University of Cincinnati

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I, Elad Mokadi, hereby submit this original work as part of the requirements for the degree of Master of Community Planning in Community Planning.

It is entitled: Modeling the Future Impact of Cincinnati’s Proposed Streetcar on Urban Land Use Changes

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Modeling the Future Impact of Cincinnati’s Proposed Streetcar on Urban Land Use Changes

A thesis submitted in partial fulfillment of the requirements for the degree of
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Abstract

The construction of Cincinnati’s streetcar system, which has been planned since the year 2007, will supposedly begin during the fall of 2011. The $128-million project is intended to increase connectivity between the city’s two major employment centers, and foster economic growth in its urban core. Ever since its inception, the project has provoked controversies in the local community regarding its future impact on urban growth and redevelopment. The project supporters argue that it would increase commercial and retail activities, and boost property values; opponents insist that the system will be underutilized, redundant, and constitute a misuse of scarce public resources.

This study explores the impact of the proposed streetcar system on land use transitions, by employing an advanced Geographic Information System (GIS) based land use change model. In an attempt to reconstruct the major arguments behind the public debate, the study models land use changes as represented by three scenarios: (1) the supporters’ narrative, (2) the opponents’ narrative, and (3) a baseline scenario which does not include the streetcar line. Since land use changes are reliable indicators of redevelopment processes, the study has the potential to contribute to a better understanding of urban redevelopment dynamics and increase public involvement in planning processes, both in Cincinnati and in similar-scale cities.

The study first had identified the streetcar supporters and opponents’ arguments and quantified them into various spatial criteria. It then incorporated those criteria into a Cellular Automata (CA) – Markov Chains model, to generate future land use distribution raster images. Finally, the model outcomes were evaluated using spatial-statistical analyses. The study sheds a new light on the escalating dispute between the streetcar opponents and its supporters.
results indicate that supporters and opponents’ scenarios beget distinct results in terms of land use changes. Under both scenarios, however, the streetcar establishment would impact its surrounding area to some extent.
Acknowledgements

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Above all, I would like to thank to my dear wife, Dr. Eleanor Glass, for sharing with me this challenging period and for standing by me at both moments of stress and times of success. I would not have been able to do it without you!
# Table of Contents

1. INTRODUCTION....................................................................................................................... - 1 -

2. LITERATURE REVIEW ........................................................................................................ - 6 -
   2.1 The Basic Concepts of Cellular Automata
   2.2 CA Application to Urban Systems
   2.3 Cellular Automata - Markov Chain Model

3. STUDY RATIONALE AND RESEARCH STATEMENT ......................................................... - 11 -

4. CONCEPTUAL FRAMEWORK AND METHODOLOGY ...................................................... - 14 -
   4.1 Framework
   4.2 Study Area

5. MODEL APPLICATION ........................................................................................................... - 18 -
   5.1 Markov Transition Probabilities
   5.2 Multi-Objective Suitability Analysis
   5.3 Land Use Change Simulation

6. EVALUATION ......................................................................................................................... - 43 -
   6.1 Similarity Degree between Scenarios
   6.2 Evaluation of Land Use Distribution and Proportion
   6.3 Evaluation of Land Use Transitions

7. DISCUSSION ........................................................................................................................ - 51 -
   7.1 Methodological Aspects
   7.2 Model Application Aspects

8. CONCLUSIONS ..................................................................................................................... - 57 -

REFERENCES ............................................................................................................................. - 61 -

APPENDIX 1 ............................................................................................................................... - 64 -

APPENDIX 2 ............................................................................................................................... - 66 -
1. Introduction

Planning for a modern fixed guide-way transit system in Cincinnati’s urban core has been taking place since the year 2000 (HDR 2010; FTA et al. 2011). In 2007, city leaders proposed a streetcar system intending to increase connectivity between the downtown area and its adjacent neighborhoods. They have also expected that the streetcar would trigger revitalization and redevelopment of the steadily deteriorating urban core. The Cincinnati City Council approved the project in May 2010.

The proposed 4.9 mile route, which is presented in Figure 1, extends from the Ohio riverfront, through the Central Business District and the neighborhood of Over-The-Rhine (OTR), and climbs uphill to the University of Cincinnati main campus. The route connects two of the region’s major employment centers and passes alongside many of its cultural venues, market places, and public spaces. The first streetcar is expected to begin service in 2013, given the construction work will start in the fall of 2011 (City of Cincinnati and FTA 2011)\(^1\).

The public expenditure required for the streetcar construction has been estimated in $128 million. The city’s strong ambition to carry out the project despite the relatively heavy public expenditure (in local terms), have given rise to a strong political resistance. It provoked a continuing bitter public dispute focuses on the necessity of the system and its impact on the city. In November 2009, an attempt to stop the project in a ballot was failed (Horstman 2009), but the controversy around the project has only escalated ever since.

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\(^1\) In April 2011, during the finalization of the current study, the City of Cincinnati proposed a modified route. This study, however, takes into account the original route that was approved by City Council in May 2010.
On October 10, 2010, *The Cincinnati Enquirer* opened its Sunday Forum with the title: “Downtown Streetcar – A Financial Gamble” (Figure 2). Above the headline, the newspaper editor explained the story behind it: “The $128 Million streetcar is a go, and its route has been decided. Now the city can only wait (and hope) for the investment to pay off” (Horstman 2010a, p.1). The headline, like many others posted in the local media, revealed serious doubts regarding the new transit system’s capability to serve its intended purposes.
The streetcar feasibility studies and cost-benefit analyses were conducted by HDR Inc. (2007a, 2007b, 2010). They comprehensively assessed and quantified the projected redevelopment impact of the streetcar. They focused predominantly on the transit premium that the streetcar is expected to generate. Based on economic risk analysis, the studies concluded that over a 20-year period the project will yield more than $211 million in public revenue, resulted from commercial and residential development along the streetcar corridor.
The Economics Center for Education and Research scrutinized the streetcar feasibility study. Although it found the assessments to be credible, it raised doubts regarding the application of experience in other US cities as foundations for economic development patterns in Cincinnati (Vredeveld et al. N.D.). Indeed, the analyses were based on studies of streetcar systems’ impact across the US, while lacking local criteria. For instance, the feasibility study provides a simple assessment of the potential redevelopment in a 3 city blocks corridor around the proposed alignment (HDR 2007a). This assessment was actually derived from a study of Portland (OR) streetcar’s impact on its environs. Finding from Portland were directly applied on Cincinnati, while the significant differences between the two cities were not considered.

Further economic and environmental impact assessments of the project examined land value change and current land use policies, but lack of in-depth land use study (HDR 2007b; HDR 2010; FTA et al. 2011). In fact, besides supportive brief reports, a comprehensive study of land use change impact was never conducted nor initiated (Moore 2010, personal communication, October 29, 2010).

To fill in this gap, the main objective of the current study is simulating the potential land use changes that would follow the proposed streetcar establishment. It thereof sheds some light on Cincinnati’s future development patterns and may facilitate the on-going dispute.

In order to simulate future land use changes, the study employs a model based on Geographic Information System (GIS). It is a Cellular Automata model that integrates statistical and spatial analyses.

This paper thoroughly describes the model application, outcomes, and verification. The introduction provides the study context. It is followed by chapter 2 (literature review), which
focuses on the concepts of Cellular Automata model and their application in urban studies. Chapter 3 presents the study rational and the research statement. The model framework is explained in chapter 4, followed by a detailed description of the model application and verification in chapter 5. Chapter 6 presents the evaluation of the model and its results, and chapter 7 discusses potential improvements and recommendations for future applications. Chapter 8 is a comprehensive summary of the study.
2. Literature Review

2.1. The Basic Concepts of Cellular Automata

The concept of cellular automata (CA) is originally associated with the field of computer science and the theory of continuous dynamic systems. Physical science studies in the 1930s and 1940s yield a conceptual model for simulating spatio-temporal dynamics. The model has since evolved and been employed in various scientific fields such as physics, chemistry, hydrodynamic, ecology, and medical science. The introduction of CA model to geography and urban studies occurred only in the mid-1980s (Benenson and Torrens 2004; Mitsova-Boneva, 2008).

Universally, CA models incorporate 5 fundamental components: cells, lattices, states, neighborhoods, and transition rules. The cell is an individual automaton that constitutes the smallest and most fundamental spatial entity in the model. A cluster of Cells forms a grid space, also known as the ‘lattice’. Lattices are ‘lucid’ grid-cell tessellations of either one-dimensional or two-dimensional surface\(^2\), represent the study area. Each cell in the lattice has a state, which is its specific stored value. States are subject to transitions and offer a flexible platform to display the model attributes. The states transitions are determined by the last two components; the surrounding cells, which compose the neighborhood, and transition rules.

