Optimizing Leaf Sweeping and Collection in the Argentine city of Trenque Lauquen

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Trenque Lauquen

- Located 445 kilometres west of Buenos Aires.
- More than 33,000 inhabitants.
- Covers 400 hectares.
- Has more than 600 block sides with treed medians facing.

Leaf Sweeping Methods

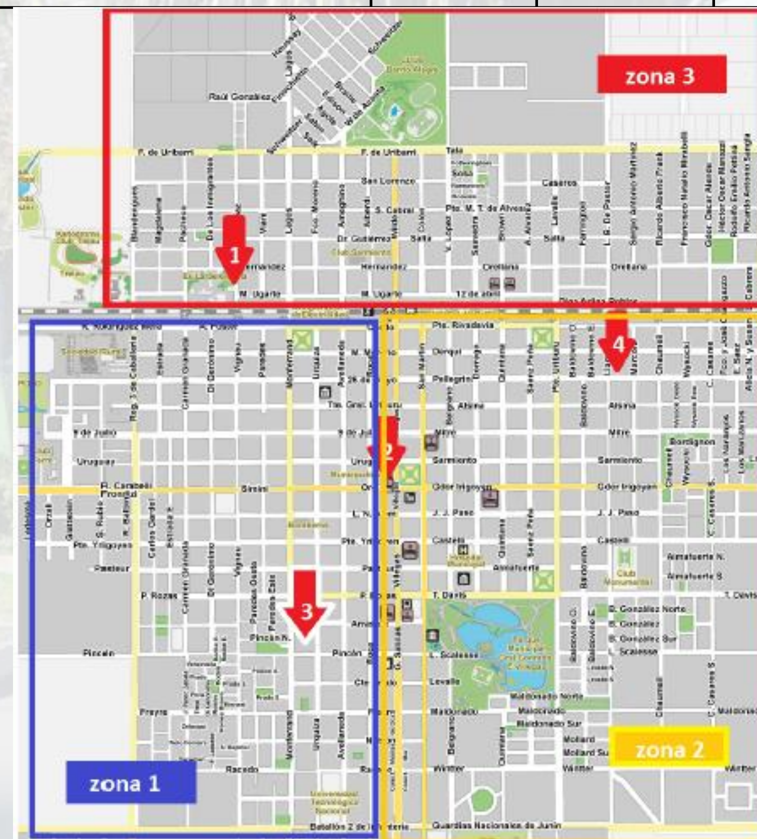
- **Mechanical**:
  - Street cleaner machines
  - Operate along the inner (median) curbs (not impeded by parked vehicles)

- **Manual**:
  - 84 street sweeper employees spread across three city zones
  - Work along the outer curbs

Manual Method

- Sweepers work 6-hour shifts (5 to 5.5 hours on duty), Monday thru Friday
- Deposit leaves in bags at predetermined street corners.

	ZONA 1	ZONA 2	ZONA 3
No. of (single block) curbs to be swept	629	678	507
No. of sweepers	21	35	28
Average no. of block sides per sweeper	30	19	18



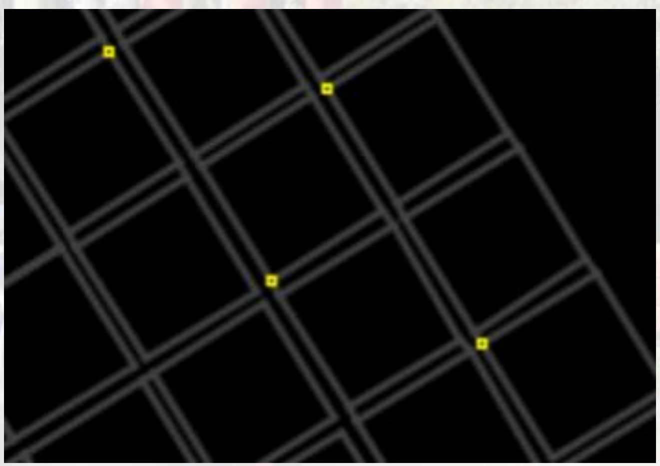
- Bags are picked up at corners by two collection trucks covering each zone.

