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

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13/08/24

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Introduction

An unusual Opportunity

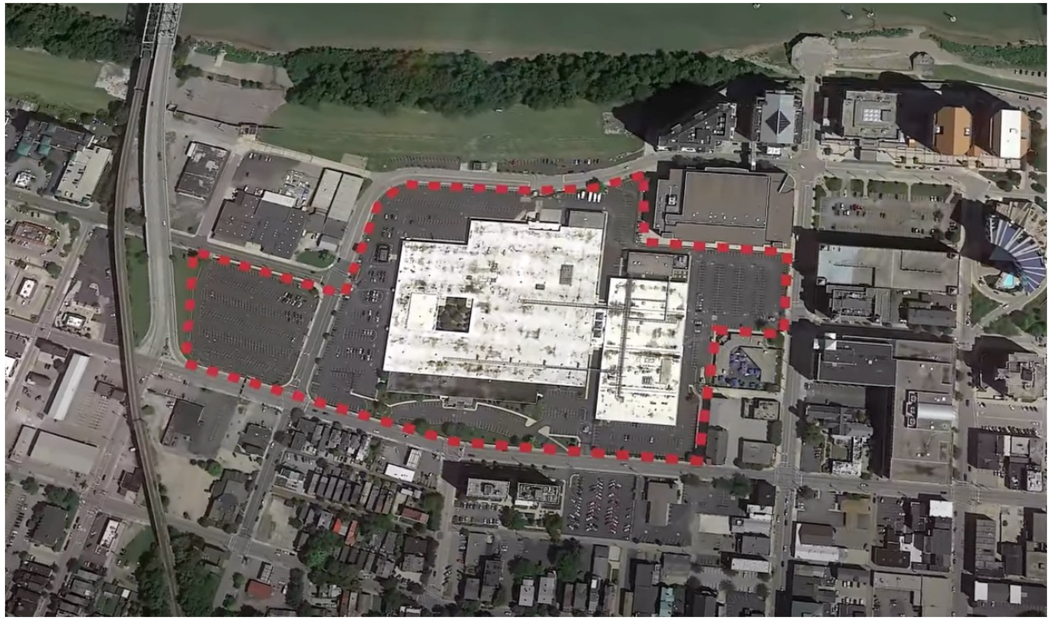
- An empty 10 hectares area in the city center
- Many possibilities:

  housing, shopping, walkable streets,

  a transportation hub, sports infrastructure, park …

History of the site

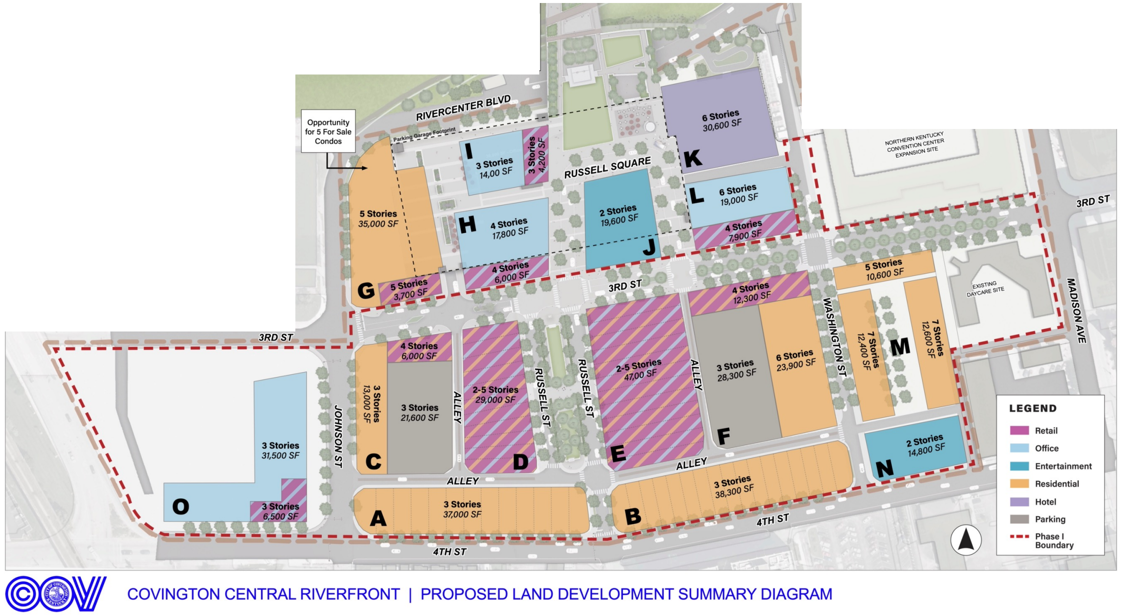
Before the 1960s: a well integrated area