CA neighborhoods represent some sort of spatial phenomenon. They define the spatial context of the lattice and determine the automata’s inputs. In urban CA models, neighborhoods can pose concepts such as commuting fields, market areas, and zones of influence. While

\(^{2}\) Some scientific fields employ today three-dimensional lattices.
neighborhood typically consist of the objected automaton’s adjacent cells, it is important to
distinguish between three archetypes: (1) Von Neumann 3×3 neighborhood, which is composed
of four cells and excludes the diagonal neighbors, (2) Moore 3×3 neighborhood that consists of
all the 8 surrounding cells, and (3) Von-Neumann 5×5 neighborhood. Transition rules are the
model parameters that dictate cells behavior during model iterations. They are mathematical
expressions that virtually represent the spatial processes in the model’s area of focus.
Predefined by the modeler, transition rules pose criteria of constraint and acceleration, which
specify the future state of a cell, based on inputs from its neighborhood (Torrens 2003; Benenson and Torrens, 2004).

Finally, another fundamental element of CA models is their relation to time. In
definition, CA models simulate not only spatial relationships, but also incorporate the temporal
dimension. They apply dynamic iterations of transition in an accumulative process of self-
reproduction. Moreover, transition occurs concurrently in several places on the lattice, as
several automata are activated at any given time and at any iterative step (Torrens 2003).

2.2. CA Application to Urban Systems

The field of urban modeling has substantially expanded over the last three decades. A
new generation of urban models has developed consequently to the evolutions of new
modeling methods and advanced Geographic Information Systems (GIS) (Benenson and Torrens
2004). Classic urban geography theories, such as spatial interaction, gravity model, central place
theory, bid rent equations, and distance decay, are still in existence, but they are now incorporated into computerized simulations (Adhvaryu 2010).

One of the new techniques adopted in urban modeling since the 1980’s is Cellular Automata (CA). Broadly speaking, CA urban models focus on exploration of ideas and hypotheses about the evolution of urban areas. They are based on micro-level interaction between entities in the urban field, and changes are corresponding to logical user-determined transition rules. Also considered as a branch of Urban Geosimulation, CA models are usually utilized in engaging the future and in attempts to solve present problems in metropolitan areas. They are most commonly applied to simulate land development, urban growth, and land use transition (Benenson and Torrens 2004; Torrens 2003).

Among the academic community, CA urban models are perceived as one of the most successful methods for simulating urban systems (Mitsova-Boneva 2008). Santé et al. (2010) describe the main features because of which CA models are so suitable to urban systems simulations: simplicity, flexibility, intuitiveness, ability to incorporate both spatial and temporal variation and processes, and the capability of modeling complex dynamic systems. Other attribute that makes CA so useful in simulating urban systems are their capability to simulate several characteristics of urban systems; their ability to represent almost any area unit or geographic entity, and to connect between them by cells and neighborhoods; and the integration of urban theory concepts such as spatial interaction and gravity models (Mitsova-Boneva 2008).

In sum, CA models consider space and time, and are dynamic and flexible in terms of scale and distance. They reflect the object nature of urban systems, and the dynamic
relationship between the urban objects. Like urban systems, which are complex, adaptive, and dynamic, CA urban models contain objects and elements that virtually *behave* and mutually affect each other (Torrens 2003).

Indeed, several CA-based models and tools have become prominent and useful in modeling urban systems. Nevertheless, the application of classic CA model to urban systems raised several issues. For instance, urban systems are human environments, affected by human decisions and actions, as well as by other various internal and external factors. As such, urban systems are much complex and less predictable than other environments of CA applications. Other issues are lack of consideration for geographic location, and the unlimited space provided by the model. Attempts to address these issues by urban geographers and planners yield the integrations of classic CA models with other techniques such as fuzzy logic control, artificial neural networks, and Markov chain analysis (Benenson and Torrens 2004).

Noteworthy, one of the most influential attempts to simulate land use dynamics using CA was actually applied to Cincinnati, OH. White and Engelen (1997) employed CA land use change model to simulate Cincinnati’s past urban growth, incorporating three basic location principles as the model variables basis: (1) attraction and repulsion effects of spatial elements on land uses, (2) the distance decay of these spatial effects, and (3) site specific factors.

### 2.3. Cellular Automata - Markov Chain Model

Clark Labs (MS), the developer of IDRISI GIS software, has successfully addressed many challenges in dynamic simulation of land cover/land use change in the development of
the software. Modules within the general IDRISI environment include CELLATOM, which is a purely cellular automata model and CA_MARKOV, which combines cellular automata with Markov chain analysis (Mitsova-Boneva 2008).

Markov chain analysis utilizes a transition probability matrix to determine the possibilities and probabilities of each cell to change from one state to another. In the context of land use change, the matrix is based on past land use transition patterns as guidelines to predict future transitions. One method to develop the transition probability matrix is to compare two land use distribution images from two different points in time (Eastman 2009).

Cellular Automata (CA) analysis is a technique to simulate spatio-temporal dynamics, as described above. In practice, CA urban models integrate a series of suitability analyses, by which they apply multiple spatial factors and constraints on simulated processes of land use development. As such, CA incorporates the spatial dependency factors in the models. Together, CA and Markov analyses generate a more accurate prediction (Eastman 2009).
3. Study Rationale and Research Statement

Uncertainty regarding the impact of planned projects on the built environment is a common issue in many (if not in all) planning processes. In the case of Cincinnati’s streetcar system, this uncertainty prompts profound public disagreements. The dispute around the streetcar establishment is at the center of the local public attention, as supporters and opponents debate on several issues such as the economic return on investment, alignment appropriate location, and volume of ridership (Horstman 2010b).

In essence, the dispute centers on the streetcar “value premium” effect, which is an indicator of increase in real-properties value or other related economic assets, as a result of the system operation (TRB 2010). City officials and streetcar advocates insist that the streetcar will initiate substantial value premium in the city urban core, as well as throughout the city as a whole (Baverman and Bernard-Kuhn 2010). Meanwhile, many Cincinnatians dwell on many unanswered questions related to the streetcar’s presence in the heart of the city and the potential economic return on the substantial public investment (Horstman 2009; 2010a; 2010b).

The major arguments of the Cincinnati’s streetcar dispute parties are outlined in Appendix 1. They derived from various publications such as local and national newspapers, the Cincinnati streetcar feasibility studies, and CATO Institute’s articles. Additional arguments were acquired through personal communication with project managers who evaluated the streetcar environmental and economic potential impact, as well as with city officials who were involved in the route design of the proposed system. Also incorporated are the views of experts who
conducted socioeconomic analyses and environmental impact assessments, and who are engaged in the streetcar planning and conflict resolution processes.

The two narratives revealed in Appendix 1 can be summarized as follows:

- **Streetcar supporters’ narrative:** The streetcar system would serve thousands of people daily. It will foster economic development, increase commercial and retail activities, and advance housing stock. It would affect in particular the area surrounding the streetcar’s proposed alignment, but would also influence the city as a whole.

- **Streetcar opponents’ narrative:** The system will be underutilized and redundant in terms of both ridership and urban redevelopment. It might attract a few businesses and residents from other neighborhoods into the route’s surrounding streets, but will not generate any significant change in the city’s development pattern. Thus, it is a senseless waste of public resources.

  Many of the arguments raised by both supporters and opponents cannot be validated until the system becomes fully operational as they are all but grounded facts. The dispute, however, underscores the need for a framework of systematic assessment that can reduce uncertainty by applying agreed-upon criteria seated in planning theory and practice. Uncertainty and evolving public disputes are inherent to most publicly funded and private projects. Under such circumstances, a broad consensus is often required in order to advance the project through its implementation phase (Brooks 2002). In the light of Supporters and opponents’ narratives, this study seeks to address the need for building consensus, and to reduce the uncertainty around the streetcar project. It aims at analyzing the relationship
between the streetcar and the built urban environment and thus focuses on the modeling and projection of land use changes.

Correspondingly, the main research questions of this study are: (1) what is the difference of the streetcar’s projected impact on land use as derived from opponents and supporters’ narratives, and (2) whether the streetcar impact on land use are significant. The considered aspects are spatial extent, land use distribution, and land use transition. In order to answer these questions, a CA-Markov land use change model is employed using IDRISI Taiga software (Eastman 2009). The model illustrates urban land use changes that would evolve as a result of the establishment of the streetcar.
4. Conceptual Framework and Methodology

4.1. Framework

The study simulates the streetcar system’s impact on urban land use in Cincinnati, considering the supporters’ and the opponents’ narratives. It incorporates their arguments in three land use change scenarios:

Scenario 1 incorporates criteria that reflect the narrative of the streetcar supporters.

Scenario 2 revolves around the narrative drawn by the streetcar opponents.

Scenario 3 represents a no streetcar scenario. It is used as a baseline for comparison.

