



Optimizing Urban Redevelopment: An Operational Approach to Land Use and Transportation

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Introduction

An unusual Opportunity



- An empty 10 hectares area in the city center
- Many possibilities:
 - housing, shopping, walkable streets,
 - a transportation hub, sports infrastructure, park ...

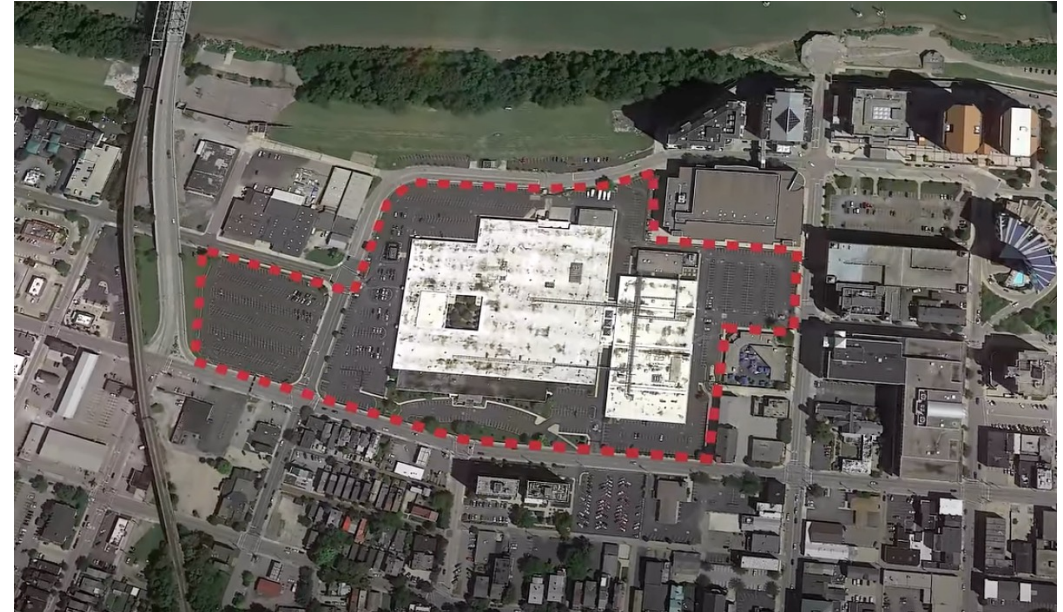


History of the site

Before the 1960s: a well integrated area



From 1960 to 2019: an IRS building
Was shut down in 2019





An aerial architectural rendering of a proposed urban development project. The scene is viewed from an elevated perspective, showing a dense cluster of buildings along a waterfront. On the left, a large body of water (likely a lake or river) is visible, bordered by a green shoreline with trees. The development consists of various building types: multi-story apartment complexes with flat roofs, some featuring rooftop parking or green spaces; smaller, more traditional townhouses or row houses; and commercial-style buildings with large windows and flat roofs. The buildings are interspersed with green spaces, trees, and pedestrian walkways. A road with a crosswalk is visible in the foreground, and a parking lot with several cars is shown. The overall design suggests a mix of residential and commercial uses in a walkable, urban environment.

KZF DESIGN **hw**
Designing Better Futures hub+weber

Modeling and Linearization

Holistic Model

Holistic Model

Decision Variables: \mathbf{x} : government decision variable in $\mathbb{R}_+^{|\mathcal{K}|}$ indicating on site distribution
 \mathbf{w} : government decision variable in $\{0, 1, 2\}^{|\mathcal{S}|}$ indicating bike lane development