From 1960 to 2019: an IRS building

Was shut down in 2019

Revitalizing the Urban and Social Fabric



A Mixed-Use Development with Retail, Office, Entertainment, Residential, Hotel and Parking

A Sustainable place with green spaces that aims at Revitalizing the Urban and Social Fabric

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:

Utility | Distance Malus | Bike Coverage Bonus | Bike Continuity Bonus

$$u_{i,C}^B = \sum_{k\in\mathcal{K}} \alpha_{i,k}\,\mathbf{x}_k - \lambda_1^B \|C\| + \lambda_2^B \sum_{l=1}^{n_C} \mathbf{w}_{s_C^l} \, \|s_C^l\| + \lambda_3^B \left(\sum_{l=1}^{n_C-1} \mathbb{1}(\mathbf{w}_{s_C^l}\,\mathbf{w}_{s_C^{l+1}} > 0)\right)\left(\frac{\|C\|}{n_C - 1}\right)$$

$$u_i^D = \sum_{k\in\mathcal{K}} \alpha_{i,k}\,\mathbf{x}_k - \lambda_1^D \|\tilde{C}_i^D\| - \lambda_2^D f_P(\mathbf{x})$$

Parking Malus

$$u_i^S = \beta^S = 0$$

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

Car Objective: $g_D(\mathbf{x}, \mathbf{x}) = I_0 \, p^D_0 + \sum_{i>2} I_i \, p^D_i$

Our Non-Linear Problem:

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

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

Area Constraint

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

Bike Lane Budget Constraint

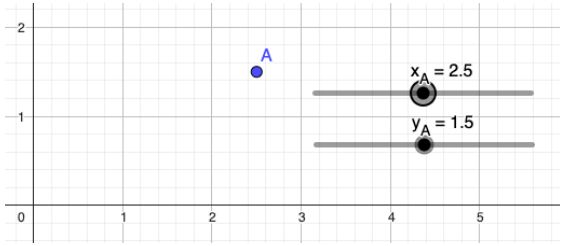
$$\mathbf{x} \geq 0$$

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

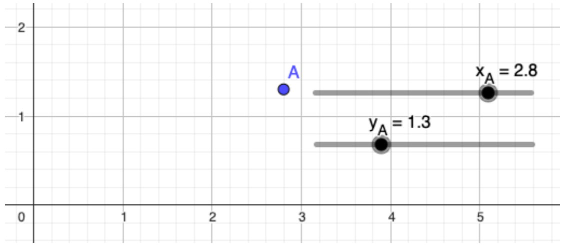
SOS2 Linearization

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

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

SOS2 Reformulation

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

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

$$\sum_k x_k \le M^A$$

$$\mathbf{x} \ge 0$$

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

$$\lambda \ge 0$$

$$\sum_{j^B,j^D} \lambda^i_{j^B,j^D} = 1 \qquad \forall i \in \mathcal{I}$$

$$(\lambda^i_{j^B,j^D})_{j^B\le N} \text{ satisfies a SOS2 constraint} \qquad \forall i \in \mathcal{I}, j^D \le N$$

$$(\lambda^i_{j^B,j^D})_{j^D\le N} \text{ satisfies a SOS2 constraint} \qquad \forall i \in \mathcal{I}, j^B \le N$$

$$u_i^B = \sum_{j^B,j^D} \lambda^i_{j^B,j^D} \tilde{u}^B_{j^B} \qquad \forall i \in \mathcal{I}$$

$$u_i^D = \sum_{j^B,j^D} \lambda^i_{j^B,j^D} \tilde{u}^D_{j^D} \qquad \forall i \in \mathcal{I}$$

$$p_i^B = \sum_{j^B,j^D} \lambda^i_{j^B,j^D} f^B_{\mathrm{MNL}}(\tilde{u}^B_{j^B}, \tilde{u}^D_{j^D}) \qquad \forall i \in \mathcal{I}$$

$$p_i^D = \sum_{j^B,j^D} \lambda^i_{j^B,j^D} f^D_{\mathrm{MNL}}(\tilde{u}^B_{j^B}, \tilde{u}^D_{j^D}) \qquad \forall i \in \mathcal{I}$$