The study utilizes the CA_MARKOV module in IDRISI Taiga, integrating two advanced methods to model land use changes: Markov chain analysis and Cellular Automata analysis (Eastman 2009). Additionally, spatial criteria integrated in the model have been developed and constructed using ESRI ArcGIS (v.10) rich toolset.

Figure 3 presents a flow chart of the study framework and schematically describes the entire study. As can be seen, the study simulates the three scenarios in terms of land use changes, using the CA_MARKOV model. It then evaluates the model outputs to yield proper conclusions. The analysis is conducted in three steps as follows.

I. **Markov transition:** Markov transition probabilities are derived based on a cross tabulation between an earlier and later land use images using MARKOV module in IDRISI. This step allows the detection of areas with higher potential for transitioning from one land use class to another.
II. **Multi-objective suitability analysis**: spatial suitability variable are integrated to incorporate spatial dependency factors and constrains for each of the simulated land use categories, under each of the three scenarios. The analysis is conducted using IDRISI Multi Criteria Evaluation Decision Wizard.

III. **Land use change simulation**: a Cellular Automata - Markov Chain analysis (CA_Markov) model is applied to simulate land use change over a period of 10 years based on the criteria derived for each of the three scenarios.

![Figure 3: A flow chart of the framework for systematic assessment of the public dispute.](image)
4.2. Study Area

Delineating the study area, I primarily focused on the area in which the streetcar impact would occur, according to the most optimistic streetcar backers. On the other hand, I took into account the edge effects and the modifiable aerial unit problem (MAUP) (Mitsova-Boneva 2008). Also considered was the CA_MARKOV model technical requirement for a rectangular study area.

The study area, displayed in Figure 4, encompasses a rectangle of 72.2 square miles. Focusing on the City of Cincinnati, it covers 50.4 square miles (63%) of the city municipal area, and includes 40 of its 52 neighborhoods. It embodies partially or fully 15 other municipalities in the states of Ohio and Kentucky, such as Springfield Township (OH), St. Bernard (OH), Norwood (OH), Covington (KY) and Newport (KY).

As can be seen in Figure 4, the rectangular area horizontally centers the streetcar proposed route, as its boundary lies approximately 4 miles both eastward and westward. Vertically, the streetcar is situated at the southern portion of the rectangle, stretches approximately 6.5 miles away from the northern boundary. The study area extends as far as 7.6 miles from the proposed route (at the northeastern corner).

Due to data limitations, I minimized inclusion of areas outside of Hamilton County, Ohio. Whereas the employed model entails a rectangular study area, I confronted certain difficulties in obtaining the required dataset for the Kentucky portions of the study area, located south of the Ohio River. While captured in the study area, these portions were partially excluded from the study. They are included in the general land use projections but excepted from some of the spatial criteria. Hence, I omitted those portions from the model outcomes evaluation as well.
Such omission does not spoil the analysis; due to the physical barrier posed by the Ohio River south of the southern streetcar turnaround point, the impact on land use in Northern Kentucky would assumingly be marginal.

Figure 4: The study area is a 72.2 sq. mile rectangle, encompasses areas in 2 states and 3 counties. (Data sources- CAGIS 2011, OKI 2010)
5. Model Application

5.1. Markov Transition Probabilities

The derivation of Markov transition probabilities requires historical land use images from two different periods (Figure 5). In this analysis, I used 2000 and 2010 land use distributions derived from parcel data. The datasets for Hamilton County, OH were obtained from the Cincinnati Area Geographic Information System (CAGIS). Additional land use data, which are used to cover the Kentucky portion of the study area, were obtained from the Ohio-Kentucky-Indiana Council of Governments (OKI) and from Northern Kentucky Area Planning Commission (NKAPC). The land use data were reclassified into four categories as presented in Table 1: residential, commercial, public, and industrial.

The reclassified land use images were run through the Markov module in IDRISI to generate two matrices: (1) a Markov Transition Probability Matrix that describes the probability of each category to change to every other category; and (2) a Markov Transition Areas Matrix, which designates the number of pixels that are expected to change from one category to another in the next time period (Eastman 2009). In addition, the Markov module generates a raster of the Markov Transition Areas, which indicates the probability of each pixel to transition to a different state during each model iteration (Eastman 2009).
Figure 5: Images of study area land use reclassified for 2000 and 2010. Classes 1-4 respectively denote residential, commercial, public, and industrial land uses.

Table 1: Aggregative reclassification of land use data

<table>
<thead>
<tr>
<th>Model Classification</th>
<th>Land use 2000 image (OKI)</th>
<th>Hamilton Co. 2010 (CAGIS)</th>
<th>Kenton Co. 2010 (NKAPC)</th>
<th>Campbell Co. 2010 (NKAPC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Code</td>
<td>Class</td>
<td>1</td>
<td>Residential</td>
<td>residential</td>
</tr>
<tr>
<td>2</td>
<td>Commercial</td>
<td>O, MU</td>
<td>Retail/service, office</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Public</td>
<td>Underdeveloped, institutional, other (river), unclassified.</td>
<td>PS, PR, IN, ED, AG, VA</td>
<td>Public/semi-public, recreation and open space, vacant, not coded</td>
</tr>
<tr>
<td>4</td>
<td>Industrial</td>
<td>PU, LI, HI</td>
<td>industrial</td>
<td></td>
</tr>
</tbody>
</table>
5.2. Multi-Objective Suitability Analysis

In IDRISI, multi-objective suitability analysis can be completed using the Multi Criteria Evaluation Decision Wizard (MCE-DW). MCE-DW guides the modeler through each objective, and prompts him/her to incorporate constraints and factors, by which CA models incorporate spatial dependency (Eastman 2009). Constraints and factors, conjointly named criteria, dictate the simulated urban development patterns, as they bring in spatial aspects and urban components that influence land use transformation. Constraints are the areas excluded from further modification. Factors are inputs variables that determine the level of suitability of each cell for a particular objective. Constraints are constructed by the Boolean method and are re-classed into values of ‘1’ and ‘0’. Factors are standardized on a continuous scale of a byte-level range between 0 and 255 to ensure maximum differentiation. The 0-255 range evolves from the byte images’ radiometric resolution of 8 bit, used in this study. This standardization method allows the modelers to compare, combine, and evaluate factors with different units of measurement scale and range (Eastman 2009).

As oppose to the qualitative-hypothetical scenarios, CA criteria are quantitative and concrete. The conversion from theoretical scenarios to quantitative parameters is, ergo, the first actual stage in the model development. In the current model, I incorporated ten criteria for suitability analysis. The variables were selected based on the study area characteristics, literature review, and data availability. The variable selection underwent ‘reality verification’ prior to their application in the model. On April 4, 2011, I introduced the model criteria to the Cincinnati Enquirer journalist, Mr. Barry Horstman, who covered much of the streetcar public dispute in recent years. Mr. Horstman confirmed that the model criteria were appropriate for
the Cincinnati urban realm and convincingly represented the parties’ narratives. The flow chart in Figure 3 refers to this process as “pre-application verification”.

The selected criteria variables include seven factors and three constraints. The factors are (1) streetcar route proximity, (2) population and (3) high employment density, (4) market land value, (5) public facilities, (6) landmarks, and (7) bus stops. The constraints are (1) zoning regulation, (2) topographic slope, and (3) public land.

Census 2010 Demographic data at the census tract level was obtained from the US Census Bureau’s American FactFinder website. Employment data at the Traffic Analysis Zones (TAZ) level for the year 2010 was provided by the OKI GIS department. All the other feature classes were derived from CAGIS and NKAPC databases, provided by the University of Cincinnati. Utilizing ArcGIS geoprocessing tools, I carefully generated feature classes from the above sources, clipped them to fit the study area, and converted them to raster datasets for the MCE analysis in IDRISI. The following subsections (5.2 and 0) discuss in more detail the ‘behavior’ of each criterion under the baseline, the supporters’ and the opponents’ scenarios.

5.2.1. Factors

When designing the suitability factors that affect land use spatial patterns, I took into account attraction/repulsion effects, distance decay, and site specific factors. This approach is founded in the influential application of CA model on Cincinnati, done by White and Engender (1997). Factors are represented as continuous surfaces at a byte-level where 0 signifies full repulsion, and 255 represents full attraction. In other words, this range indicates the suitability degree of each cell to undergo transition/s to different land use class. I used a set of fuzzy
membership functions, provided in IDRISI to apply the attraction/repulsion and distance decay effects. Following that, pixels carrying value of 0 (zero) were reclassified to 1 (one).

Different weighting schemes were used under each scenario to reflect the arguments presented by streetcar opponents and supporters (Appendix 1). Table 2 depicts the model weighting schemes. As can be seen, some factors were assigned relatively higher weights in scenario 1 than in the two other scenarios. Moreover, two of the factors - public facilities and Landmarks - have distinct structure in scenario 1 (see below). As a result, the number of factors varies between scenarios. An ‘offset factor’ was incorporated in order to eliminate any undesired difference between factors’ weights, while maintaining the variation in factor number between scenarios. The offset factor covers the whole study area and poses value of 1 (minimal suitability). It fills virtually any weighting gap created between the scenarios by not employing factors, or by assigning relatively lower weights to certain factors.