Utilities:

$$\begin{aligned}
 u_{i,C}^B &= \underbrace{\sum_{k \in \mathcal{K}} \alpha_{i,k} \mathbf{x}_k}_{\text{Utility}} \underbrace{- \lambda_1^B \|C\|}_{\text{Distance Malus}} + \underbrace{\lambda_2^B \sum_{l=1}^{n_C} \mathbf{w}_{s_C^l} \|s_C^l\|}_{\text{Bike Coverage Bonus}} + \underbrace{\lambda_3^B \left(\sum_{l=1}^{n_C-1} \mathbb{1}(\mathbf{w}_{s_C^l} \mathbf{w}_{s_C^{l+1}} > 0) \right) \left(\frac{\|C\|}{n_C - 1} \right)}_{\text{Bike Continuity Bonus}} \\
 u_i^D &= \sum_{k \in \mathcal{K}} \alpha_{i,k} \mathbf{x}_k - \lambda_1^D \|\tilde{C}_i^D\| - \underbrace{\lambda_2^D f_P(\mathbf{x})}_{\text{Parking Malus}} \\
 u_i^S &= \beta^S = 0
 \end{aligned}$$

Multinomial Logit (MNL)

Dependency between Utilities and Choice Probabilities:

$$p_{i,C}^B(\mathbf{w}, \mathbf{x}) = \frac{\exp(u_{i,C}^W)}{\exp(u_i^S) + \exp(u_i^D) + \sum_{C' \in \mathcal{A}_i} \exp(u_{i,C'}^W)}$$

$$p_i^D(\mathbf{w}, \mathbf{x}) = \frac{\exp(u_i^D)}{\exp(u_i^S) + \exp(u_i^D) + \sum_{C' \in \mathcal{A}_i} \exp(u_{i,C'}^W)}$$

$$p_i^S(\mathbf{w}, \mathbf{x}) = \frac{\exp(u_i^S)}{\exp(u_i^S) + \exp(u_i^D) + \sum_{C' \in \mathcal{A}_i} \exp(u_{i,C'}^W)}$$

- Main Advantage: Much more realistic than a proportional model
- Main Disadvantage: Red bus Blue bus Paradox

Government's Problem

Bike Objective:

$$g_B(\mathbf{w}, \mathbf{x}) = \rho_1 \mathbf{x}_1 \sum_{C \in \mathcal{A}_1} p_{1,C}^B + \sum_{i>2} I_i \sum_{C \in \mathcal{A}_i} p_{i,C}^B$$

Car Objective:

$$g_D(\mathbf{x}, \mathbf{x}) = I_0 p_0^D + \sum_{i>2} I_i p_i^D$$

Our Non-Linear Problem:

$$\max_{\mathbf{w}, \mathbf{x}} \quad \mu_B g_B(\mathbf{w}, \mathbf{x}) + (1 - \mu_B) g_D(\mathbf{w}, \mathbf{x})$$

$$\text{s.t.} \quad \sum_{s \in \mathcal{S}} \mathbf{w}_s \|s\| \leq M^B$$

$$\sum_k \mathbf{x}_k \leq M^A$$

$$\mathbf{x} \geq 0$$

$$\mathbf{w} \in \{0, 1, 2\}^{|\mathcal{S}|}$$

} Area Constraint

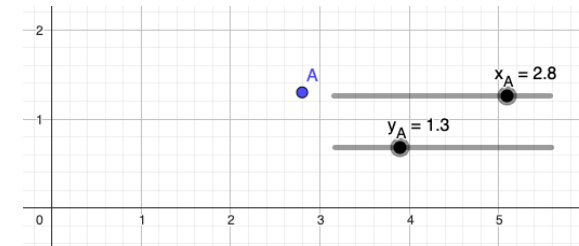
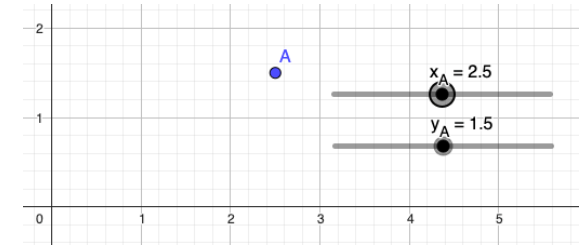
} Bike Lane Budget
Constraint

SOS2 Linearization

Idea of 2D SOS2 constraints:

$$A = (x_A, y_A) = 0.5 \times 0.5 \cdot (1, 2) + 0.5 \times 0.5 \cdot (1, 3) + 0.5 \times 0.5 \cdot (2, 2) + 0.5 \times 0.5 \cdot (2, 3)$$

$$A = (x_A, y_A) = 0.2 \times 0.7 \cdot (1, 2) + 0.8 \times 0.7 \cdot (1, 3) + 0.2 \times 0.3 \cdot (2, 2) + 0.8 \times 0.3 \cdot (2, 3)$$