Granular Model

Reason for this Granularity

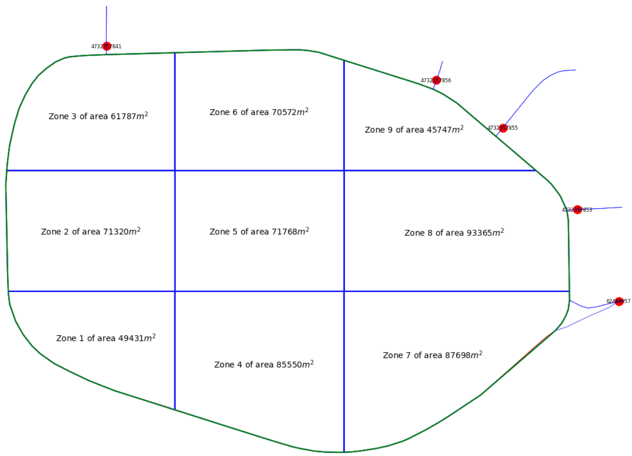
Steps of Urban Redevelopment:

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

$$
\begin{aligned}
u^B_{i,C,j,k} &= \alpha_{i,k}\,\mathbf{x}_{j,k} - \lambda_1^B \|C\| + \lambda_2^B \sum_{l=1}^{n_C} \mathbf{w}_{s_C^l} \|s_C^l\| + \lambda_3^B \left(\sum_{l=1}^{n_C-1} \mathbb{1}(\mathbf{w}_{s_C^l}\,\mathbf{w}_{s_C^{l+1}} > 0) \right) \left(\frac{\|C\|}{n_C - 1} \right) \\
u^D_{i,j,k} &= \alpha_{i,k}\,\mathbf{x}_{j,k} - \lambda_1^D \|\tilde{C}^D_{i,j}\| - \lambda_2^D f_P(\mathbf{x}) \\
u^S_{i,k} &= \beta^S = 0
\end{aligned}
$$

Granular (Non-Linear) Model:

$$
\begin{aligned}
\max_{\mathbf{w},\mathbf{x}} \quad & \mu_B\ g_B(\mathbf{w},\mathbf{x}) + (1-\mu_B)\ g_D(\mathbf{w},\mathbf{x}) \\
\text{s.t.} \quad & \sum_{s\in\mathcal{S}} w_s \|s\| \le M^B \\
& \sum_k x_{j,k} \le M_j^A \qquad \forall j \in \mathcal{J} \\
& \sum_j \mathbb{1}(\mathbf{x}_{j,k} > 0) \le N_k \qquad \forall k \in \mathcal{K} \\
& \mathbf{x}_{j,k} \ge m_k\, \mathbb{1}(\mathbf{x}_{j,k} > 0) \qquad \forall j,k \in \mathcal{J} \times \mathcal{K} \\
& \mathbf{x} \ge 0 \\
& \mathbf{w} \in \{0,1,2\}^{|\mathcal{S}|}
\end{aligned}
$$

