Efficient and sustainable waste collection

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STRC 2019

Content

1. Project scope and goals

Scope:
Collection of non-recoverable waste in Swiss municipalities

- **Current state:** curbside system with rear-loaded trucks causes high fuel consumption, emissions and noise
- **Future:** improve waste collection process by designing efficient and sustainable strategies

Source: Schwendimann AG

1. Project scope and goals

Goals:

1. Develop **innovative waste collection concepts**
   - modern, electric vehicles

Source: Kyburz Switzerland AG

1. Project scope and goals

Goals:

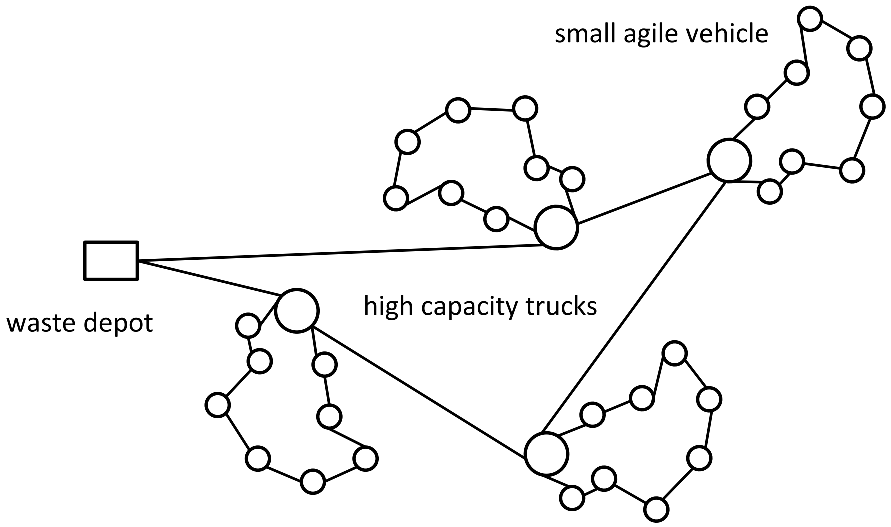
1. Develop **innovative waste collection concepts**
   - modern, electric vehicles
   - containers with compressors

Source: System-Alpenluft AG

1. Project scope and goals

Goals:

1. Develop **innovative waste collection concepts**
    - modern, electric vehicles
    - containers with compressors
    - multi-stage system with intermediate depots or synchronization

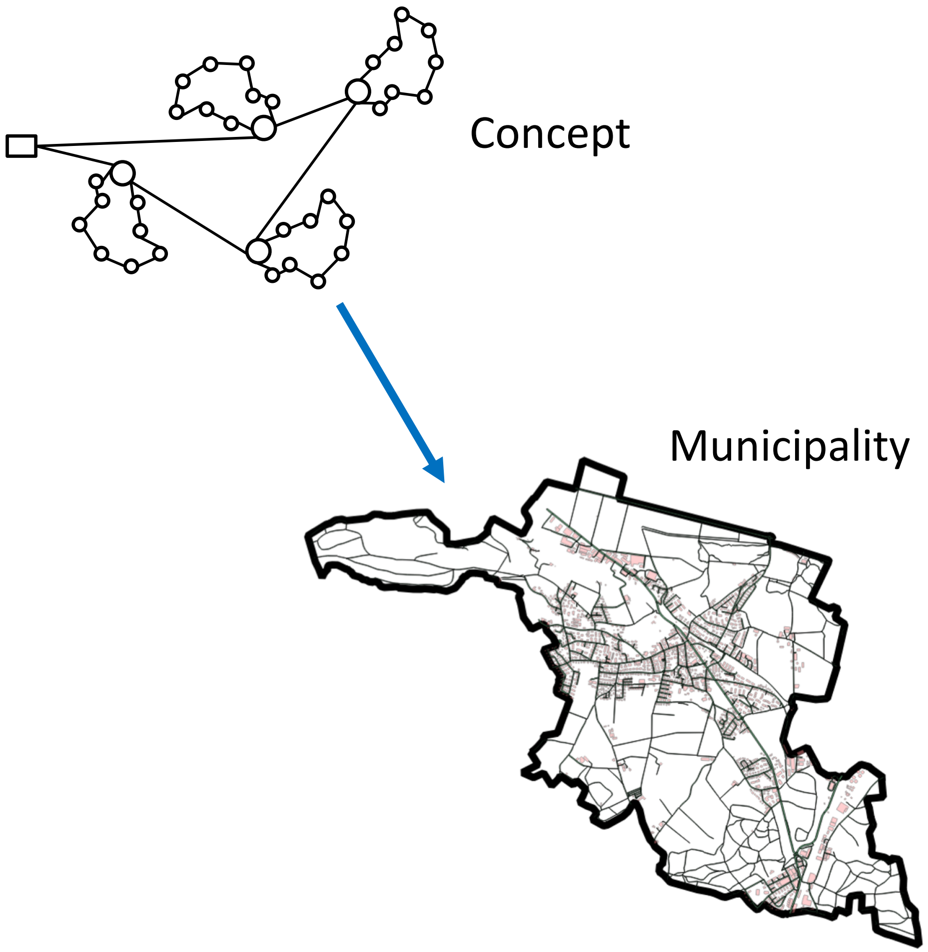


1. Project scope and goals

Goals:

1. Develop **innovative waste collection concepts**
   - modern, electric vehicles
   - containers with compressors
   - multi-stage system with intermediate depots or synchronization

2. Develop **mathematical models and optimization algorithms**
   - optimally design a waste collection concept for a given municipality
   - generate key figures, such as energy requirements or financial costs, to support decision-making process

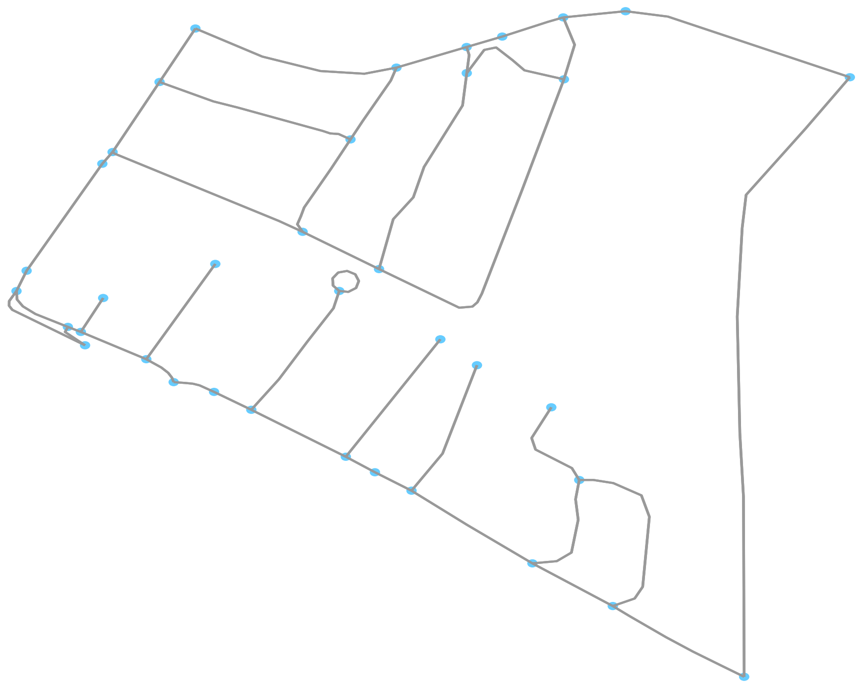


2. Current state of the project

Data processing

1. Original street network from Open Street Map

Instance (a small section of a municipality):
37 nodes
90 edges



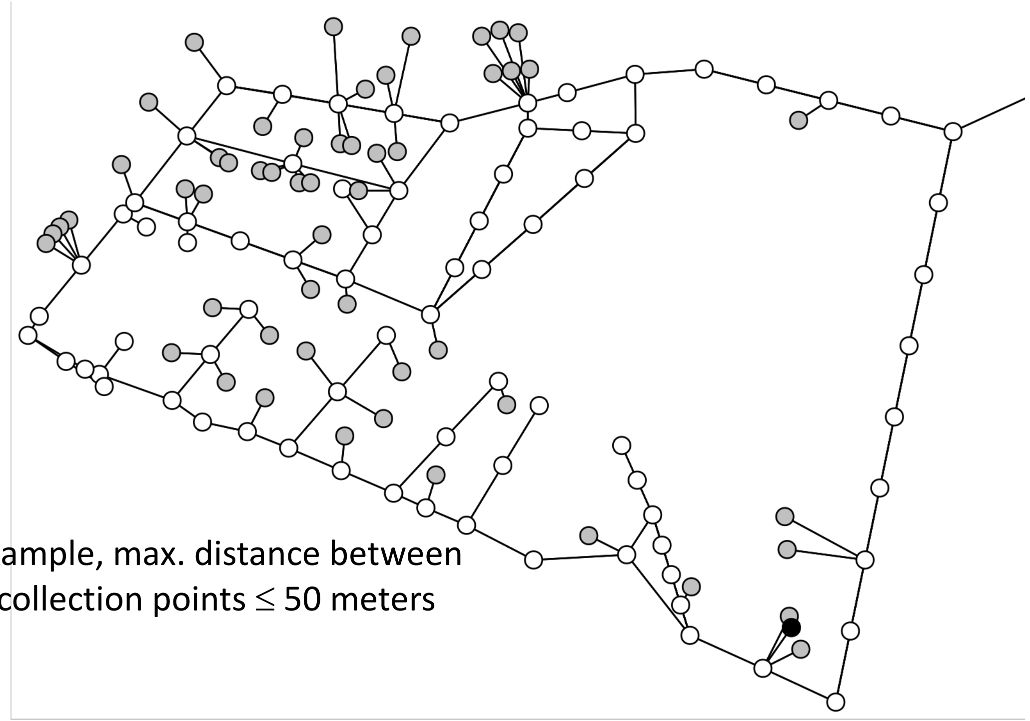
2. Current state of the project

Data processing

1. Original street network from Open Street Map
2. Add nodes for all possible collection points (white)
3. Add household nodes (gray) and connect each with closest (Euclidean dist.) node on street
4. Estimation of waste production based on
   - number of inhabitants (data from BFS)
   - machine learning of video recordings