Some factors affect land use in a similar way under each individual scenario while others vary in their influence. Likewise, some factors’ effects vary between land use classes while others pose similar effect on all classes. For example, the land value factor poses similar effects under all three scenarios, but affects differently each land use class. The effects of bus stops factor on all land uses are identical, but their weights differ between scenarios. Also, some of the factors affect all land use, while others affect only one of them (see Table 2).

Some of the factors integrate a ‘walk-ability distance’ in their structure. Obviously, walk-able distances differ based on various criteria, e.g. topographic conditions, weather, destinations, time of the day, as well as the pedestrian characters and preferences. In this model, I referred to a distance of 1,200 feet (365 m) as a walk-able distance.
**Table 2**: Factor’s relative weights for multi criteria evaluation

<table>
<thead>
<tr>
<th>Factors</th>
<th>Affected Land Uses</th>
<th>Supporters Scenario (1)</th>
<th>Opponents Scenario (2)</th>
<th>Baseline Scenario (3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Streetcar proximity</td>
<td>all categories</td>
<td>0.15</td>
<td>0.10</td>
<td>0</td>
</tr>
<tr>
<td>Population density</td>
<td>all categories</td>
<td>0.15</td>
<td>0.15</td>
<td>0.15</td>
</tr>
<tr>
<td>High density employment</td>
<td>commercial</td>
<td>0.15</td>
<td>0.15</td>
<td>0.15</td>
</tr>
<tr>
<td>Land value</td>
<td>all categories</td>
<td>0.15</td>
<td>0.15</td>
<td>0.15</td>
</tr>
<tr>
<td>Public facilities</td>
<td>residential</td>
<td>0.10</td>
<td>0.10</td>
<td>0.10</td>
</tr>
<tr>
<td>Streetcar public facility</td>
<td>residential</td>
<td>0.05</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Landmarks</td>
<td>commercial</td>
<td>0.10</td>
<td>0.10</td>
<td>0.10</td>
</tr>
<tr>
<td>Streetcar landmarks</td>
<td>commercial</td>
<td>0.05</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Bus stops</td>
<td>all categories</td>
<td>0.10</td>
<td>0.05</td>
<td>0.05</td>
</tr>
<tr>
<td>Offset factor</td>
<td>all categories</td>
<td>0</td>
<td>0.20</td>
<td>0.30</td>
</tr>
<tr>
<td>Total</td>
<td>-</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
</tbody>
</table>

**Proximity to the streetcar route.** The impact of the streetcar route on land use is a focal point in the dispute between the project’s supporters and opponents. The parties disagree about the area of influence, magnitude, and net economic growth the project will stimulate. Hence, while influences all land use classes, this factor creates the most significant differentiation between the three scenarios.

Under Scenario I, based on project supporters’ narrative, the streetcar generates new mixed-use development, attracting residential, commercial, and public land use to a large area around the streetcar, especially in the areas that are located at a walking distance. This factor, displayed in Figure 7a, was designed to accommodate both the relatively high magnitude of the attraction effect in a walk-able distance from the alignment, and the geographic limitation of this effect. The area of impact was limited by dominant physical barriers (the Ohio River, Highways I-75 and I-71, and MLK Avenue). As depicted in proponent’s narrative, it captures the
city CBD, the adjacent neighborhood of Over-The-Rhine (OTR) and the uptown district, including the University of Cincinnati and the hospitals’ campuses. Suitability/attraction values are 255 within a walk-able distance of 1,200 feet from the alignment; they linearly decline until reaches a value of one (1) in the area boundary (and beyond them).

Based on opponents’ narrative, under scenario II the streetcar merely affects its immediate proximity, attracting new development only to the adjacent streets. To illustrate these features (Figure 7b), the factor poses highest suitability degree (255) to a distance of half city block (200 feet) from the proposed alignment. Then, suitability values linearly decrease to a minimal value of 1 (one) in a distance of 600 feet and beyond (Figure 7b). Under Scenario III, the streetcar route does not exist thus the factor was eliminated.

In sum, this factor differs between scenarios 1 and 2 in three aspects: (1) magnitude of impact, (2) the extent of distance decay, and (3) factor relative weight. Figure 6 provides a schematic chart that demonstrates the suitability/attraction value assigned by the streetcar proximity factor in each of the scenarios, as a function of distance.

![Figure 6: Suitability degrees assigned by the streetcar proximity factors, as a function of distance from the proposed alignment.](image-url)
Population density. Populated residential areas attract different land use developments to different degrees, corresponding to their density. For instance, commercial land uses (retails) are attracted to dense residential areas due to higher market threshold. Residential developments (and public uses) are attracted by the proximity of large population due to existing infrastructure and what appears as a successful residential area. The impact of populated areas on industrial land uses is usually negative; the noxious effects of industry repel housing, thus manufactory plants are usually located far from populated areas (White and Engelen 1997; Barredo et al. 2003). Sparsely populated areas are usually utilized for industrial zones or other repelling uses for residences. They are inherently less attractive for new residential, public, and commercial developments.
To reflect the population density effects on land use changes, I distinguished industrial land use class from all the other categories; as can be seen in Figure 8, this factor poses a linearly decrease function for industrial land uses, where unpopulated areas are most attractive and densely populated areas are repulsive. For all the other categories, the function is inverted. However, to reflect no suitability for industrial land uses, as opposed to minimal suitability for all the other land uses, the former’s function starts at value 1, while the latter begins at 50 (see Figure 8 and Figure 10).

Population densities were calculated using the ratio between census tracts’ total population (Census 2010 data) and tracts’ area. It was found that population density in the study area ranges between 0.2 and 27.1 inhabitants per acre (Figure 9). A linear monotonically decreasing function was assigned to create fuzzy membership and rescale population density to the 0 -255 range (Figure 10). No major differences were found between the parties’ narratives with regard to this factor, thus it was kept constant under all scenarios.

Figure 8: Attraction/repulsion degrees assigned by linear functions of population density.
Figure 9: Calculating population density for census tracts.

Figure 10: Reclassifying tracts to fuzzy membership using (a) increasing linear function for residential, commercial, and public land uses categories, and (b) declining linear function for the industrial land use category.
**Areas of high-density employment (HDE).** Employment density was calculated at the Traffic Analysis Zones (TAZ) level as the number of employees per acre. It was found that the average employment density is 39 employees per acre. TAZs carrying values higher than the average were identified as areas of HDE. Those areas are (1) the central business district; (2) the Uptown area, which includes University of Cincinnati’s East and West campuses; and (3) the center city of Norwood (see Figure 11). Since HDE areas traditionally attract commercial development, it is assumed that they would pose a considerable impact on future commercial development.

In order to reflect the attraction effect of HDE areas, as well as the distance decay of such an effect, I assigned a monotonically decreasing sigmoidal fuzzy membership function, using IDRISI MCE Wizard (Figure 12). The resultant image of this function is shown in Figure 13. Control point ‘c’ is 2640 feet (or 0.5 mile) to feature steeper distance decay beyond this distance from each TAZ of HDE. Control point ‘d’ refers to the greatest distance exists between any high employment area to the study area edges (33790 feet). It was assigned in order to avoid zero-suitability cells across the study area. This function is held constant for all three scenarios but is applied only on commercial land use.
Figure 11: Calculating employment density per Traffic Analysis Zones.

Figure 12: Assigning a monotonically decreasing sigmoidal fuzzy membership function, using IDRISI MCE Wizard.
**Land value.** Ruled by the market forces, land values are indicators of multiple variables such as wealth level, crime rate, distance from an urban core, and the use of land. Hence, they adequately manifest the socioeconomic profile of any area and district, as well as the ability of an area to attract different land uses. In a generic free market urban environment, higher land value indicates a wealthier, safer and more desirable zone, while lower land value may reveal high poverty and crime rates, lower accessibility to amenities, and bleakness.

The inclusion of land value factor in the model is somewhat problematic. This is because one of the most significant factors of land value is actually land use. That is, land use and land value mutually affect one another; any change in land use directly impacts the market value of a land parcel and vice versa. The factor is integrated nevertheless, due to its adequate association with communities’ profile, and thus its crucial implication for land use distribution.
In land use terms, commercial land use and wealthy residential communities characterize districts that pose the highest land value. Moderate land values traditionally attract more residential development and public uses, but also commercial uses. Lower land values are most appropriate for industrial use, public uses, and low-income housing, but they are *usually* less attractive for new residential or commercial developments.