Area Constraint in zone j

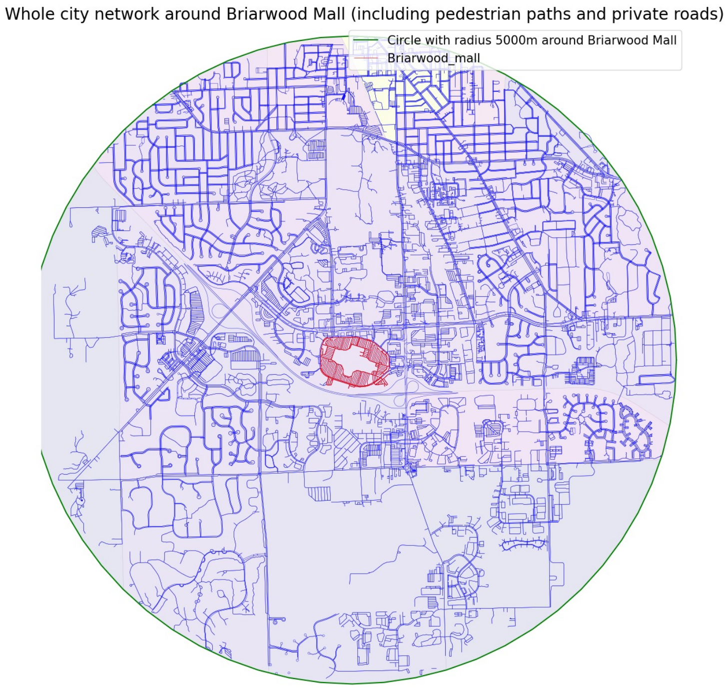
Max number of land-use k buildings

Minimal Area for each land-use k building

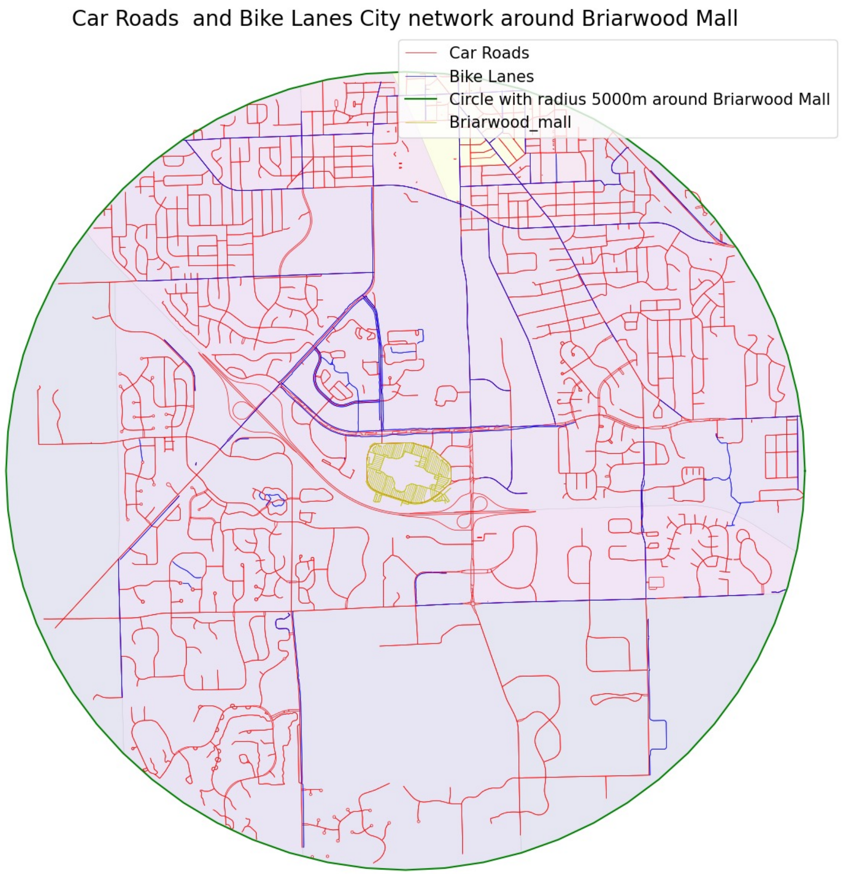
Case Study:
Briarwood Mall, Michigan

History of the site

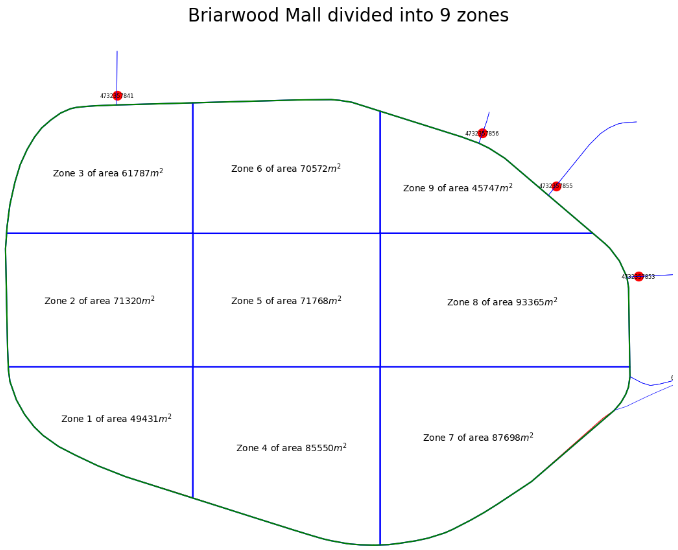
- A 1970s mall necessitating a transition
- A 20 hectares Parking
- A 32 hectares zone within Ann Arbor City