Source: David Jenni, master's thesis, Hochschule Luzern

Instance (a small section of a municipality):
133 nodes
548 edges



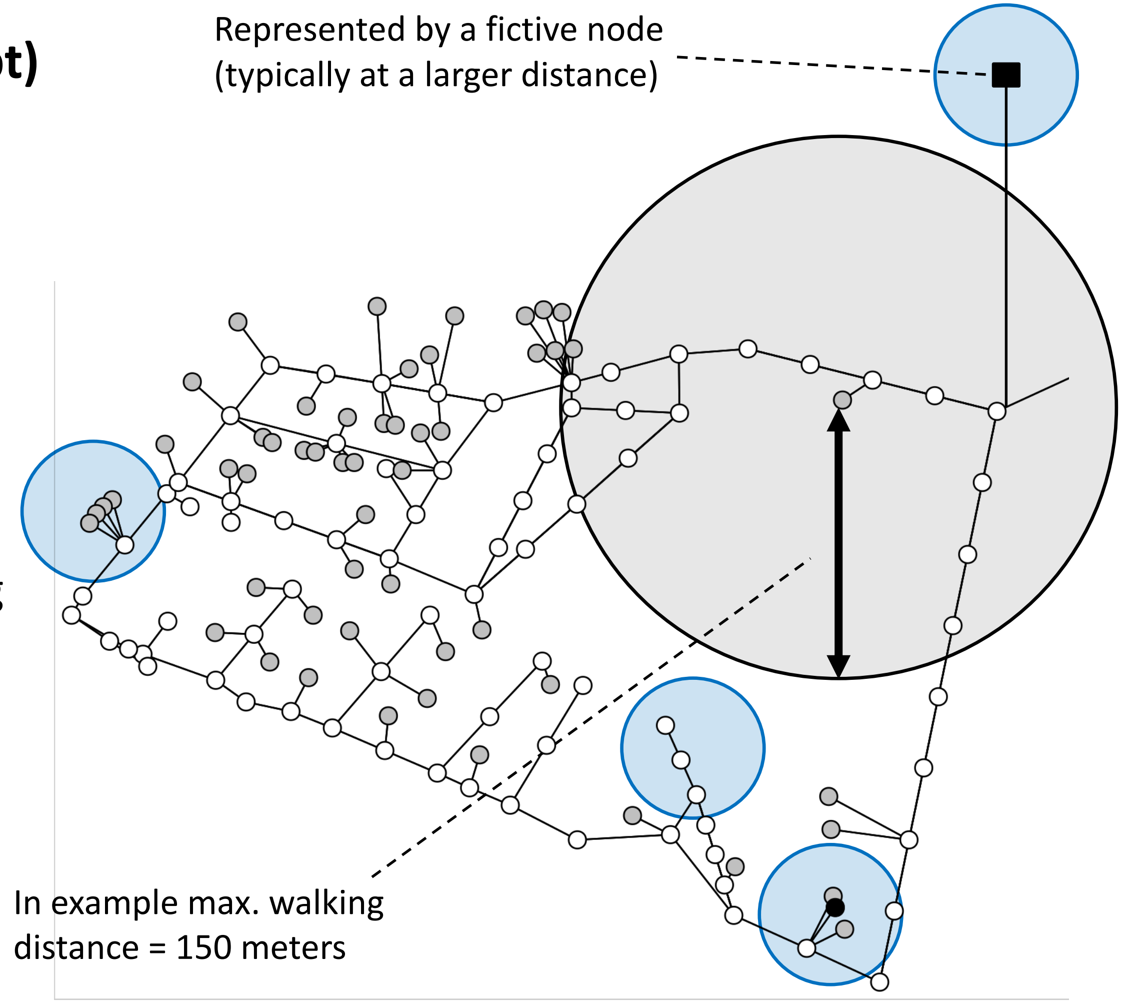
In example, max. distance between two collection points $\leq$ 50 meters

2. Current state of the project

Simple waste collection problem (single-level concept)

Characteristics of the problem

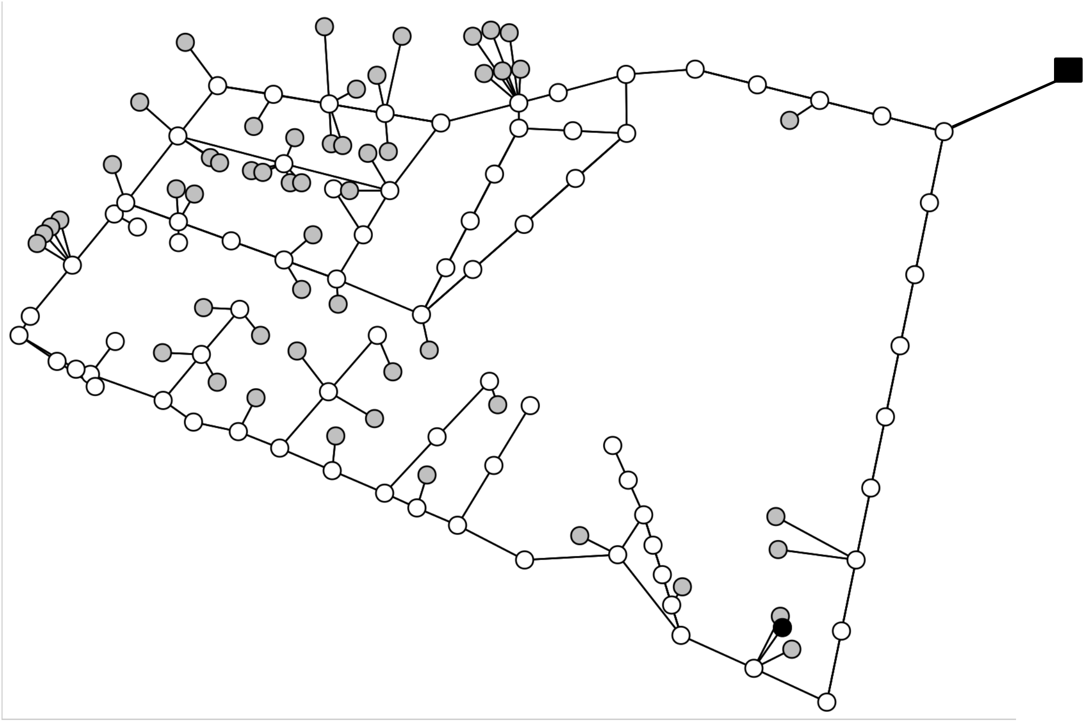
- Homogenous fleet with given capacity at the vehicle depot (black)
- Waste depot (black square) connected with closest (Euclidean dist.) street node
- Estimated waste production at household nodes (gray) based on number of inhabitants
- Fixed maximum walking distance for households to bring their waste
- Opening costs for each possible collection point (white)
- Travel costs for walking distances and collection route distances



