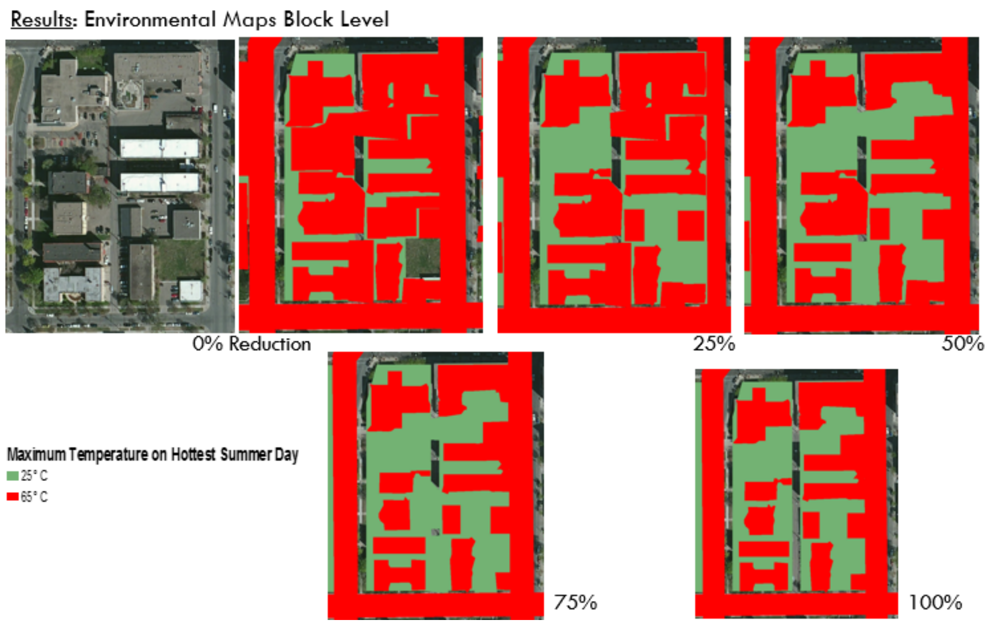

Figure 19. The urban heat island effect at the block level for each reduction scenario.

Looking at the city-wide numbers does reveal however that there would be some significant change. The number of acres at cooler temperatures would increase 14.7%, and the number of acres at high temperatures would decrease 23.4% (Figure 20). The baseline scenario showed a surface temperature per acre of 44.8° C, which went down to 42.7°, 41.5°, 40.6°, and then to 40.2°, a decrease of 4.6° from 0% reduction to 100% reduction (Figure 21).

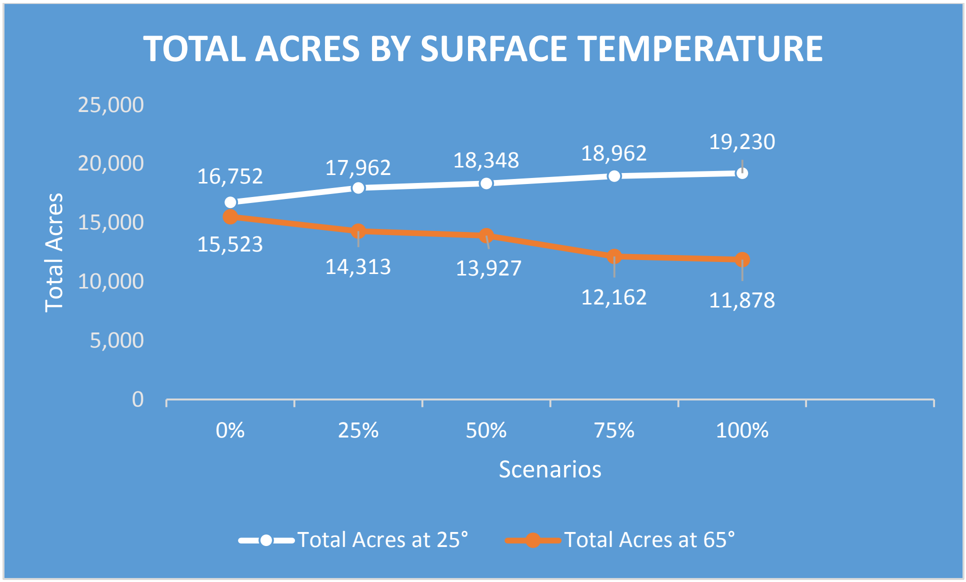

Figure 20. Total acres at each surface temperature.