In order to accommodate market land value factor in the model, I computed the average market land value for each census tract. The calculation was based on the ratio between a parcel market land value and its area in square feet (Figure 14). Once the square footage value of each parcel was calculated, all parcel features were dissolved into their corresponding census tracts, assigning the average square footage value to each tract. Land values in the study area are ranged between $2.55 and $267.73 per square foot, while the average value is $25.

Similarly to the population density factor, suitability values were assigned for each of the objective land use classes, proportionally to the average land value: Areas that pose highest land value were characterized by high suitability to commercial land use, while moderate land use values were assigned to attract residential development and public uses. Lower value regions pose high suitability for industrial land uses. I used an Excel spreadsheet and the IDRISI Reclass module to reclassify the tracts to the 1-250 range, corresponding to the chart in Figure 15. As can be seen, the mean value of $25 posed a control point, in which the slope and/or directions of each function was altered. Figure 16 displays the resultant images, which were used equally in all scenarios.
Figure 14: Calculating land value ($ per square foot) of all land parcels in the study area.

Figure 15: The functions used to reclassify land values to fuzzy membership suitability degree.
Figure 16: Representing land value suitability by fuzzy membership classification for (a) residential, (b) commercial, (c) public and (d) industrial land use, where ‘250’ represents the highest suitability degrees and ‘1’ represents the lowest one.

**Public facilities and landmarks.** These two criteria were constructed as nodal factors in a similar manner, but they influence different land use categories. Public facilities factor represents nodal locations of all schools, public library, public medical clinics, and open civic spaces (parks and plazas) in the study area. It affects only residential land use. Landmarks factor is constituted by site of interest and tourist attraction, i.e. museums, culture venues, sport facilities, historic sites, and academic institutions. It influences commercial land use only.
The basic assumption of the public facility factor is that homebuyers, renters, and residential developers are more likely to select sites located nearby established public facilities, which makes those sites more attractive for residential development. Correspondingly, landmarks and the areas around them are considered more attractive for commercial development, as they attract relatively large amount of consumers. It is also assumed that both factors’ attraction effects are local, that is- within a walk-able distance.

Designing these factors, I created a 1,200 feet buffer around each public facility and landmarks. I assigned a maximal suitability value (255) to cells that fell within those buffers, and utilized IDRISI MCE Wizard to create monotonically decreasing fuzzy membership functions beyond them, to reflect the distance decay up to 5000 feet (just less than 1 mile) from the sites.

As Figure 17(a and b) exhibits, a sigmoidal curve is indicative of public facilities while a J-shaped curve indicates the decay in landmarks factor. This difference derives from the assumption that residences tolerance relatively larger distance than retail shops.

In scenarios 2 and 3, where the streetcar is a failure or do not exist, all public facilities and landmarks land use redevelopment to the same extent. In scenario 1, where the streetcar is a success, the magnitude of the attraction effect is depended on a site distance from the streetcar alignment; facilities and landmarks located within a walk-able distance of 1200 feet from the route pose stronger impact than facilities located elsewhere in the study area. This assumption is correlated to the supporters’ narrative and incorporated by assigning a relatively higher weight to facilities and landmarks located near the streetcar alignment (see Table 2).
Figure 17: Assigning fuzzy membership functions to (a) public use facilities factor, (b) landmarks factor.

**Bus stops.** Bus stops attract relatively more new development to their very close proximity, as they considerably increase the connectivity and accessibility of their surrounding sites; residences, consumers, citizens, and employees, can arrive more easily to those sites, thus they are assumed to be slightly more attractive to all land use. In order to account for the impact of bus stops, a J-shaped fuzzy membership function, with control points in 600 feet and 1200 feet, was applied (Figure 18). Presumably, a successful streetcar will increase public transportation use overall, thus this factor has a relatively higher weight in scenario 1 (see Table 2).
Figure 18: Assigning fuzzy membership function to bus stop factor.

5.2.2. Constraints

Throughout the urban space there are areas of restricted development and no-build zones. These areas can be defined by regulation (zoning) or pose limitation on new developments due to natural conditions and massive infrastructure plants. Constraints are the criteria that bring these elements into the model. Unlike factors, constraints do not assign a degree of attractiveness or suitability, and are not continuous. They are Boolean images that differentiate suitable areas from unsuitable areas (cell values of 1 and 0 respectively). Zoning regulations, topographic slopes, and public lands are the constraints included in this model.
**Zoning codes** are the regulatory expressions of communities’ land use policy. They are artificial development constraints that limit certain land uses to certain locations in the municipal area. The city of Cincinnati and its adjacent jurisdictions regulate land development using Euclid zoning codes. In their codes, there are approximately 20 zoning classes (districts), by which the different communities enforce their land use and building rules.

Generally, zoning codes are much more complex in their land use classification than they are employed in the current model. Real-world zoning codes incorporate ample of details and specifications. For instance, in the case of Cincinnati zoning code, some of the commercial districts permitting some sorts of residential land uses and vice versa. In order to integrate zoning codes in the model, however, each designated zoning district either permits or restricts each of the objective land uses, with no ‘grey areas’.

The binary classification was derived from the zoning codes of the City of Cincinnati (City of Cincinnati 2011) as it is the predominant municipality in the study area. The resultant Boolean images are displayed in Figure 19. Appendix 2 provides a table on which the reclassification of zoning district was based. As can be seen in the table, zoning constraint was not applied to public land uses due to the nature of such uses. Both the narratives of streetcar opponents and supporters assert that the city would modify its zoning code in the streetcar area, in order to accommodate and encourage mixed land use redevelopment (O’Tool 2010). The zoning constraint in scenarios 1 and 2 were correspondingly modified to permit any residential and commercial (though not industrial) new development along the streetcar route.
**Topographic slope.** The study area consists of a rather hilly landscape; whereas the valley floors and plateaus are flat, the slopes between them are relatively steep (White and Engelen 1997). The municipal code of the City of Cincinnati prohibits development on slopes of 20 percent gradient or above (City of Cincinnati 2011). Therefore these areas were excluded from future development in the simulation. Figure 20a presents the slope constraint resultant image.

**Public lands.** This is a ‘pseudo constraint’, which is incorporated in the model due to the ‘un-model-ability’ of governmental spatial actions. To be more explicit, CA_MARKOV model is not capable to predict future land use allocation, public projects, and governmental investments, as they are subject to politics, economic climate, and government decisions. For that reason, areas classified as public lands in the existing land use remain constant throughout the simulation. This includes railways, highways, and the street network, as well as parks, and water bodies. The public lands constraint image is displayed in Figure 20b.

![Residential Zoning Constraint](image1.png) ![Commercial Zoning Constraint](image2.png) ![Industrial Zoning Constraint](image3.png)

**Figure 19:** Boolean images of zoning constraint. The red areas are suitable and the black areas are unsuitable.
5.2.3. Aggregating Weighted Criteria

IDRISI MCE Wizard provides a powerful platform to aggregate all factors and constraints into one composite image for every modeled objective (land use class). The wizard multiplies each factor by its relative weight and integrates the factor using weighted average. It then incorporates the constraints to exclude unsuitable areas from the composition. The resultant image is an aggregative composite, in which each cell poses a suitability/attraction value of 0-255, which respectively denote the range between ‘totally unsuitable’ and ‘most suitable’ (Eastman 2009). Such a process was carried out 12 times to produce composite images for each one of the 4 land use classes, under each one of the 3 scenarios. Relative (trade-off) weights were assigned according to Table 2. The resultant composite images are presented in Figure 21.
Table 21: Suitability images ordered by land use categories (rows) and scenarios (columns). The same color scheme is applied to all twelve resultant composite images, where 0 = unsuitability and 255 = maximum suitability. Notice the variation in suitability/attraction values in the urban core and along the proposed streetcar alignment. This variation derives from the factors’ alteration, especially the Streetcar Proximity factor.

<table>
<thead>
<tr>
<th>Residential</th>
<th>Commercial</th>
<th>Public Land</th>
<th>Industrial</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supporters’ Scenario (1)</td>
<td>Opponents’ Scenario (2)</td>
<td>Baseline Scenario (3)</td>
<td></td>
</tr>
</tbody>
</table>
5.3. Land Use Change Simulation

My intention was to build a model that represents real-world occurrences, considering various factors and constraints, commonly accounted for in transportation and land use analyses. CA_MARKOV module takes into account the Markovian land use change stochastic probabilities, but also incorporates spatial dependency criteria, corresponding to their relative weights. At this phase of the study, everything was ready to execute the CA_MARKOV model of land use change, as all the required components were obtained:

- A basis land use image (Land Use 2010, Figure 5), which is designated as a ‘modeling origin’, from which the first land use transitions occur.
- Markov transition area matrix, which was generated from the comparison between the earlier and the later land use images in Markov analysis (see section 5.1).
- A transition suitability image collection, which is the group of composite images that incorporate weighted factors and constraint of spatial dependency (see section 5.2).