2. Current state of the project

Simple waste collection problem (single-level concept)

To determine:

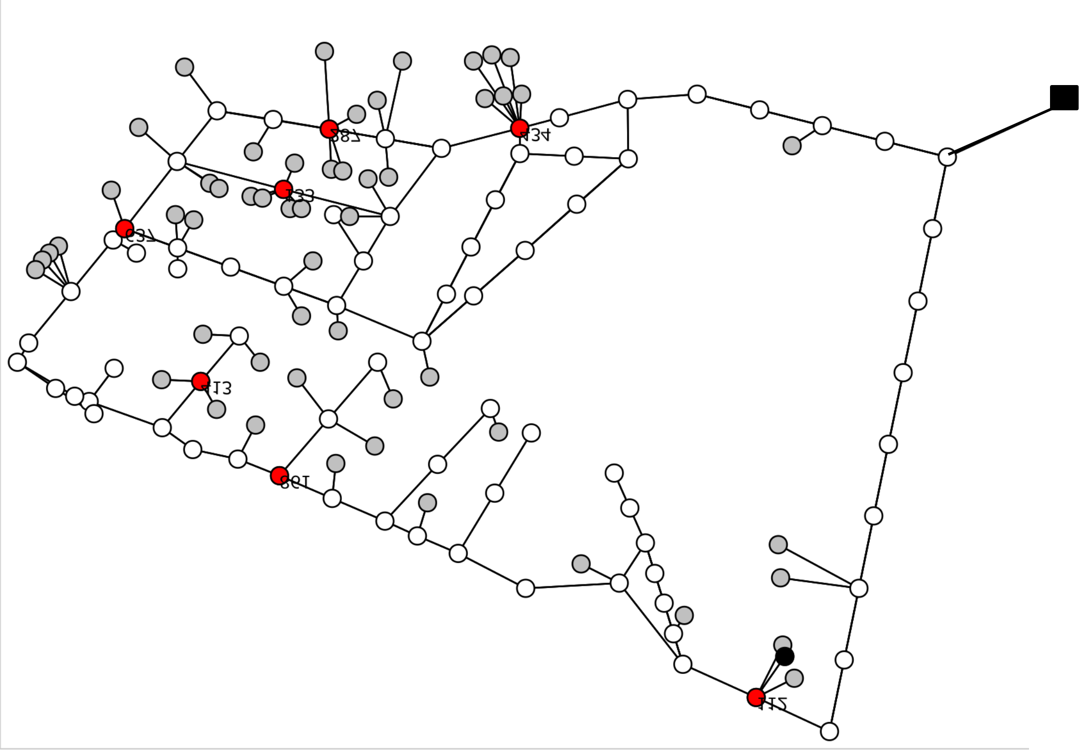


2. Current state of the project

Simple waste collection problem (single-level concept)

To determine:

1. Determine open waste collection points (red points)

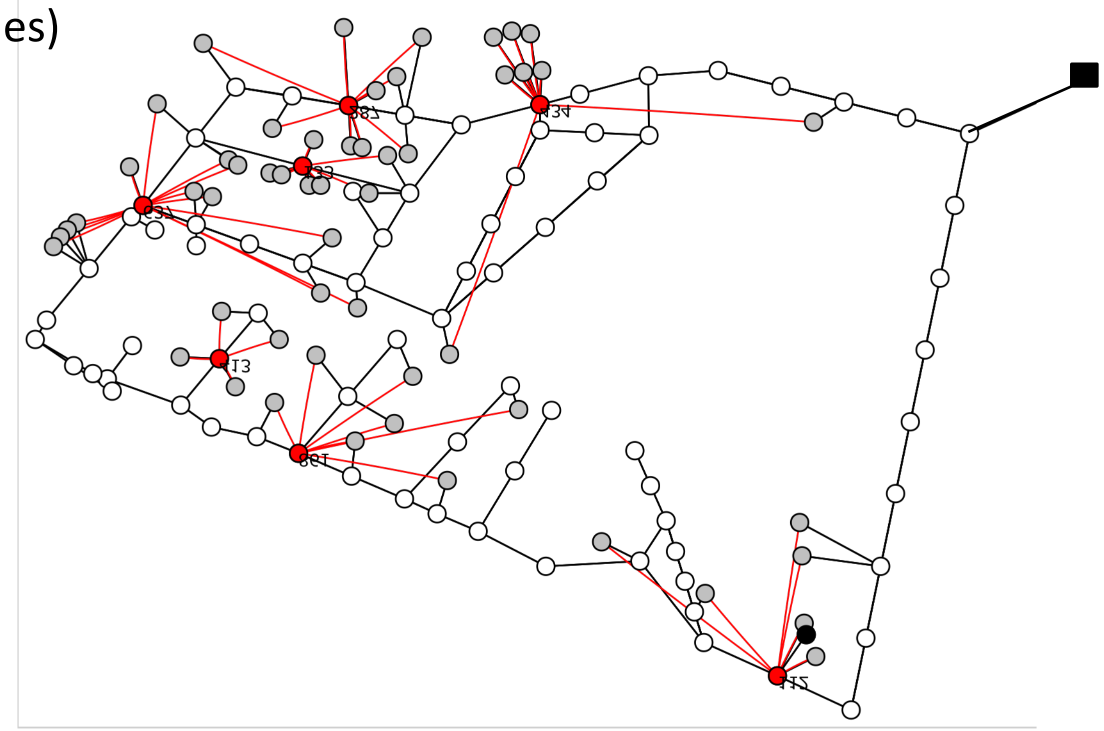


2. Current state of the project

Simple waste collection problem (single-level concept)

To determine:

1. Determine open waste collection points (red points)
2. Assign households to closest open collection point (red lines)



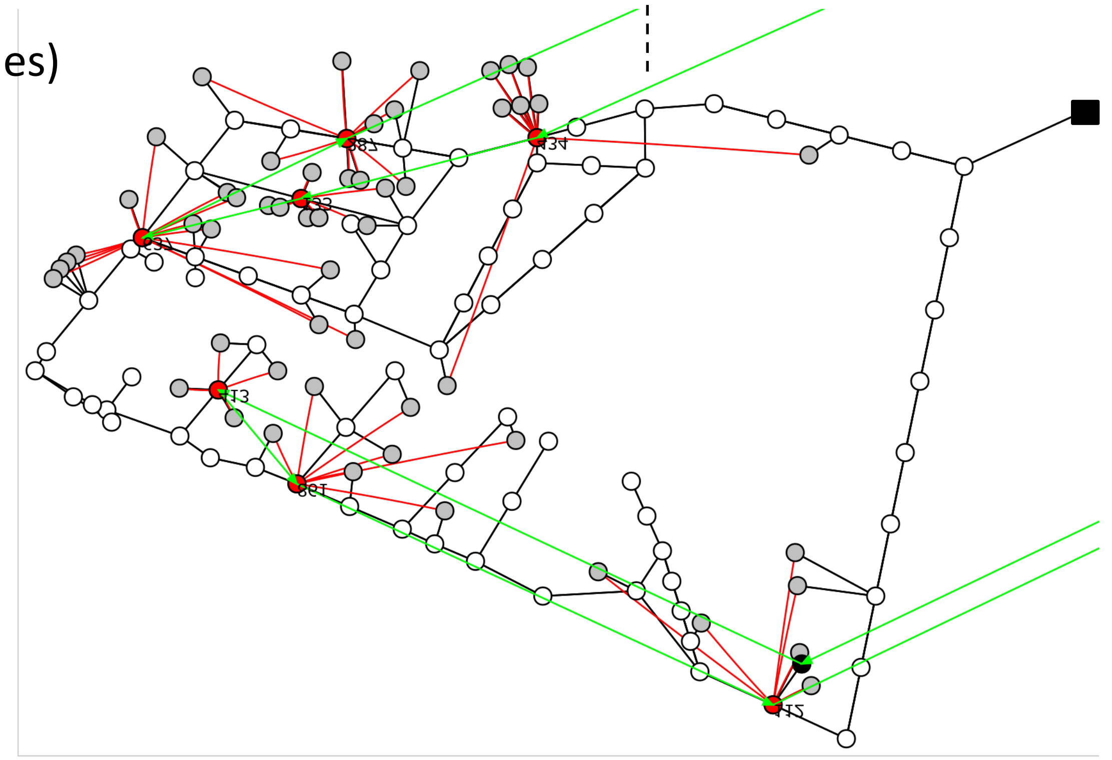
2. Current state of the project

Simple waste collection problem (single-level concept)

To determine:

1. Determine open waste collection points (red points)
2. Assign households to closest open collection point (red lines)
3. Determine collection routes (green arrows)

Illustrated as direct lines and open towards waste depot
(length: shortest distance on street network)