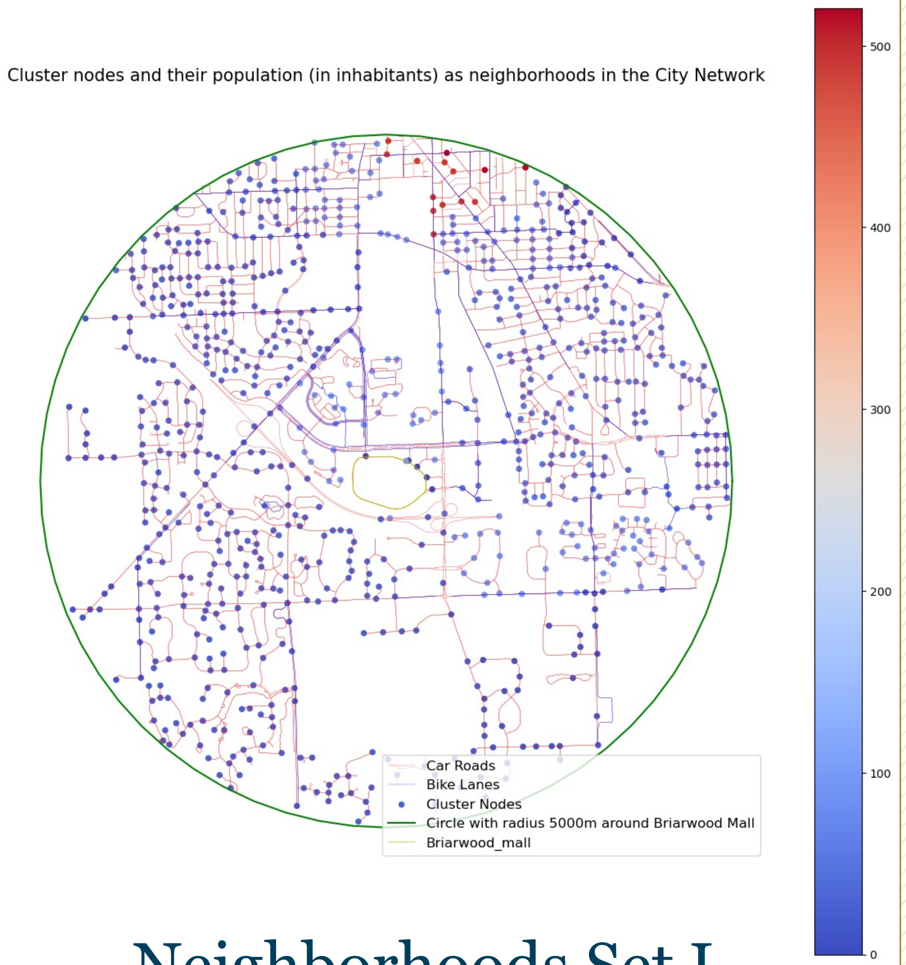
The Status Quo city Network



Road Sets S and Shortest Paths A_i



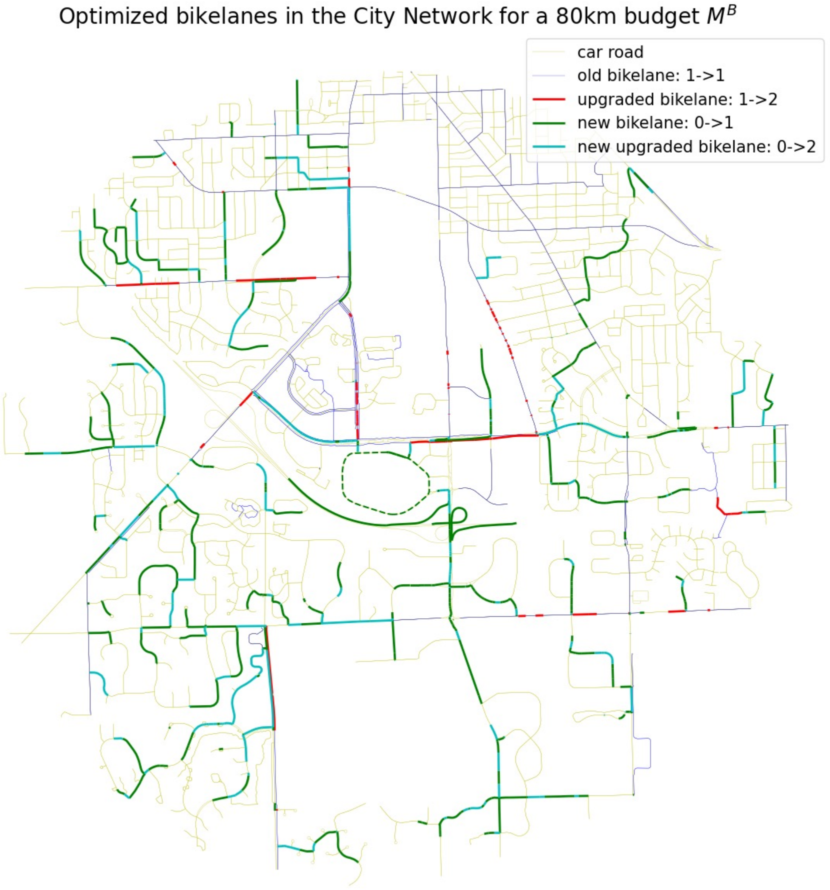
Zones Set J

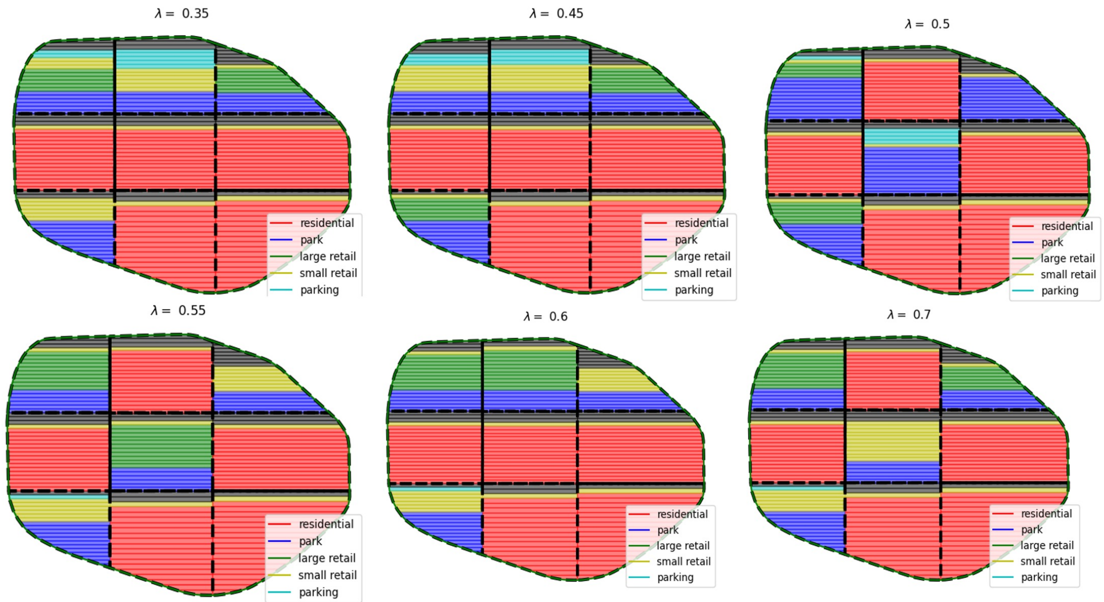