General Formula: $A = (x_A, y_A) = (\lceil x_A \rceil - x_A) \times (\lceil y_A \rceil - y_A) \cdot (\lfloor x_A \rfloor, \lfloor y_A \rfloor) + (\lceil x_A \rceil - x_A) \times (y_A - \lfloor y_A \rfloor) \cdot (\lfloor x_A \rfloor, \lceil y_A \rceil) + (x_A - \lfloor x_A \rfloor) \times (\lceil y_A \rceil - y_A) \cdot (\lceil x_A \rceil, \lfloor y_A \rfloor) + (x_A - \lfloor x_A \rfloor) \times (y_A - \lfloor y_A \rfloor) \cdot (\lceil x_A \rceil, \lceil y_A \rceil)$

SOS2 Formula: $A = (x_A, y_A) = \sum_{i,j \in \mathbb{Z}^2} \lambda_{i,j} \cdot (i, j)$

$(\lambda_{i,j})_{i \in \mathbb{Z}}$ satisfies a SOS2 constraint $\forall j \in \mathbb{Z}$

$(\lambda_{i,j})_{j \in \mathbb{Z}}$ satisfies a SOS2 constraint $\forall i \in \mathbb{Z}$

SOS2 Reformulation

$$\max_{\mathbf{w}, \mathbf{x}, p, \lambda} \quad \mu_B g_B(\mathbf{w}, \mathbf{x}) + (1 - \mu_B) g_D(\mathbf{w}, \mathbf{x})$$

$$\text{s.t.} \quad \sum_{s \in \mathcal{S}} w_s \|s\| \leq M^B$$

$$\sum_k x_k \leq M^A$$

$$\mathbf{x} \geq 0$$

$$\mathbf{w} \in \{0, 1, 2\}^{|\mathcal{S}|}$$

$$\lambda \geq 0$$

$$\sum_{j^B, j^D} \lambda_{j^B, j^D}^i = 1 \quad \forall i \in \mathcal{I}$$

$$(\lambda_{j^B, j^D}^i)_{j^B \leq N} \text{ satisfies a SOS2 constraint} \quad \forall i \in \mathcal{I}, j^D \leq N$$

$$(\lambda_{j^B, j^D}^i)_{j^D \leq N} \text{ satisfies a SOS2 constraint} \quad \forall i \in \mathcal{I}, j^B \leq N$$

$$u_i^B = \sum_{j^B, j^D} \lambda_{j^B, j^D}^i \tilde{u}_{j^B}^B \quad \forall i \in \mathcal{I}$$

$$u_i^D = \sum_{j^B, j^D} \lambda_{j^B, j^D}^i \tilde{u}_{j^D}^D \quad \forall i \in \mathcal{I}$$

$$p_i^B = \sum_{j^B, j^D} \lambda_{j^B, j^D}^i f_{\text{MNL}}^B(\tilde{u}_{j^B}^B, \tilde{u}_{j^D}^D) \quad \forall i \in \mathcal{I}$$

$$p_i^D = \sum_{j^B, j^D} \lambda_{j^B, j^D}^i f_{\text{MNL}}^D(\tilde{u}_{j^B}^B, \tilde{u}_{j^D}^D) \quad \forall i \in \mathcal{I}$$

Granular Model

Reason for this Granularity

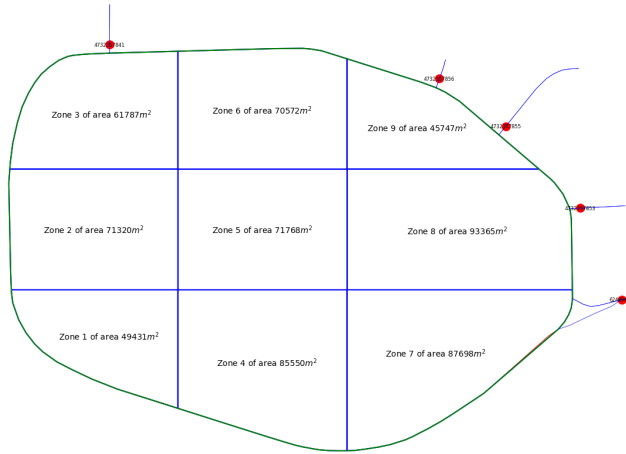


Steps of Urban Redevelopment:

- 1) Road Network Infrastructures
- 2) Land-Use allocation within each zone

Granular Model

Briarwood Mall divided into 9 zones



Granular Utilities:

New Utility term only considering land-use k in zone j

$$u_{i,C,j,k}^B = \underbrace{\alpha_{i,k} \mathbf{x}_{j,k}}_{\text{New Utility term}} - \lambda_1^B \|C\| + \lambda_2^B \sum_{l=1}^{n_C} \mathbf{w}_{s_C^l} \|s_C^l\| + \lambda_3^B \left(\sum_{l=1}^{n_C-1} \mathbb{1}(\mathbf{w}_{s_C^l} \mathbf{w}_{s_C^{l+1}} > 0) \right) \left(\frac{\|C\|}{n_C - 1} \right)$$

$$u_{i,j,k}^D = \alpha_{i,k} \mathbf{x}_{j,k} - \lambda_1^D \|\tilde{C}_{i,j}^D\| - \lambda_2^D f_P(\mathbf{x})$$

$$u_{i,k}^S = \beta^S = 0$$

Granular (Non-Linear) Model:

$$\max_{\mathbf{w}, \mathbf{x}} \quad \mu_B g_B(\mathbf{w}, \mathbf{x}) + (1 - \mu_B) g_D(\mathbf{w}, \mathbf{x})$$

$$\text{s.t.} \quad \sum_{s \in \mathcal{S}} w_s \|s\| \leq M^B$$

$$\sum_k x_{j,k} \leq M_j^A \quad \forall j \in \mathcal{J}$$

$$\sum_j \mathbb{1}(\mathbf{x}_{j,k} > 0) \leq N_k \quad \forall k \in \mathcal{K}$$

$$\mathbf{x}_{j,k} \geq m_k \mathbb{1}(\mathbf{x}_{j,k} > 0) \quad \forall j, k \in \mathcal{J} \times \mathcal{K}$$