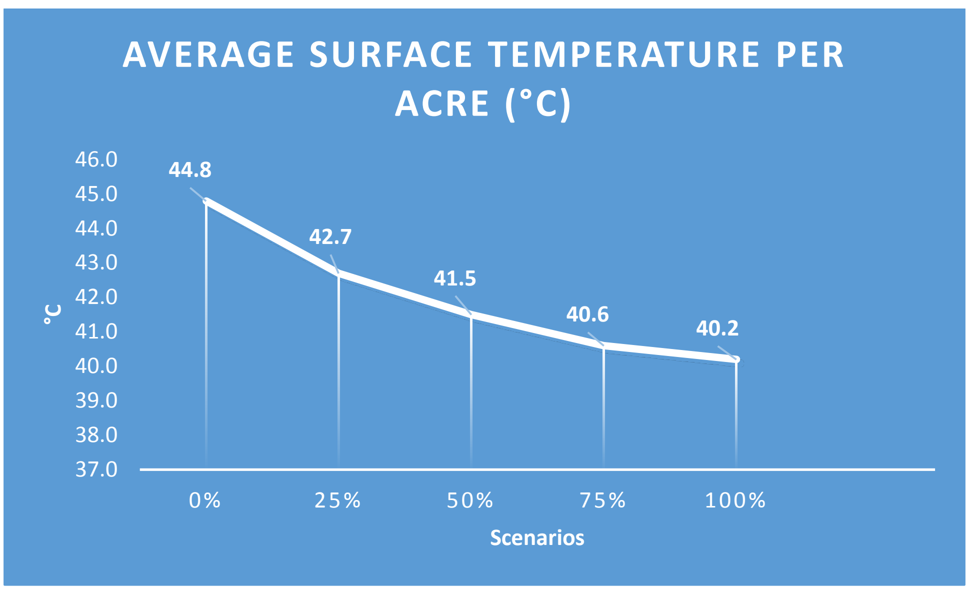

Figure 21. Average Surface Temperature per Acre (°C)

Social

In present day Minneapolis, using the auto mode share equation, a 60.6% automobile mode share was calculated throughout the entire city (Figure 22). This mode share declines to 39.5% mode share if 100% of parking were eliminated. This corresponds to 6.6 people per acre using cars to commute (Figure 23). The commuters per acre via car would reduce to 4.3 people.