Neighborhoods Set I

Results

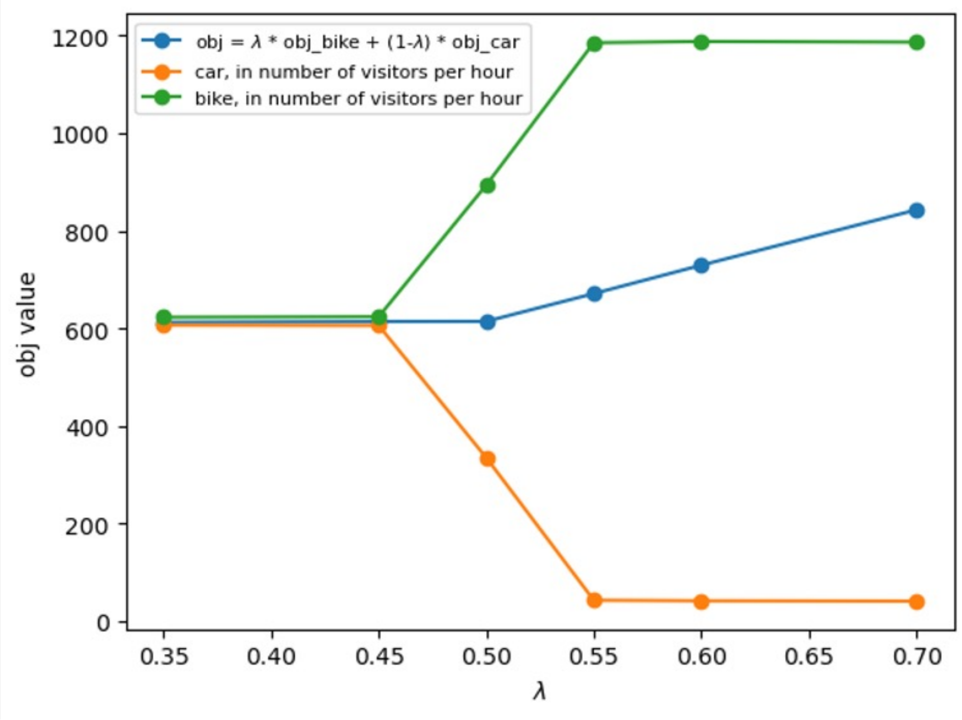
- Takes into account both Coverage and Continuity
- Seems relatively independent with μ_B



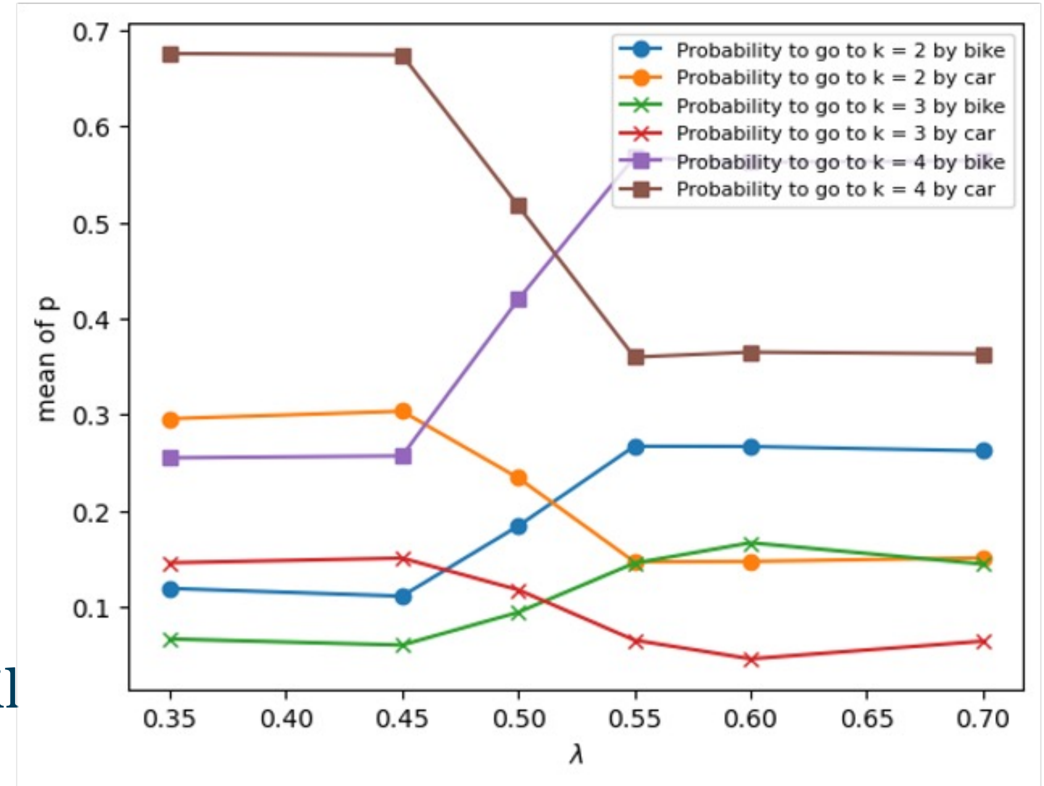


- Prioritizes the most accessible zones for non-residential land-use
- Parking Area decreases with μ_B

Results



- Interesting values between 0.45 and 0.55
- When $\mu_B << 0.5$, 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