$$\mathbf{x} \geq 0$$

$$\mathbf{w} \in \{0, 1, 2\}^{|\mathcal{S}|}$$

} Area Constraint in zone j

} Max number of land-use k buildings

} Minimal Area for each land-use k building

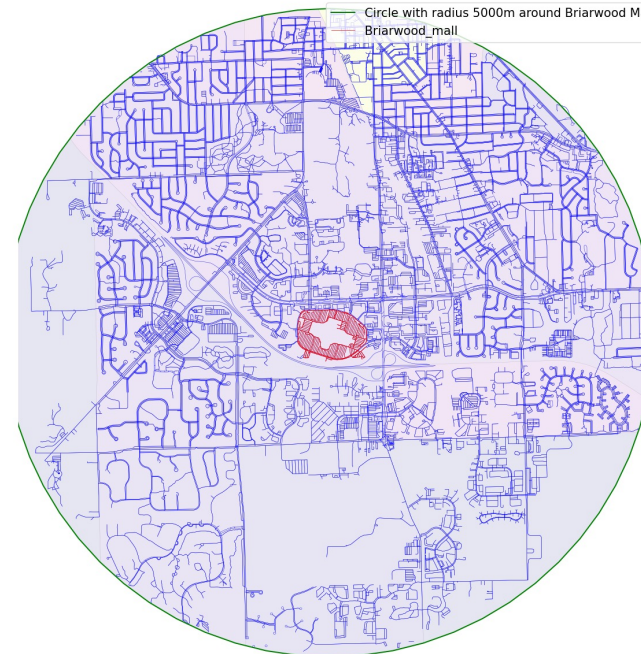
Case Study: Briarwood Mall, Michigan

History of the site



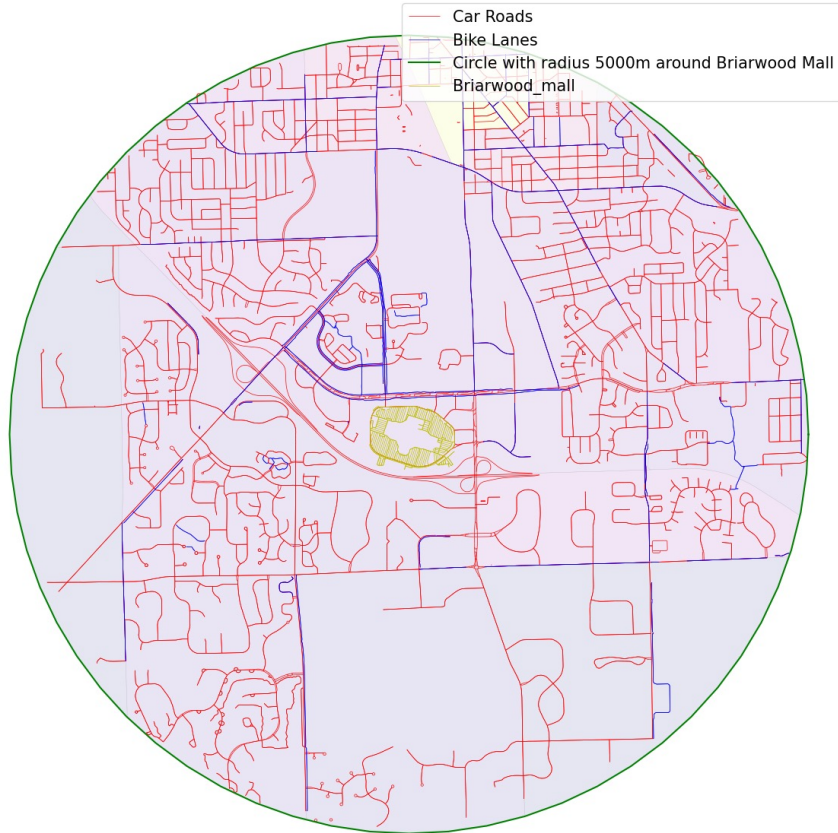
- A 1970s mall necessitating a transition
- A 20 hectares Parking
- A 32 hectares zone within Ann Arbor City

Whole city network around Briarwood Mall (including pedestrian paths and private roads)