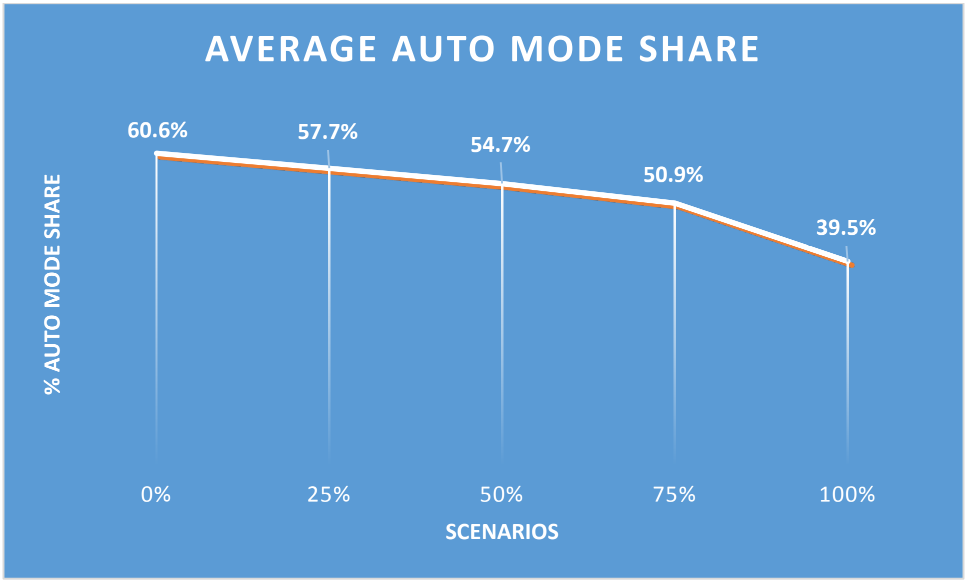

Figure 22. Average Auto Mode Share

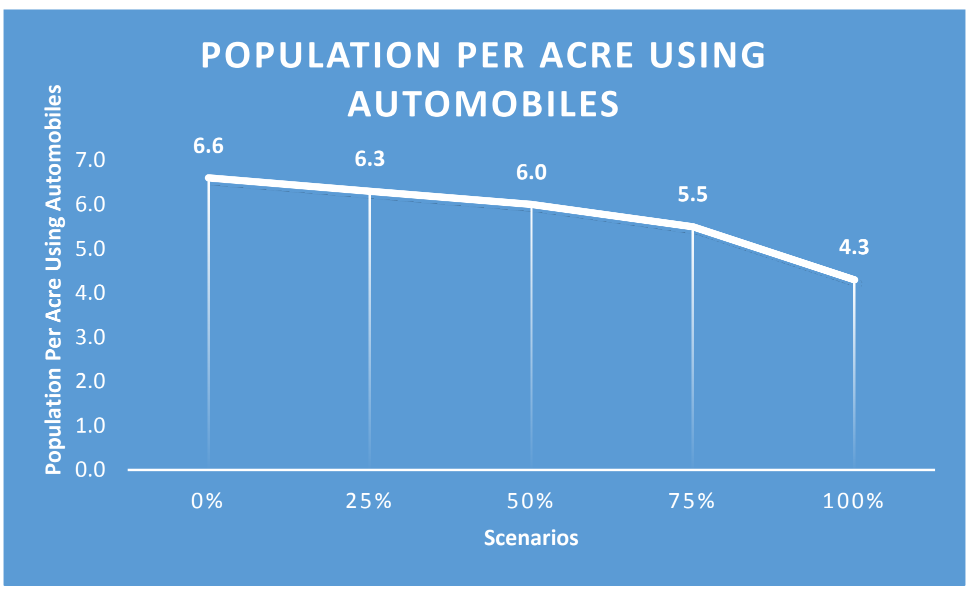

Figure 23. Population per Acre Using Automobiles

Note that this number is not zero because the formula used had people using cars even if there were no parking. Although the widespread adoption of self-driving cars could disrupt this formula, the lessened parking would likely not dissuade people who no longer have any reason to park. The maps show census block groups in the city as they reduce their parking supply, and the corresponding increase in automobile mode share (Figure 24).