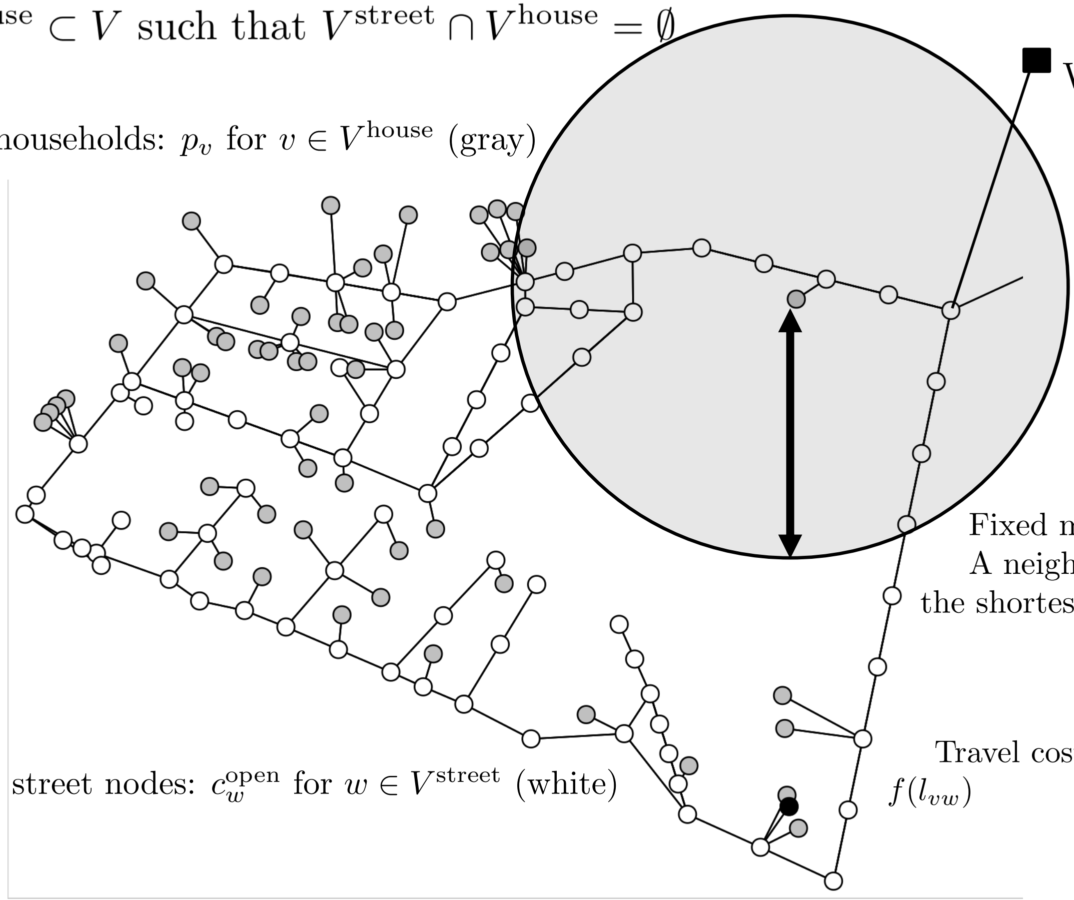


3. A first MILP model

Given a complete directed graph $G = (V, A)$, with street nodes $V^{\text{street}} \subset V$ and household nodes $V^{\text{house}} \subset V$ such that $V^{\text{street}} \cap V^{\text{house}} = \emptyset$

Waste depot $\sigma_2 \in V$

Waste production at households: p_v for $v \in V^{\text{house}}$ (gray)



Fixed maximum walking distance: d

A neighbourhood $N(v, d) = \{w \in V^{\text{street}} : l_{vw} \leq d\}$ for $v \in V^{\text{house}}$ such that the shortest walking distance from v to w on street network is at most d

Travel cost as function of length of shortest path from v to w in G: $c_{vw}^{\text{trav}} = f(l_{vw})$

Opening cost at street nodes: c_w^{open} for $w \in V^{\text{street}}$ (white)

Vehicle depot $\sigma_1 \in V$ with homogenous fleet and given load capacity k per vehicle

3. A first MILP model

Objectives of the simple waste collection problem:

1. : Find a subset $V^{\text{coll}} \subseteq V^{\text{street}}$ of open waste collection points
2. : Assign each node $v \in V^{\text{house}}$ to exactly one collection point $w \in N(v,d) \cap V^{\text{coll}}$, such that w is the closest open point to v.
3. : Find a set of routes to collect the total waste at each node $w \in V^{\text{coll}}$.

Binary variables:

x_{vw} indicates if an arc is traversed by a vehicle
y_w defines if the node $w \in V^{\text{street}}$ is a collection point
z_{vw} indicates if node $v \in V^{\text{house}}$ is assigned to node $w \in V^{\text{street}}$

Other variables:

g_w for the amount of waste to be collected at node $w \in V^{\text{street}}$
l_v for the load on the vehicle at node v
$\alpha_v^{\min}$ for the minimum walking distance from each household $v \in V^{\text{house}}$ to an open collection point $w \in N(v,d) \cap V^{\text{coll}}$

3. A first MILP model

$$\min \sum_{w} c_w^{\text{open}} * y_w + \sum_{v \in V} \sum_{w \in V:(v,w) \in A} c_{vw}^{\text{trav}} * z_{vw} + \sum_{v \in V} \sum_{w \in V} c_{vw}^{\text{trav}} * x_{vw}$$

- minimize opening, assignment and travelling costs

s.t.

$$\sum_{w \in N(v,d)} z_{vw} = 1, \qquad \text{for all } v \in V^{\text{house}}$$

- each household has to be assigned to exactly one street node

$$\sum_{v \in V^{\text{house}}} p_v * z_{vw} = g_w, \qquad \text{for all } w \in V^{\text{street}}$$

- the total waste amount at a collection point is the sum of the waste of the assigned households, linking variables z with g

$$g_w \leq y_w * k, \qquad \text{for all } w \in V^{\text{street}}$$

- a collection point must be open, if it has a positive waste amount, linking variables g with y

$$\sum_{w \in N(v,d)} c_{vw}^{\text{trav}} * z_{vw} = \alpha_v^{\min} \qquad \text{for all } v \in V^{\text{house}}$$

