Aalto-yliopisto
Perustieteiden
korkeakoulu

Optimizing Infrastructure Improvements in Bus Rapid Transit Systems (Presentation of finished thesis)

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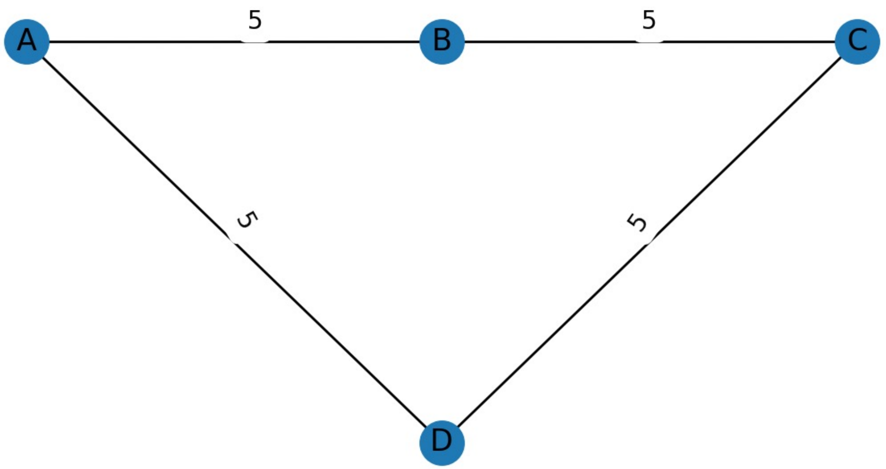
Backround and Literature

- There is available budget to upgrade bus line network to contain Bus Rapid Transit (BRT) lines
- Upgrading parts of the network makes it faster and more attractive for customer to use
- Budget is wanted to be used optimally, so that as many new passengers as possible are attracted

- Question: With limited budget, which parts of the bus line network should be upgraded, to gain maximum amount of new passengers?

- Studied in a path graph setting and wider range of constraints in article by Schiewe et al. [2023]

Given input



Example graph with weights

Weighted graph that is used to model the bus line network:

- Nodes are bus stops
- Edges are roads
- Weights are travel times

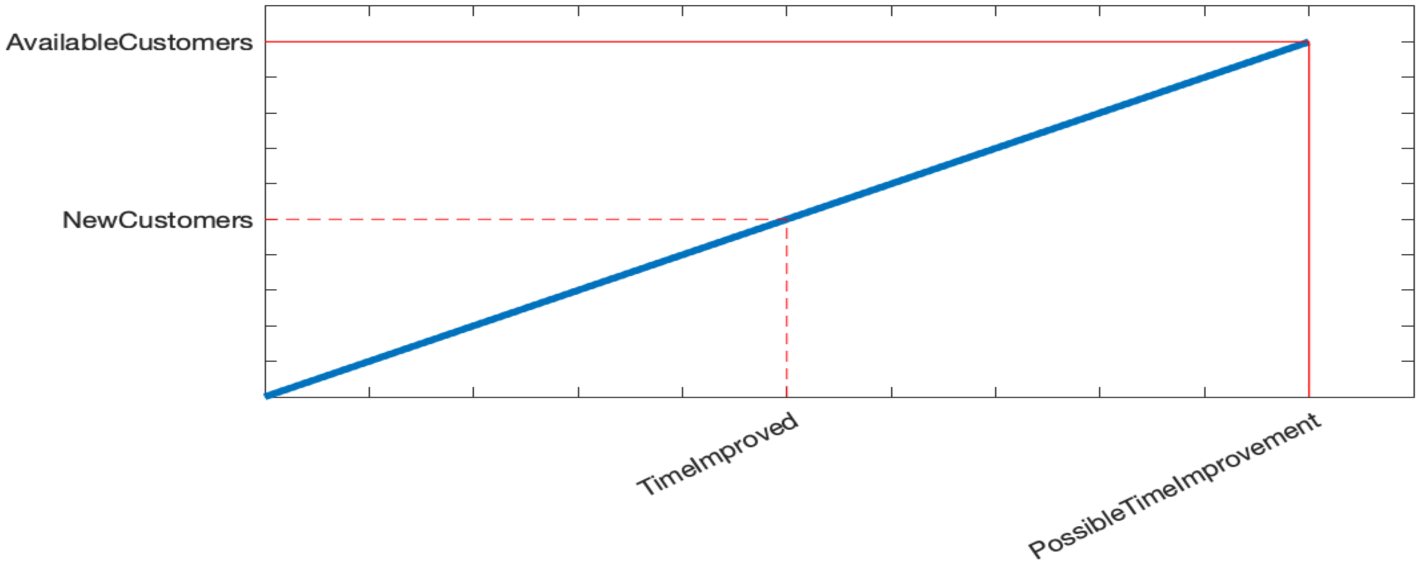
Other given parameters:

- Travel time improvement of upgrading each edge
- Amount of available new customer for source and target nodes
- Cost of upgrading edges
- Budget for all the upgrades

Assumptions

- All passengers travel by shortest paths, before and after upgrades
- New customers of specific source-target node pair are gained linearly, depending of the proportion of possible travel time upgrade:

$$NewCustomers = \frac{TimeImproved}{PossibleTimeImprovement} * AvailableCustomers$$



Binary-Integer Program

From given input and assumptions we can construct an integer program:

Objective function:

$$G'(\overline{x}) = \sum_{e \in E} x_e u_e \sum_{(u,v) \in O : e \in SP_{(u,v)}} \frac{a_{(u,v)}}{L(u,v) - L'(u,v)}$$

Constraint:

$$\text{s.t.} \qquad \sum_{e \in E} x_e c_e \leq b$$

Variables:

$$x_e \in \{0, 1\} \text{ for all } e \in E$$

Objective Function

Binary variable indicating if edge **e** is upgraded

Travel time improvement of edge **e**, if upgraded

Available new customers for source **u**, target **v**

$$G'(\overline{x}) = \sum_{e \in E} x_e u_e \sum_{(u,v) \in O : e \in SP_{(u,v)}} \frac{a_{(u,v)}}{\underbrace{L(u,v) - L'(u,v)}}$$

Sum through set of all edges in the graph

Sum through set of all source-target pairs, whose paths cross edge **e**

Maximum travel time improvement from original

Problem in Objective Function

- **SP$_{(u,v)}$** is the shortest path from node **u** to node **v,** which is dependent of weights, which are dependent on updates done
- Solving this objective function is out of scope for this thesis

$$G'(\overline{x}) = \sum_{e \in E} x_e u_e \sum_{(u,v) \in O \, e \in SP_{(u,v)}} \frac{a_{(u,v)}}{L(u,v) - L'(u,v)}$$

Solution: Iterative algorithm

- Iterative algorithm which uses fixed shortest paths based on previous iterations solution for upgraded edges is introduced:

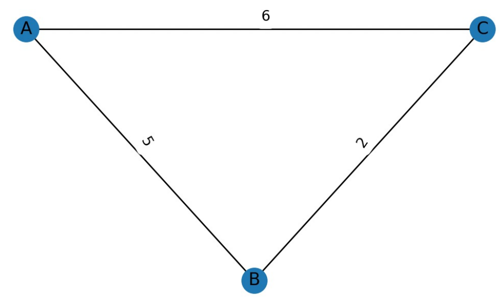
Algorithm 1

```
procedure EdgesToUpgrade(graph, newCustomers, budget)
    upgradedEdges ← ∅
    W_new ← shortestPaths(graph, upgradedEdges)
    W_old ← ∅
    while W_new ≠ W_old do
        upgradedEdges ← Optimize(graph, newCustomers, W_new, budget)
        W_old ← W_new
        W_new ← shortestPaths(graph, updatedEdges)
    end while
    return W_new
end procedure
```