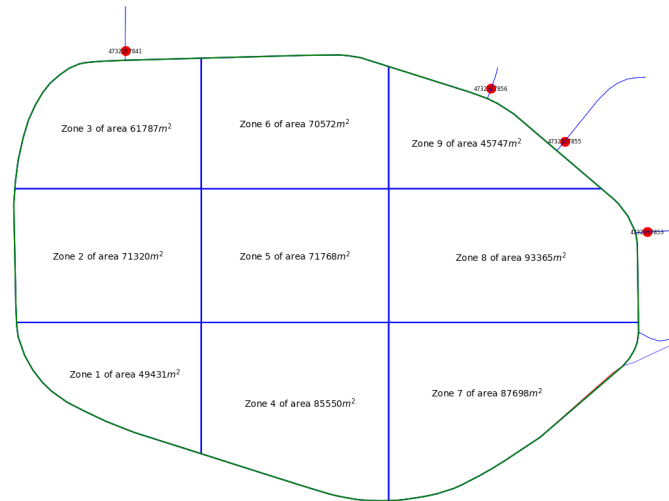
The Status Quo city Network

Car Roads and Bike Lanes City network around Briarwood Mall



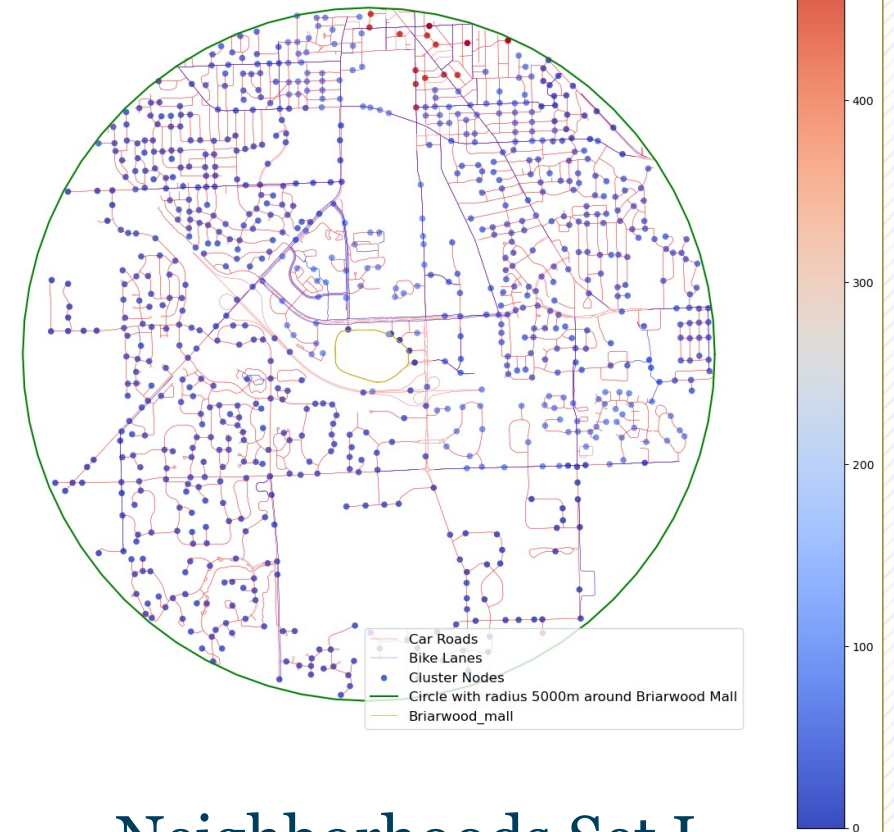
Road Sets S and
Shortest Paths A_i

Briarwood Mall divided into 9 zones



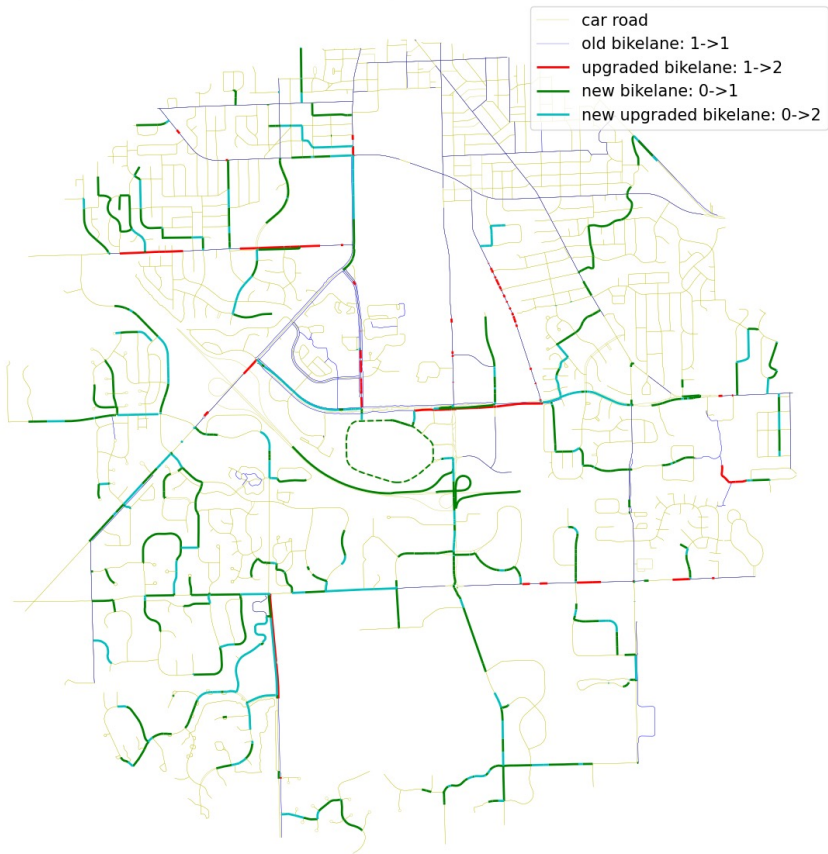
Zones Set J

Cluster nodes and their population (in inhabitants) as neighborhoods in the City Network