- defines the walking distance to the assigned collection point, linking variables z with α

$$\alpha_v^{\min} \leq c_{vw}^{\text{trav}} + (1 - y_w) * M \qquad \text{for all } v \in V^{\text{house}}, w \in N(v,d)$$

- the walking distance must be minimal when looking at the open collection points in the neighborhood, *M*: large constant

$$\sum_{w \in V^{\text{street}}:\{\sigma_1,w\} \in A} x_{\sigma_1,w} = 1, \qquad \sum_{v \in V^{\text{street}}:\{v,\sigma_2\} \in A} x_{v,\sigma_2} = f, \qquad x_{\sigma_2,\sigma_1} = 1$$

- the routes start and end at the waste depot and have to visit the vehicle depot once (at beginning and end of the collection)

$$\sum_{v \in V} x_{vw} = y_w, \qquad \text{for all } w \in V^{\text{street}}$$

- all collection points must be visited exactly once

$$\sum_{w \in V:\{vw\} \in A} x_{vw} = \sum_{w \in V:\{wv\} \in A} x_{wv}, \qquad \text{for all } v \in V^{\text{street}}$$

- same number of incoming and outgoing arcs used by the vehicle

$$l_v \leq k, \qquad \text{for all } v \in V^{\text{street}} \qquad l_1 = l_2 = 0$$

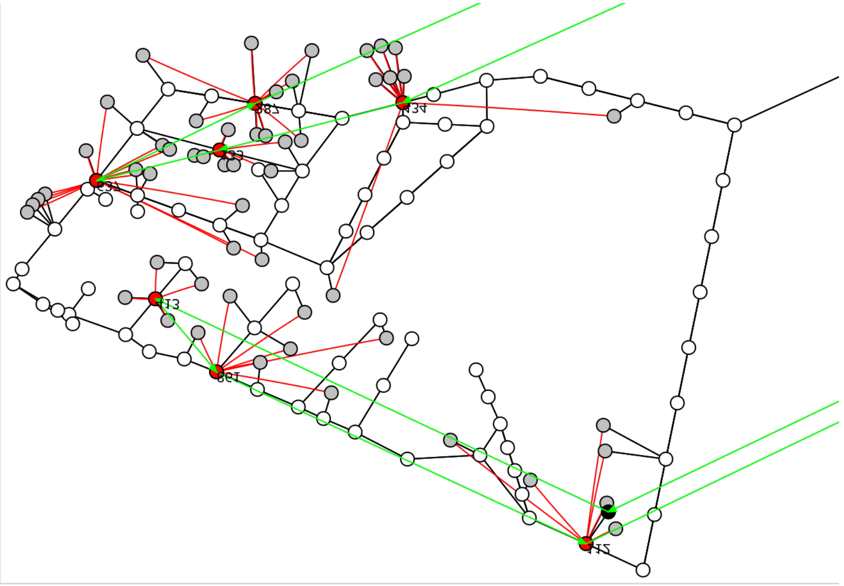
$$l_w - l_v \geq g_w - (1 - x_{v,w}) * k, \qquad \text{for all } \{v,w\} \in A$$

- prevents sub-tours by defining the load on the vehicle (similar to Miller-Tucker-Zemlin TSP formulation)

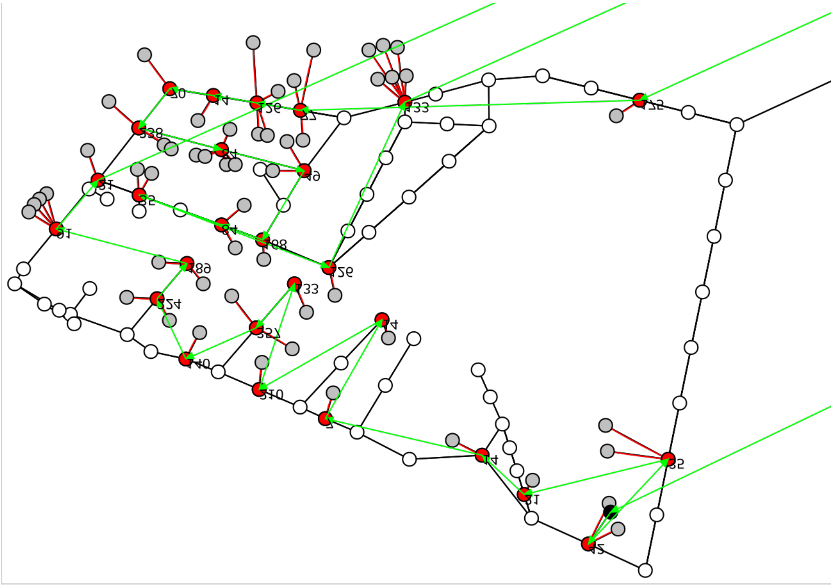
3. A first MILP model

Application

- given the instance of a small section of a municipality with simple cost functions
- what are the consequences of different maximum walking distances?