- Global optimum is not guaranteed

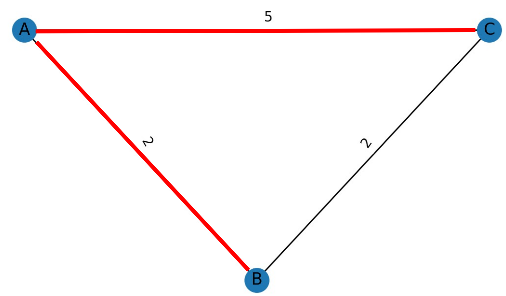
Example of algorithm

Initial phase



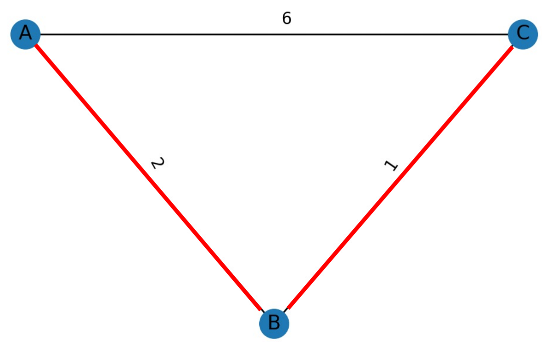
Source, Target	Available
A,C	10
A,B	10
B,C	1