The module runs through all the objectives and allocates cells to each one of them, corresponding to the transition probabilities and the spatial criteria. In addition, the module involves the specification of a weighing contiguity filter. The filter assigns lower weights to pixels that have high suitability scores but are not in close proximity to the existing constellations of cells of the same land use class. During each iteration, each land use class becomes consecutively a host category (Eastman 2009). In the current model I used a 5x5 contiguity filter.

This complex procedure is done several times, according to the number of iterations that indicated by the modeler. In the current study, the specified iteration number was 10, thus
the simulation period was 10 years. The outcome is an image that depicts a spatial depended projection of land use distribution over a specified period. I applied the model on each one of the scenarios to generate three future land use distribution images, for a hypothetical ten-year period upon the streetcar system’s inauguration (Figure 22).

**Figure 22:** CA_MARKOV projected land use distribution images for the year 2020, under streetcar supporters’ scenario (1), opponents’ scenario (2), and the baseline scenario (3). The same color palette was applied to all images (1-residential; 2-commercial; 3-public; 4-industrial). The 2010 land use distribution is depicted here again for comparison.
6. Evaluation

At first glance, the land use projection images displayed in Figure 22 appear to be quite similar to each other. In order to get a better sense of the differences and quantify their distribution, I utilized IDRIS’s Crosstab and Histo modules. The former is a pixels cross-tabulation analysis between the resultant images, producing a new dataset that categorizes each possible combination of pixels from the compared input images. The latter produces numeric (or graphic) cells frequency and proportion within an image (Eastman 2009). The modules were utilized to calculate the similarity between images, and land use distribution, proportion, and transition under each scenario.

Since both streetcar opponents and supporters assert that changes would occur merely in the streetcar environs, the evaluation was carried out in three distinct geographic extents: (1) the entire study area excluding the Kentucky portion, (2) the city’s urban core, which is the area of the streetcar impact indicated by the project supporters (Figure 7a), and (3) the streets along the proposed route, which compile the area to be affected according to streetcar opponents (Figure 7b). Doing that, I was able to assess the changes in different scales.

6.1. Similarity Degree between Scenarios

The initial evaluation compared the CA_MARKOV projected land use distribution images to each other. This evaluation considered the Kappa Index of Agreement (KIA) as the indicator for the similarity degree between the different scenarios. KIA is a commonly used statistical indicator that constitutes an accurate assessment of the similarity level between the cell values of two datasets. KIA values range between 0 (complete dissimilarity) and 1 (identical datasets).
(Mitsova-Boneva 2008). In the context of the current study, high similarity, where $KIA > 0.85$, implies insignificant variations of land use projections.

Table 3 presents the analyses results. The KIA values are higher than 0.85 when considering the entire study area, which indicates that there are no substantial differences in land use projections in that scale. When the comparison is limited to the area delineated by the supporters and the opponents, however, the cross-tabulations beget $KIA < 0.85$, indicating considerable differences.

The first implication, if so, is that land use changes in respect to the streetcar installment will occur under both opponents and supporters' scenarios. Moreover, though the impact is higher in the adjacent streets, as suggested by both parties, land use transition in surrounding neighborhoods is also significant, corresponding to the supporters’ arguments. Variations between the three scenarios definitely exist; they are, however, less substantial than what opponents and supporters would expect, as all KIA values are greater than 0.5.

**Table 3**: KIA values derived from each combination of land use projections

<table>
<thead>
<tr>
<th>Analysis Area</th>
<th>Supporters vs. Baseline</th>
<th>Opponents vs. Baseline</th>
<th>Supporters vs. Opponents</th>
</tr>
</thead>
<tbody>
<tr>
<td>The entire study area</td>
<td>0.93</td>
<td>0.97</td>
<td>0.92</td>
</tr>
<tr>
<td>(excluding Kentucky portion)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cincinnati’s Urban Core</td>
<td>0.71</td>
<td>0.85</td>
<td>0.68</td>
</tr>
<tr>
<td>(Figure 7a)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Streetcar’s adjacent streets</td>
<td>0.67</td>
<td>0.73</td>
<td>0.72</td>
</tr>
<tr>
<td>(Figure 7b)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Noteworthy, the comparison between the opponents’ scenario and the baseline scenario derive the highest KIA values in each row. As predicted, this implies that their simulations beget the most similar land use transitions in any geographic scale. The two resultant images, however, are certainly dissimilar and this implies that the streetcar would definitely affect land use change under opponents’ scenario.

6.2. Evaluation of Land Use Distribution and Proportion

Utilizing IDRISI Histo module and MS Excel, I quantified the projected land use distribution, attempting to detect what proportion of area each land use category occupies. Presumably, this information is essential for the variation assessment, as well as for further economic evaluation (which is out of the scope of this study). The results are presented in Figure 23-Figure 25.

Figure 23 ratifies what we have already known from the previous evaluation- there are no significant differences between the three scenarios when considering the entire study area. We shall notice the slight differences in numeric terms between the basis (2010) distribution and the projected (2020) distributions. However, since we deal with an area of 41,102 acres, the implications of these differences on spatial distribution are not essential. Inspecting the charts in Figure 24 and Figure 25, one can find some interesting variations, both between scenarios and between areas of observation.

The common feature is the predominance of public land use class, which occupies significantly larger area than any other class. Its relatively high proportion is not surprising; this category consists of the streets network, parks, schools, and institutional uses, and was largely 'protected' from transition by the 'public land' constraint.
The proportion of the residential category decreases as the analysis approaches the city center and the planned streetcar alignment; it declines from approximately 30% in the whole study area, to just more than 10% in the streetcar adjacent streets. Under supporters’ scenario, the streetcar establishment will discourage residential land use; it occupies relatively less area then under the two other scenarios, both in the urban core and in the streetcar adjacent streets.

The commercial land use category experiences reverse trend- it occupies less than 10% of the whole study area but captures up to 21-24% of the streetcar close proximity. Under scenario 1, commercial land uses occupy slightly more area than under the two other scenarios. Commercial land use’s figures in scenarios 2 and 3 are almost identical when considering the urban core and the streetcar close proximity.

Industrial land uses are relatively higher in the urban core, especially under scenario 1, where they win 23% of the land. Under both scenario 2 and scenario 3, industrial land use category is not as dominant and occupies less than 20%. In the streetcar adjacent streets, industrial land use is relatively more prevalent in scenario 3, where no streetcar would be established.

In sum, Figure 23-Figure 25 depict significant differences between scenario 1 and scenarios 2 and 3. Under scenario 1, it is projected that the streetcar will advance commercial and industrial land use in the city's urban core but support only commercial land uses in the streetcar adjacent streets. The high similarity between scenario 2 and scenario 3, which derived from the KIA values (Table 3), is well seemed in Figure 23-Figure 25 as well.
Figure 23: Projected land use distribution (acres) and proportion (%) in the entire study area.

<table>
<thead>
<tr>
<th></th>
<th>Scenario 1- Supporters</th>
<th>Scenario 2- Opponents</th>
<th>Scenario 3- Baseline</th>
<th>2010 LU distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Industrial</td>
<td>5014</td>
<td>5014</td>
<td>5014</td>
<td>4028</td>
</tr>
<tr>
<td>Public</td>
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<td>19154</td>
<td>19154</td>
<td>20921</td>
</tr>
<tr>
<td>Commercial</td>
<td>4028</td>
<td>4069</td>
<td>4069</td>
<td>2384</td>
</tr>
<tr>
<td>Residential</td>
<td>12906</td>
<td>12865</td>
<td>12865</td>
<td>13728</td>
</tr>
</tbody>
</table>

Figure 24: Projected land Use distribution (acres) and proportion (%) in the city’s urban core.

<table>
<thead>
<tr>
<th></th>
<th>Scenario 1- Supporters</th>
<th>Scenario 2- Opponents</th>
<th>Scenario 3- Baseline</th>
<th>2010 LU distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Industrial</td>
<td>664</td>
<td>437</td>
<td>535</td>
<td>118</td>
</tr>
<tr>
<td>Public</td>
<td>1320</td>
<td>1472</td>
<td>1369</td>
<td>1719</td>
</tr>
<tr>
<td>Commercial</td>
<td>564</td>
<td>495</td>
<td>495</td>
<td>503</td>
</tr>
<tr>
<td>Residential</td>
<td>331</td>
<td>469</td>
<td>477</td>
<td>535</td>
</tr>
</tbody>
</table>
6.3. Evaluation of Land Use Transitions

In this analysis, land use projections were compared to the existing (2010) distribution, in order to reveal the trend of each land use class over time under each scenario. The observed areas are similar to the ones observed in the previous evaluations. In the current evaluation, however, the asked question is: "What are the projected changes in the distribution of land use between the existing (2010) conditions and the future conditions?" Since the previous analyses indicated that no significant changes exist when considering the entire study area, in the current analysis I do not discuss this geographic extent.