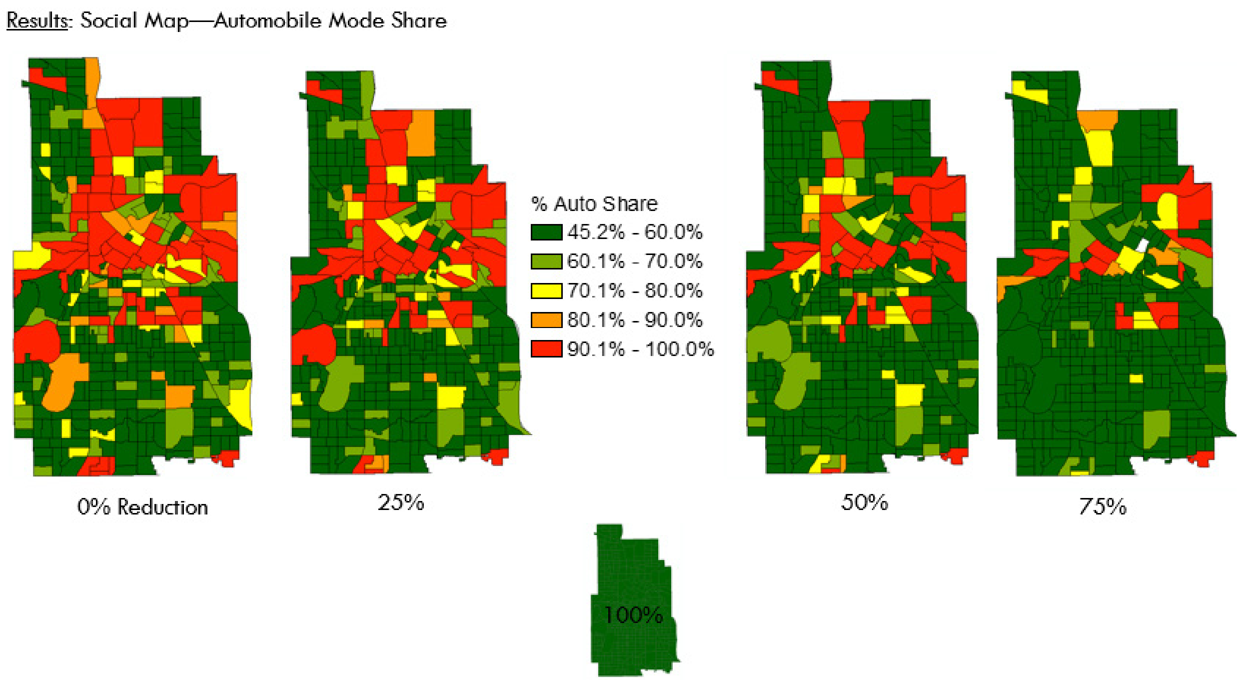

Figure 24. Automobile mode share in Minneapolis by census block group for each scenario.

Currently, 53.2% of commuters would take transit in Minneapolis using the transit mode share formula (Figure 25). This is a different formula from the one used for automobile mode share—they are not complementary. The number pulled from the census for 2014 was only 13.5%, which indicates a disagreement between the formula and the census data. This disparity could be caused the formula's derivation from downtown parking in Canadian cities (from 1996), which was applied to a current American city throughout the whole city.