After 1st iteration



Source, Target	Gained
A,C	6.6
A,B	10
B,C	0

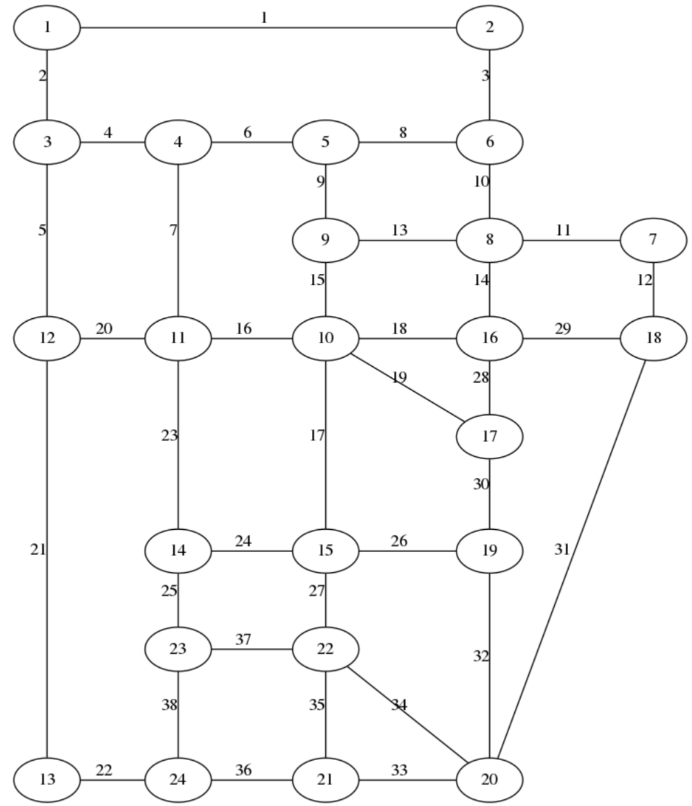
After 2nd iteration



Source, Target	Gained
A,C	10
A,B	10
B,C	1

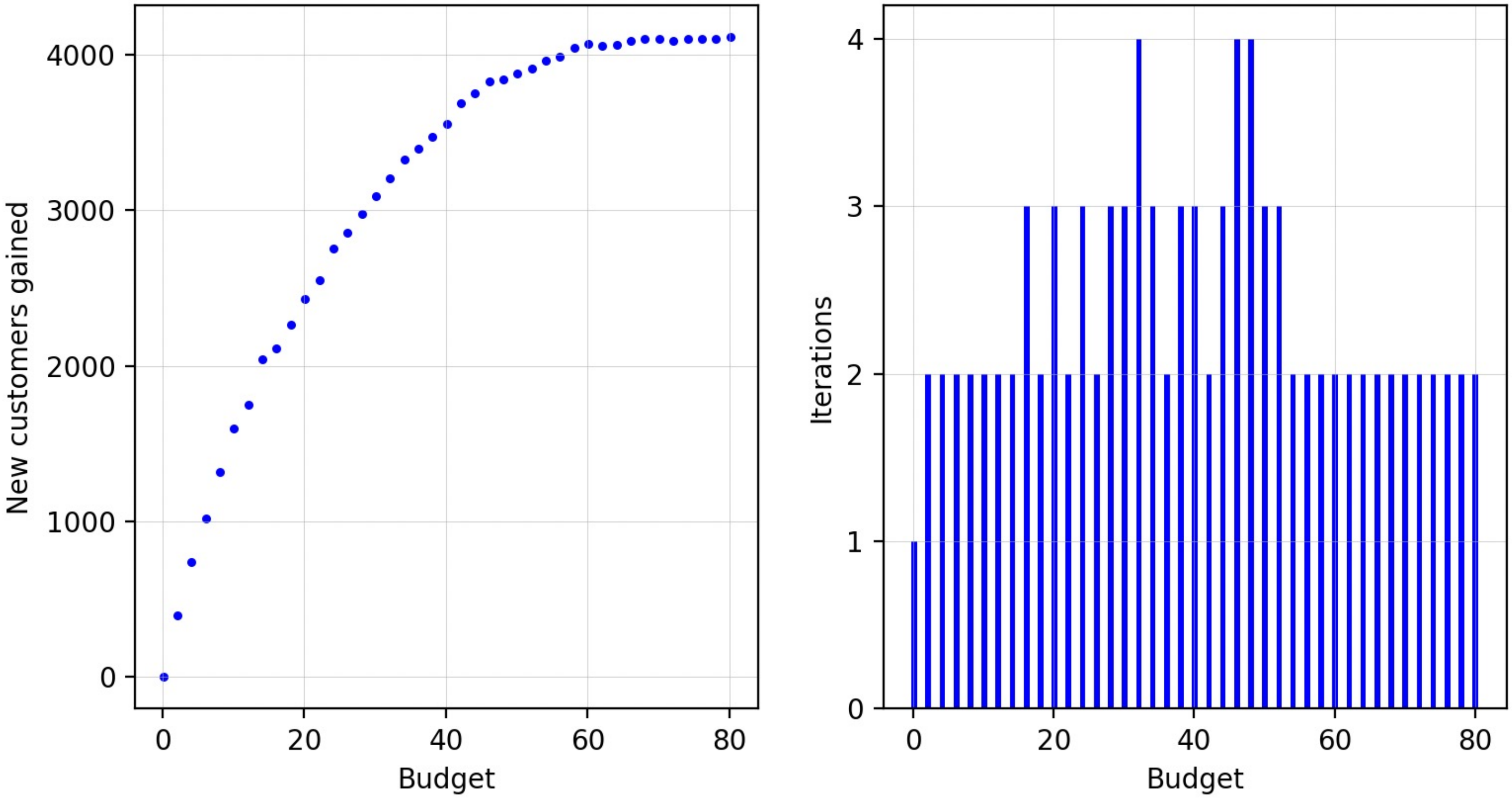
Implementation

- Python
  - Gurobi solver for optimization
  - NetworkX to work with graphs
- Two datasets Toy and Sioux Falls from LinTim



Visualisation of Sioux Falls, (Schiewe et al. 2023)

Results, Sioux Falls Dataset



References

- Rowan Hoogervorst, Evelien van der Hurk, Philine Schiewe, Anita Schöbel, and Reena Urban, ”The Bus Rapid Transit Investment Problem”, 2023, arXiv preprint arXiv:2308.16104

- P. Schiewe, A. Schöbel, S. Jäger, S. Albert, U. Baumgart, C. Biedinger, V. Grafe, S. Roth, A. Schiewe, F. Spühler, M. Stinzendörfer, and R. Urban. LinTim: An integrated environment for mathematical public transport optimization. Documentation for version 2023.12. Rheinland-Pfälzische Technische Universität Kaiserslautern-Landau, 2023. Url: https://nbn-resolving.org/html/urn:nbn:de:hbz:386-kluedo-75699