Neighborhoods Set I

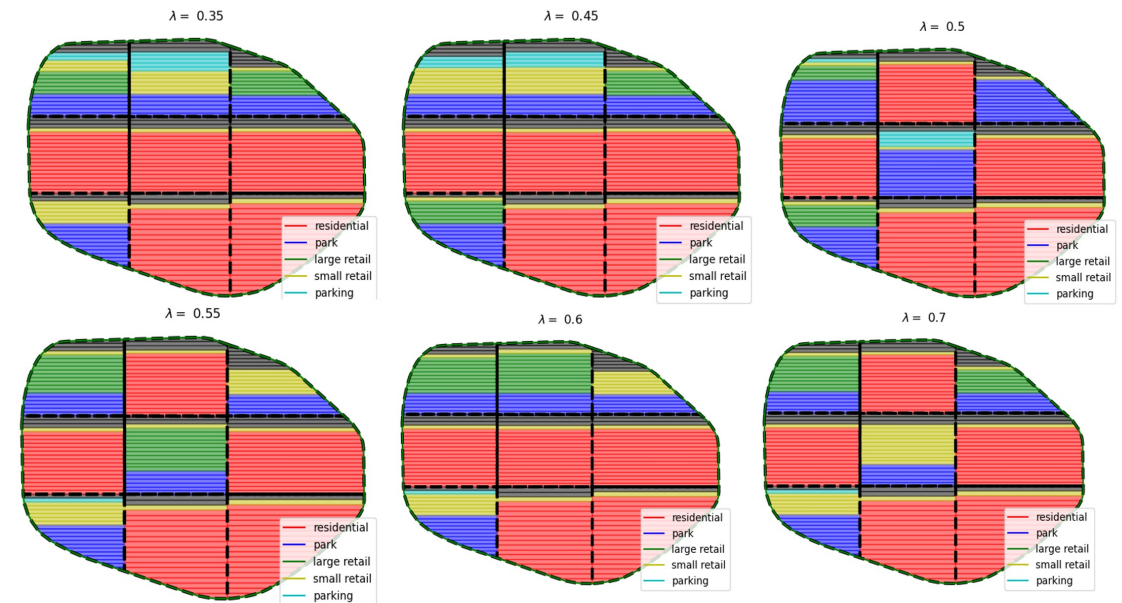
Optimized bikelanes in the City Network for a 80km budget M^B