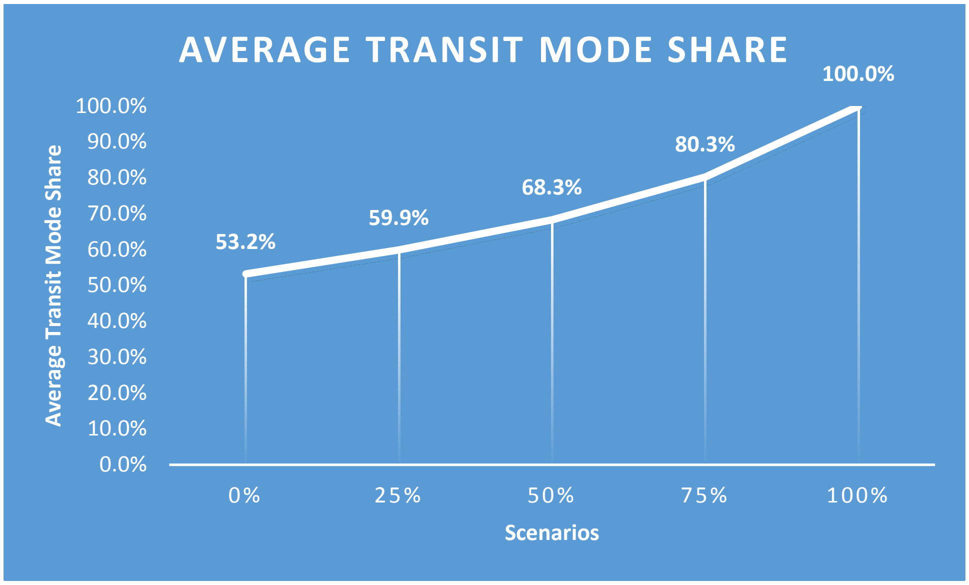

Figure 25. Average Transit Mode Share

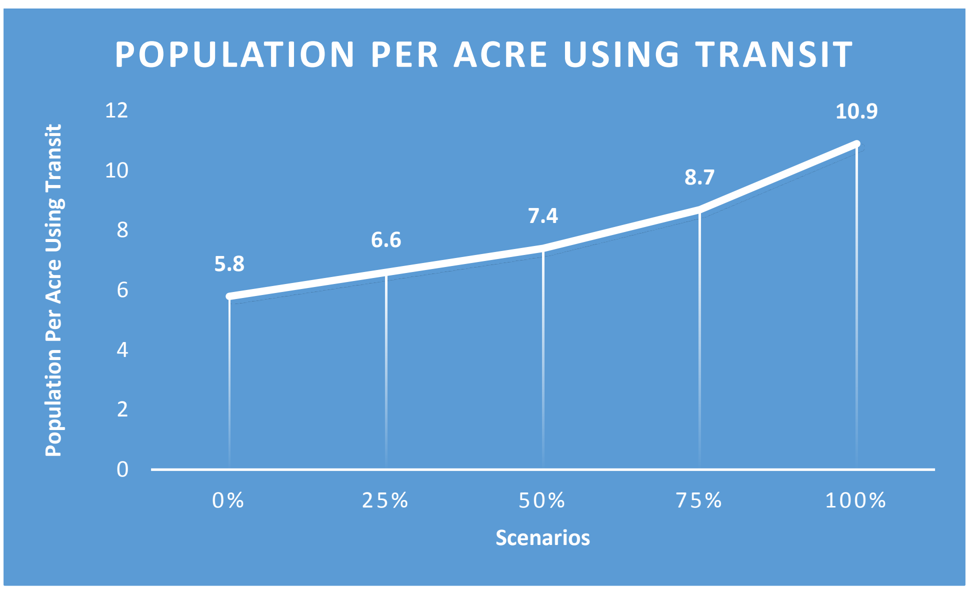

Figure 26. Population per Acre Using Transit

Derived from the census data, there were 5.8 commuters per acre using transit, but this trended upwards to 10.9 commuters per acre if all parking were reduced completely (Figure 26). Unlike the auto mode share equation, the transit mode share equation does allow for 100% of the population to use transit if all parking were eliminated. As evidenced in Figure 27, there is a correlation between high automobile usage and abundance of parking in downtown Minneapolis.

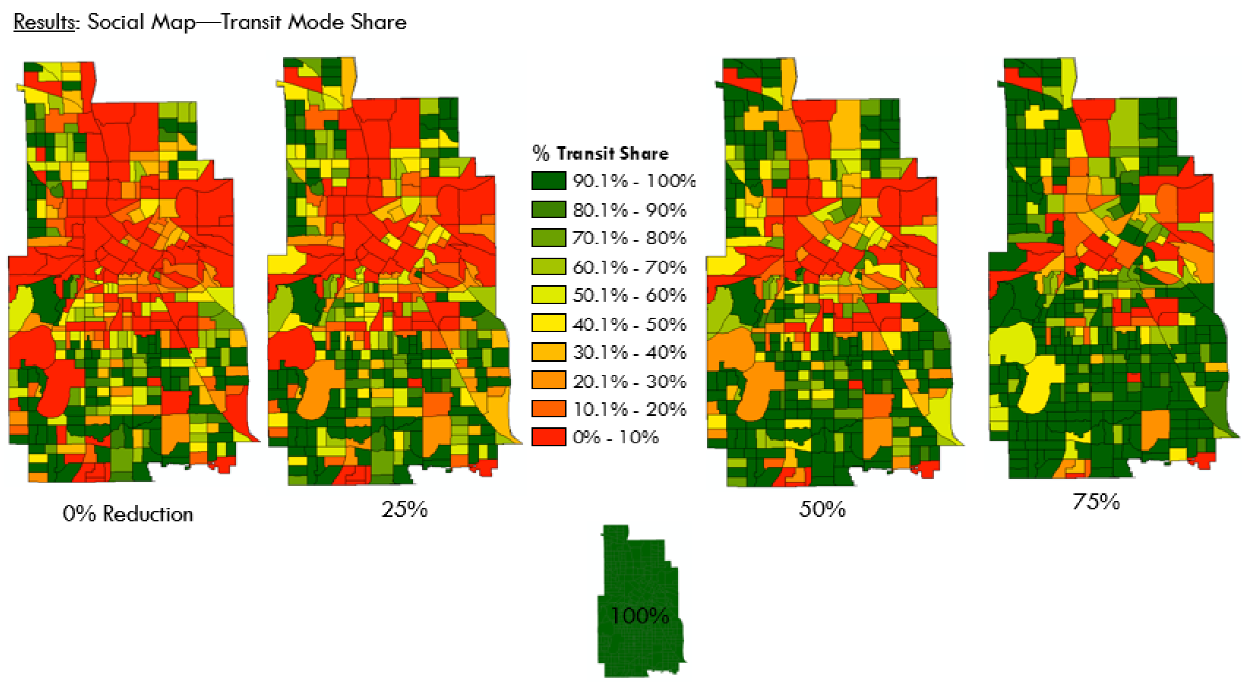

Figure 27. Transit mode share for the city of Minneapolis by census block group for each scenario.