Figure 27 and Figure 28 clarify the simulated land use transition patterns, as it depicts the changes from the existing (2010) distribution in absolute numbers (acres). Predominantly
seen, public land use would decrease and industrial land use would increase in any observed scale, under all scenarios. Industrial land use category would boost in the urban core under scenario 1, as it would grow in approximately 550 acres (Figure 27). When considering only the streetcar’s adjacent streets, this category would predominantly thrive if no streetcar will be established (scenario 3). Public land would decrease under all scenarios, especially under scenario 1 in the urban core and scenario 3 in the streetcar’s adjacent streets.

The trends of residential and commercial land uses are less definite. Residential land use will decline under all scenarios when considering the urban core, but will slightly increase along the streetcar alignment. In both extents, scenario 1 depresses the residential land use category while scenario 3 enhances it. Commercial land use will increase only when considering the city’s urban core under scenario 1. Nonetheless, this increase is relatively slight (60 acres) compare to the change in industrial land use (550 acres). On the other hand, commercial land use will slightly reduce under scenarios 2 and 3 in the urban core (-9 acres), and more significantly in the streetcar’s adjacent streets (-14 acres).

The differences between the scenarios come into sight especially with regards to residential and commercial developments. Under the supporter’s scenario, the streetcar establishment would advance commercial land use and deter residential land use. Under the opponents’ scenario, residential land use category is less depressed, but commercial land use is generally spoiled. Scenario 3 begets similar results to scenario 2 in these categories.
Figure 26: Land use projected transition (in acres) in the entire study area.

Figure 27: Land use projected transition (in acres) in Cincinnati’s urban core.
Figure 28: Land use projected transition (in acres) in the streetcar’s adjacent streets.

In sum, the model outputs indicate that:

- There are no significant differences between the outcomes of the scenarios when considering the entire study area. These differences are more substantial in the urban core and near the proposed alignment.

- The differences between the streetcar supporters’ scenario and the two other scenarios are more substantial as the distance from the planned alignment decreases.

- The differences between the projected results of the opponents’ scenario and the baseline (no-streetcar) scenario indicate that the streetcar will impact land use changes and development patterns, not only under supporters’ scenario. This contradicts opponents’ assertions that the project would not impact surrounding neighborhoods. Notwithstanding,
the high similarity between the projected results of scenario 2 and 3 implies that the impact under opponents’ scenario are quite slight.

- Residential land use will suffer if the streetcar will thrive. The no-streetcar scenario is more desirable for residential developers.
- In terms of commercial land use, the model projects slight increase only under supporters’ scenario and only when considering the urban core. Virtually, a successful streetcar would advance commercial developments, but they will not thrive in any case.
- Land use distributions vary between areas of observation and scenarios, but public land uses occupy significantly more area than any other land use in any geographic extent. However, public land use is projected a substantial reduce under all scenarios.
- The most significant increase is of industrial land use. It doubles or triples in most cases.
- In the streetcar close proximity, commercial land use would slightly decline and residential land use would increase to some extent. A thriving streetcar would merely lessen these trends.
7. Discussion

The model application presented in this paper can stand as a study by itself. In that case, we shall discuss the sources and implications of the simulation results. On the other hand, considering this study as a step in a longer-term research of CA-based land use change models, I see a great importance in discussing the lessons learned during the study and presenting some recommendations for further research. Therefore, this chapter consists of both methodological and implementation aspects of the model.

7.1. Methodological Aspects

This paper presents one of the first applications of CA_MARKOV in simulating the impact of mass-transit system on its surrounding land use transition. As such, some elements in the model, especially its criteria, are subject to improvements. The following list introduces some of these improvements. It is my hope that the reader can learn from this model and use it to improve future studies.

- **Fuzzy expression of spatial unsuitability/ repulsion**- the employed model provides the modeler with flexible environment and enables her/him to design various suitability criteria. The module uses fuzzy membership to assign suitability degree, but does not address unsuitability degree. In other words, while attraction affects are expressed by the range of 1-255, repulsion is represented by mere the value 0 (zero). For example, existing industrial zones repel residential development in their proximity, and the repulsion degree decreases
as distance from the zones increases. This phenomenon could not be reflected in the model. The incorporation of functions of negative numbers range could address this issue.

- **Adjustments of weights and factors’ distance** - in the current study, factors’ trade-off weights were determined based on the literature and personal experience with the city. Through the model implication, I have learned that the signification of these weights to the final results is crucial. I strongly recommend conducting a survey or collecting expert opinions regarding the factor weights, to generate real-world results. Expert opinions are also recommended in determining other criteria variables such as the distance decay.

- **Incorporation of population and employment projections** - population and employment densities are dynamic features that can change relatively quickly. Within a 10 years period, existing population centers can decline while other areas might gain more popularity. These changes pose significant impact on land use. Moreover, population and employment spatial pattern evolve corresponding to land use development and vice versa. In the current study, I intended to incorporate these projections by substituting existing patterns with projected pattern after five years of simulation iterations. Due to lack of resource, however, no appropriate projections were found. I recommend future modeler to seek for projections that incorporate not only past trends, but also current and future major developments.

- **Replacement of spatial analysis with network analysis** - in the current model I used spatial analysis to reflect the distance of factors’ impact. That is, impact distances, such as in the 'public facilities' and 'bus stop' factors, were determined based on Euclidian distance. If I had to reconstruct the model criteria, I would have use network analysis to reflect the real
walking or driving distances. Network analysis could have also been utilized to construct the streetcar proximity factor, by integrating the existing bus network.

7.2. Model Application Aspects

Narratives of opponents and supporters of the streetcar project were represented by two distinct scenarios, which in turn became two sets of model criteria. One may expect that these scenarios would vary from one another in their outputs, due to their different factors. The model result verification, however, indicates that the streetcar supporters and opponents scenarios would generate relatively close outcomes. The required question is what can explain this high similarity?

Recapturing the trade-off weights table (Table 2), we can see that the identical factors constitute 70% of the criteria weights. This includes the factors: population density, employment high-density, and land value (15% each), public facilities and landmarks (10% each) and bus stops (5%). The dissimilar portion, comprising the streetcar proximity factor and some variations in the nodal factors (public facilities, landmarks, and bus stops), formed a mere 20-25% of the model criteria. Moreover, the 'offset factor', which was incorporated in order to eliminate undesired difference between factors' weights, has also weakened the distinct factors, adding another similar factor.

Assigning the trade-off weights, I took into account the fact that the streetcar is only one factor in the urban system, and that despite its importance to the current study there are factors that pose higher impact in reality. A weight higher than 15% would be unrealistic and constitute
overestimation of the streetcar’s impacts. That being the case, the question to be asked is how can we better reflect the variation between scenarios? I yet to have a good answer to this question, but I think that the key here is gaining more experience, trial, and errors. Incorporation of different projection of population and employment density, corresponding to the different narratives, as mentioned in section 7.1 above, would certainly increase variation as well.
8. Conclusions

Although the streetcar project was approved by city council and received full funding, it is still fairly controversial among the people of Cincinnati, due to the required public expenditure and the uncertainty of its success. Such uncertainty, regarding the impact on the build environment, exists to a greater or lesser degree in every planed mass transportation project. Scientific assessment and visualized illustration of the projected redevelopment might reduce the uncertainty and facilitate the public dialogs about such projects. Furthermore, modeling of the city redevelopment pattern would likely help to increase public involvement in the planning process, as it illustrates the impact of the proposed streetcar on certain communities and sites. Hence, the model developed in this study might become a useful tool in engaging the public in the streetcar project and in other mass transit projects, in a rather early phase of the planning process.

In the current study I have attempted to provide an adequate response to the question: what are the projected impact of the streetcar system on urban land use? Specifically, I illustrated land use change scenarios as derived from the project opponents and supporters’ narratives, with the intention to determine how distinct they are from one another. I incorporated several spatial phenomena that would affect land use, and employed a spatial cellular automata model to simulate the scenarios’ outcome in land use terms. Finally, I evaluated the model outputs and quantified future land use distribution and transitions.

Recapturing the streetcar supporters and opponents’ narratives, we recall that the major disagreement was about the geographic extent of the streetcar impact. While supporters describe the streetcar’s impact on urban redevelopment in terms of neighborhoods and
districts, opponents argue that a significant redevelopment would occur only in the streetcar’s adjacent streets, if at all. Moreover, the latter argue that urban redevelopment may occur without regard to the streetcar’s establishment (see Appendix 1). It was found that the streetcar project would affect mainly the city urban core, and especially the streetcar adjacent streets, both under supporters’ scenario and under opponents’ scenario.

Under all scenarios, public land use would shrink and industrial land use is projected to boost, with or without the streetcar. Considerable variations exist in commercial and residential land uses; under streetcar supporters’ scenario, in the urban core, the project establishment would reduce residential development and slightly increase commercial development. Along the proposed alignment, the project would diminish an expected decline in commercial development and lessen an expected increase in residential development.