max walking distance *d = 150* meters



max walking distance *d = 2* meters

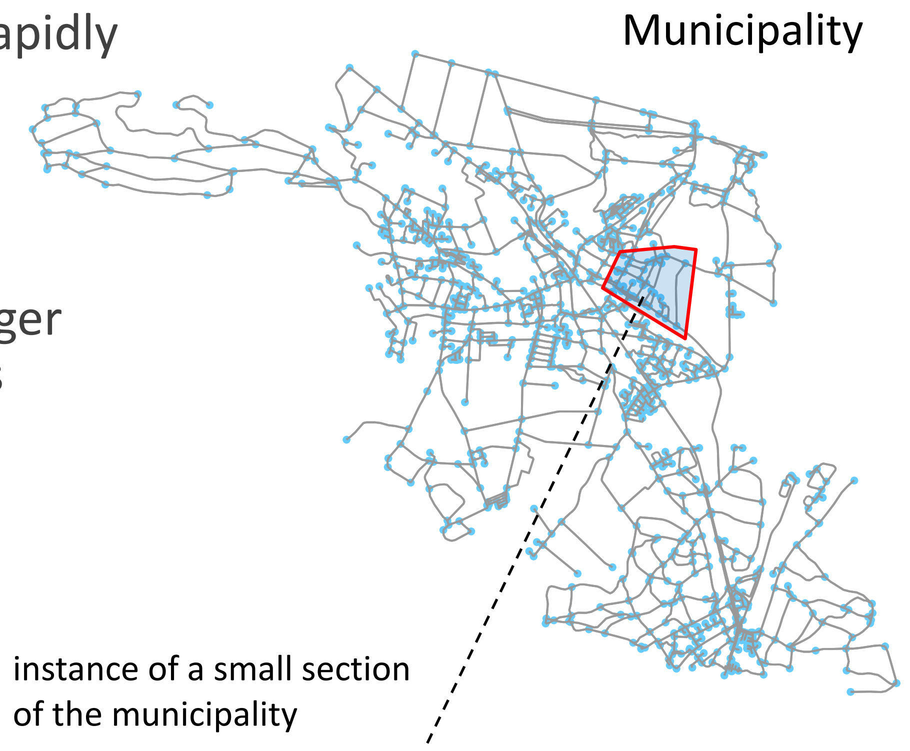
3. A first MILP model

Application

- large problem size, number of variables increases rapidly
- long run time to find optimal solutions

→ alternative solution methods necessary to solve larger problems with instances of complete municipalities

→ develop heuristics and decomposition approaches



4. Conclusion and future work

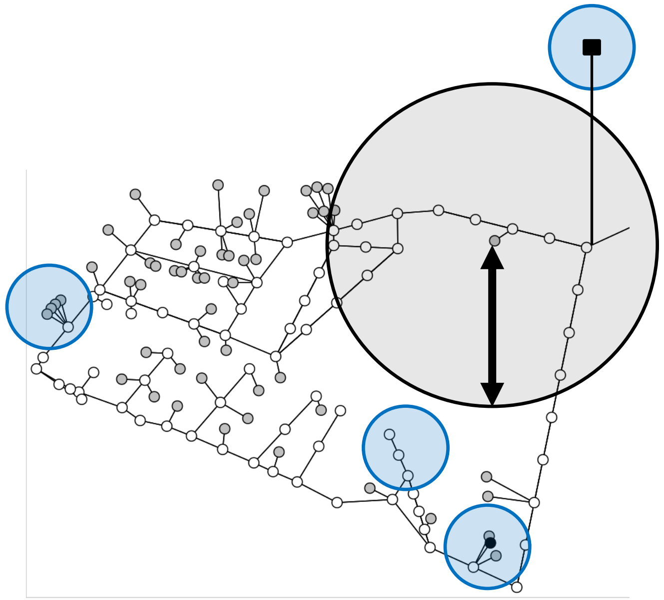
Conclusion:

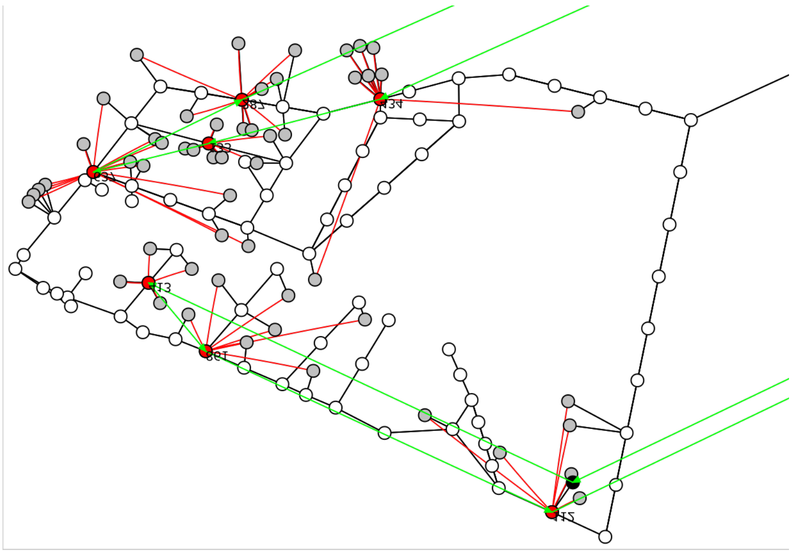
Improve waste collection process by designing efficient and sustainable strategies:

- develop innovative waste collection concepts
- develop mathematical models and optimization algorithms to optimally design a concept for a given municipality

Future work:

- develop optimization algorithms to solve practically relevant, large scale instances
- develop optimization models and algorithms for multi-level collection concepts
- create decision support tool with key figures for municipalities to choose the waste collection concept best suited for them





Thank you for your attention!

QUESTIONS?

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