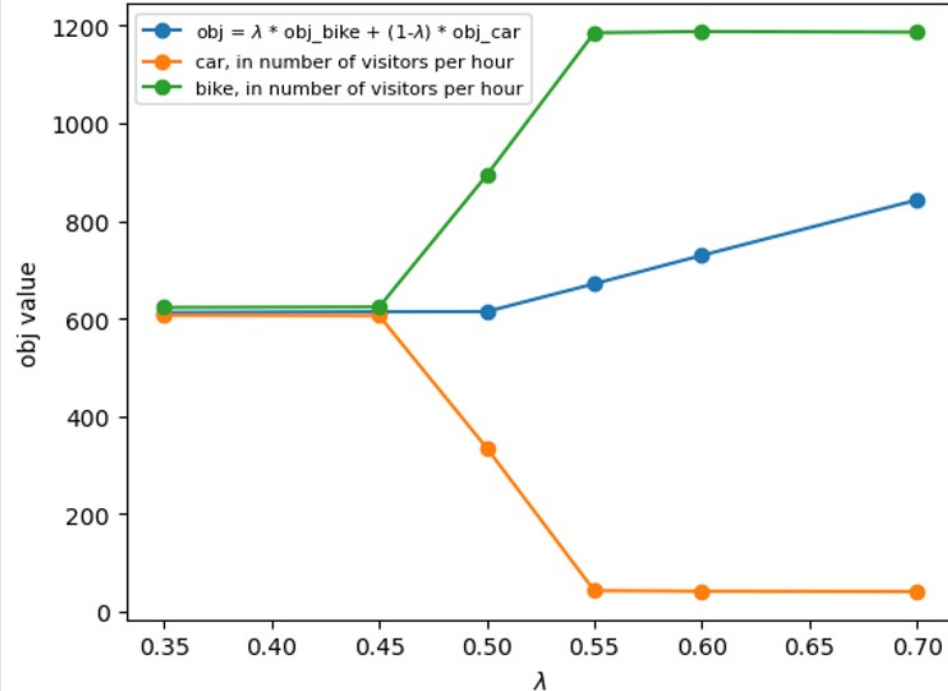
Results

- Takes into account both Coverage and Continuity
- Seems relatively independent with μ_B

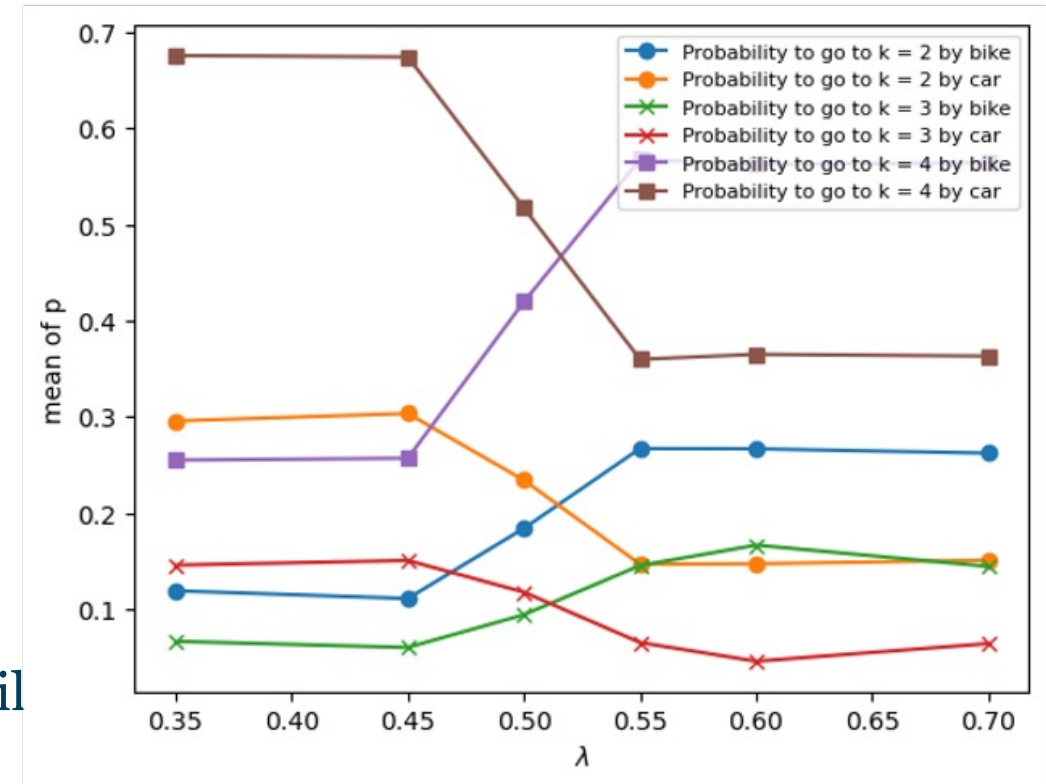
- Prioritizes the most accessible zones for non-residential land-use
- Parking Area decreases with μ_B



Results



- Interesting values between 0.45 and 0.55
- When $\mu_B \ll 0.5$, both objectives are close as the bike objective includes new residents on the site



- Car keeps its advantage until $\mu_B = 0.52$
- $k = 1, 2, 3, 4$ is residential, parks, large retail and small retail

Conclusion

Conclusion



1. Offers a novel approach to urban redevelopment, integrating both the broader transportation network and detailed site infrastructure.
2. Focusing on non-motorized transit and mixed land-use can reveal new perspectives in urban planning.
3. Need for more accurate data for coefficients representing land-use attractiveness.
4. Future improvements:
 - Optimizing internal routes within the site
 - Adding simulations of interactions between various land uses