The differences between the projected results of the opponents’ scenario and the baseline (no-streetcar) scenario are not substantial, though definitely exist. They indicate that the streetcar will impact development patterns, not only under supporters’ scenario. This contradicts opponents’ assertions that the project would not impact surrounding neighborhoods.

In sum, the area surrounding the proposed streetcar is expected to undergo moderate land use changes; light manufacturing sites, as well as new retails and office spaces, would substitute current residences and public institutions. Those changes are more substantial under supporters’ scenario; however, such alterations would occur to some extent with or without the streetcar. Indeed, the change magnitudes alter corresponding to the streetcar establishment, but those alterations are not definite. Hence, the overall impact of the proposed
streetcar on urban land use is questionable. The results support the opponents' notion that the streetcar would not make a major difference in development pattern, but only slightly affect them.

Following the model application, lessons learned and recommendations were presented. They consist of methodical and structural modification of the employed model, as well as further adjustments of the model criteria. Further analyses of the results should focus on the transit premium derived from the projected land use change. Comparisons of the model results with the streetcar feasibility studies' conclusions would be beneficial as well. Due to limitation of time and resources, such analyses are out of the scope of the current study.

Numerous cities across the US have planned and established fixed guide-way transit systems over the last two decades. It is apparent that urban mass transit systems have been resurgent as a modern and desirable mean of transportation. Moreover, they are becoming a common strategic tool to advance redevelopment in American urban cores. Nowadays, 45 streetcar systems are either planned, under construction, or built across the US (TRB 2010, p.3). In the federal level, US Department of Transportation (DOT) has recently amended its criteria for federal funding of urban transportation projects, and currently encourages new starts of transit projects in particular (Koss, 2010). Additionally, existing legislations such as CAAA, ISTEA, and TEA-21 require planners to assess the projected impact of major transportation projects on their environs land use (EPA 2000; Torrens 2000).
Cincinnati city council has recently determined to begin the streetcar construction in the fall of 2011, while the public dispute has steadily escalated\(^3\). Hence, project opponents and supporters, as well as the city's political leadership, might find this study essential. Moreover, the framework developed in the current study is applicable to similar projects elsewhere, as it provides a scientific approach towards the assessment of the impact of fixed guide-way systems on urban land use.

\(^3\) In April 2011, during the development of the current study, the city of Cincinnati modified its proposed route due to a loss of approximately $50 million in state funds. This occurred in a political background of contentions public hearings and council meetings. It appears that the controversy is far from a satisfying resolution (Horstman 5.11.2011).
References


CAGIS (Cincinnati Area Geographic Information System). (2011) Database provided by the College of DAAP, University of Cincinnati.


City of Cincinnati and FTA. (2011) Cincinnati Streetcar Project Public Hearing April 2011 [information booklet].


NKAPC (Northern Kentucky Area Planning Commission). (2011) Database provided by the College of DAAP, University of Cincinnati.

OKI (Ohio-Kentucky-Indiana) Regional Council of Government. (2010) Database provided by the College of DAAP, University of Cincinnati.


## Appendix 1

An overview of arguments as presented by the streetcar supporters and opponents

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Supporters’ arguments</th>
<th>Opponents’ arguments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall approach</td>
<td>The streetcar will spur economic development throughout the city and enhance revitalization within the central business district and the adjacent neighborhoods.</td>
<td>The streetcar is a terrible waste of public money, and it will quickly become an underutilized system.</td>
</tr>
</tbody>
</table>
| Redevelopment benefits | • Existing infrastructure, underused properties, and housing stock make the area “ripe for redevelopment” (Horstman 2010a).  
• The system will boost economic development across the city urban core, as well as throughout the city as a whole (Baverman and Bernard-Kuhn 2010).  
• Feasibility studies estimate streetcar development benefits at $211 million over 20 years of operation (HDR 2010, p.20).  
• Commercial retail and cultural venues would be much active (Cortese 2009). | • The evidences of emerging real-estate market in the proposed streetcar area are very little (Horstman streetcar area 2010a).  
• The best scenario is relocation of businesses and residences from one neighborhood to another (Horstman 2010a).  
• Transit oriented development would unlikely occur, unless the local government would offer incentives (O’Tool 2010).  
• Development might occur even without the rail line (O’Tool 2010).  
• Streetcar’s impact on the built environment in one city do not necessarily apply to other cities (TRB 2010). |
| Land Value             | • A streetcar system may increase land value and employment in its proximity (Cortese 2009; TRB 2010)  
• Almost every property along the route would increase in value (Horstman 2010a). | • Increasing land values along a rail route are offset by decreases elsewhere in the city (O’Tool 2010).  
• Increasing land values are not a result of the streetcar system, but are at the most part encouraged by governmental regulation and incentives (O’Tool 2010). |
| Public Investment      | The $128 million project is supported by state and federal | “... [T]he biggest financial gamble in the city’s history” (Horstman 2010a, |
| **Governments** | governments, which altogether fund approximately 50% of the construction expenses (Horstman 2010a). |
| **Timing of investment** | Since it is quite expensive, the project would have raised controversy and public disagreement at any time. This is exactly the right time for large investments (Horstman 2010a). |
| **Operating expenses** | Operating expenses will be funded by the future casino revenue, thus city general budget will not be injured (Horstman 2010a). |
| **Ridership** | Feasibility studies predicting about 9,000 daily trips in the tenth year of the streetcar operation (HDR, 2010, p.10). |
| **Future function** | The system will connect the city’s two major employment centers, and will transport daily thousands of people to business meetings, lunches, university courses and hospital visits (Horstman 2010a). |
| **Future social impact** | The system will attract young professionals to Cincinnati, and especially to the downtown area (Horstman 2010a). The system may alter the community characteristic and perception of an area (TRB 2010). |

- Even when the system would be revealed as inefficient, public official would maintain it active in order to avoid paying back federal dollars (O’Tool 2010). It is a bad investment in a bad timing of severe nationwide economic recession (Horstman 2010a). The system is not self-sufficient and would become a financial burden to city budget. Operating expenses would require allocations from other more essential public services and pressing needs (Horstman 2010a). City official’s optimism is based on vague assumptions and overestimations. Moreover, existing bus service is underutilized, thus another means of mass transportation is redundant (Horstman 2010a). Travel time of 20 minutes for a 3 mile trip is impractical, especially since most of the rider will have to walk a few blocks to their destination (Horstman 2010a). In best scenario, residents and capital would move to the streetcar area from other parts of the city, creating poverty in the latter (Horstman 2010a).
Appendix 2

The reclassification table used for the zoning constraint, as implied by the city of Cincinnati’s Zoning code (City of Cincinnati 2011). ‘1’ denotes suitable and ‘0’ stands for unsuitable. See description in section 5.2.2.

<table>
<thead>
<tr>
<th>Original zoning classification</th>
<th>Modeled (binary) zoning classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class</td>
<td>District</td>
</tr>
<tr>
<td>Single-family districts</td>
<td>Single-family (SF-20)</td>
</tr>
<tr>
<td></td>
<td>Single-family (SF-10)</td>
</tr>
<tr>
<td></td>
<td>Single-family (SF-6)</td>
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<td>Single-family (SF-4)</td>
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<td></td>
<td>Single-family (SF-2)</td>
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<tr>
<td>Multi-family Districts</td>
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</tr>
<tr>
<td></td>
<td>Residential Multi-family (RM-2.0)</td>
</tr>
<tr>
<td></td>
<td>Residential Multi-family (RM-1.2)</td>
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<tr>
<td></td>
<td>Residential Multi-family (RM-0.7)</td>
</tr>
<tr>
<td>Office Districts</td>
<td>Office Limited (OL)</td>
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<tr>
<td></td>
<td>Office General (OG)</td>
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<tr>
<td>Commercial Districts</td>
<td>Commercial Neighborhood (CN)</td>
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<tr>
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<td>Commercial Community (CC)</td>
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<tr>
<td></td>
<td>Commercial General (CG)</td>
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<td></td>
<td>Urban Mix (UM)</td>
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<td></td>
<td>Downtown Development (DD)</td>
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<tr>
<td>Manufacturing Districts</td>
<td>Manufacturing Agricultural (MA)</td>
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<td></td>
<td>Manufacturing Limited (ML)</td>
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<tr>
<td></td>
<td>Manufacturing General (MG)</td>
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<tr>
<td></td>
<td>Manufacturing Exclusive (ME)</td>
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<td>Riverfront Districts</td>
<td>Riverfront Residential/Recreational (RF-R)</td>
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<td></td>
<td>Riverfront Commercial (RF-C)</td>
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<td></td>
<td>Riverfront Manufacturing (RF-M)</td>
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<td>Public uses</td>
<td>Parks and Recreation (PR)</td>
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<td></td>
<td>Institutional-Residential (IR)</td>
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