The results of reducing parking agreed with the general hypotheses, but the specific predictions ranged from reasonably close to quite distant. The building value per acre if parking were replaced by buildings in a 100% scenario was $84,620, less than the hypothesis of $100,000. The property value of properties near parks in the 100% scenario was $40,960, less than the estimate of $100,000. The environmental hypothesis was closer, but still by roughly half. It hypothesized a 1° to 2° decrease in surface temperature, and there was a 4.6° reduction in the 100% scenario. The project predicted a 50% reduction in automobile mode share if all parking were eliminated, but there was only a 21.1% reduction. For transit mode share a 25% increase was hypothesized, yet the model actually showed a 46.8% increase.

Limitations

Many tangential and interesting areas of study were out of scope for this project. AVs will likely affect more than just the factors mentioned. Also many variables beyond parking influence urban heat island effect, transportation mode share, and property value. Parking lot reduction is only one very specific metric of the future of AVs. While there are many predictions about AVs, this study focused only on AVs used for car sharing. The study is based on the city of Minneapolis, while a broader study could reveal more interesting patterns about parking in the whole Twin Cities metropolitan area, such as the difference between parking in urban and suburban areas. The city of Minneapolis is relatively dense compared to its suburbs and has generally less parking. Also, this study looked only at off-street parking, ignoring parking on the street and in private garages at single family homes. The input data of the project was also limited by the accuracy and resolution of its inputs, such as the resolution of the aerial photography used, or the methods city and county planners used to estimate the market value of a property, or the applicability of the equations used to project mode share.

Presentation

This capstone project was presented at the Sixth International Conference for the Constructed Environment held in Tucson, Arizona from April 3-4, 2016. The presentation lasted around 20 minutes. Afterwards there was a discussion about the impact self-driving cars will have, the effect cars have on the current American city, and how transit may fit into the future equation.

Conclusion

This capstone project took a three-pronged approach to study how autonomous vehicles would affect the American city. By looking at the environmental, social, and economic sectors, it showed through research, metrics, data, methods and calculations how the city of the future may change. Using GIS as a tool, it projected how building and property values would rise, the urban heat island effect would be mitigated, and mode share may change. Through the project, lessons were learned from the results and also from scope, limitations, data, etc. Property values would rise but not at the rate hypothesized. The urban heat island may be mitigated in a greater degree than thought at the beginning of the project. The mode share calculations in this project may not apply to a city of the future where the link between cars and parking is severed. Looking ahead, further studies could look at a larger sample size of cities, beyond just Minneapolis. Cities could be compared by form, such as cities that were built primarily before automobiles and cities built after. Urban forms could be compared to suburban and rural forms. Each factor in this study took a relatively simplistic approach to determining results, but each factor could be scrutinized further. An exhaustive study could look at more of the variables that constitute the urban heat island effect: seasons, day/night cycles, weather, climate, shadows, different materials, etc. A more in-depth look at property values may look at actual market trends, historical data, square footage, height, government regulations, etc. Another method to use for mode share could look at historical data, or compare parking data in a larger sample of cities and their mode shares. Other factors could have been chosen for each of the three sectors: for example, the economic sector could have looked at the cost of building and maintaining parking, property tax change if parking were replaced, or any gains or losses to the total economic output of the city. For the environmental sector, connections could potentially be made between the reduction in parking and carbon emissions, citywide drainage, wildlife, plant life, etc. The research for this project did not find many connections between the social sector and parking, but potential areas to explore could be the effect reduced parking could have on crime, health, safety, happiness, or tourism. Parking is one aspect of the future autonomous vehicles may bring on the urban form, but it would also be informative to study road widths and the incorporation of other modes of transportation such as walking, bicycling or transit. Another study could look at a future where autonomous vehicles cause further sprawl, whereas this study assumes an opposite approach. The possible disruption of autonomous vehicles in the near future raises many questions; this project aimed to take a closer look at a broad survey of the issue and get a little better picture of what that future may look like.

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