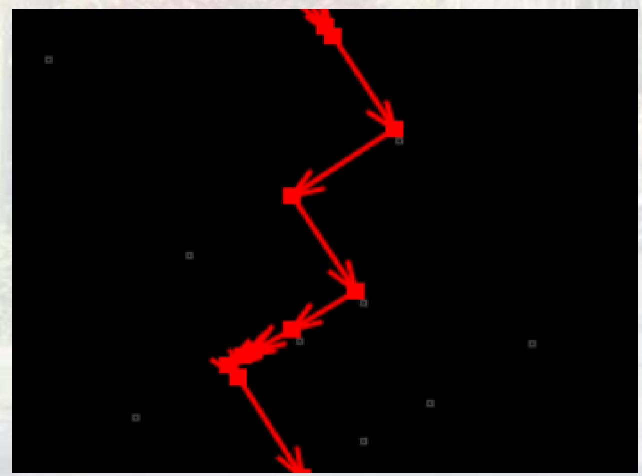
Problems…

- **Route skipping:** For various reasons, sweepers often skip streets so regulation sweep frequencies are in practice not met
- **Routes poorly defined**: Due to the above, routes are determined in the end by sweeping performed in response to complaints from local residents
- **Poor coordination between sweepers and collection trucks:** Due mainly to overlapping hours

Project Objectives

- Identify an efficient assignment of **sweepers in each zone** and the **routes** each one is to follow
- Determine **fixed points (corners)** for depositing leaf bags
- Optimize **collection truck routes** for leaf bag pickup





Solution Strategy

First Approach: Global Solution

A tentative integer linear programming model was formulated representing the global problem
Preliminary testing revealed it could not be used to solve real instances
Discretizing time produced many poor results

Second Approach: The Definitive Solution

- Problem divided into **three stages**:
  - Assignment of blocks to sweepers
  - Identification of sweeper routes and assignment of corners as bag deposit points (i.e., the second stage has two sub-stages)
  - Routing of trucks for leaf bag collection at assigned corners

- Advantages and disadvantages:
  - Solutions generated are probably suboptimal
  - Solution procedure is simpler and more flexible

Stage 1: Assignment of blocks to sweepers

- **Idea**: Generate **segments** (sets of blocks) that represent sweeper routes, then choose «optimal» coverage using an integer linear programming model.

- Model is a variation on algorithm used in:

Bonomo F., Delle Donne D., Durán G and Marenco J., “Automatic Dwelling Segmentation of Buenos Aires Province for the 2010 Argentinian Census”, Interfaces 43 (4) (2013), 373-384.

Design Considerations

- **Some factors to consider**:
  - Sweep time for each segment, related to the length of each block side included
  - Fixed number of sweepers (problem is solved for different numbers)
  - Segment compactness

Preliminaries

- **Segment sweep time:** Calculated from the lengths of the block sides and estimated time required to sweep a block side 100 metres long
- **Sweep frequency:** Pre-determined by the Municipality for each block:
  - Monday to Friday (daily sweep)
  - Alternate days (Mon-Wed-Fri one week, Tue-Thu the next)
  - Zones 1 and 2 have blocks with daily frequencies only
  - Zone 3 has blocks with both frequencies
  - Alternate-day blocks are partitioned *a priori* into two sets and the model is run for each one separately

Segment Generation Algorithm

- Start with segments of 1 single block
- Generate segments of 1 and 2 blocks by joining adjacent ones
- Generate segments of 1, 2 and 3 blocks, always ensuring segments are "connected"
- Continue up to segments of 6 blocks, keeping only the feasible ones (that is, those with sweep times falling between an *a priori* minimum and maximum). If the model can then be solved, the algorithm terminates.
- If not, the procedure is iterated as necessary by adding a block

Number of Segments

Due to the large number of feasible segments generated, a constraint was added that considers which segments retain for solving the model. If the relation between the area of a segment's convex hull and that of the segment itself is greater than 1.5, the segment is deemed to be insufficiently compact and is therefore discarded. The number of feasible segments generated and retained containing up to 8 blocks in each zone are given in the table below:

Zone	Number of feasible segments originally generated	Number of feasible segments retained for solving model
1	803,000	225,000
2	895,000	200,000
3	129,000	73,000

ILP Model

Variables

- $x_s = 1 \leftrightarrow$ segment s is part of the solution

Objective function

- Minimize "global" evaluation of solution

$$\sum_{s \in S} val_s x_s$$

Constraints

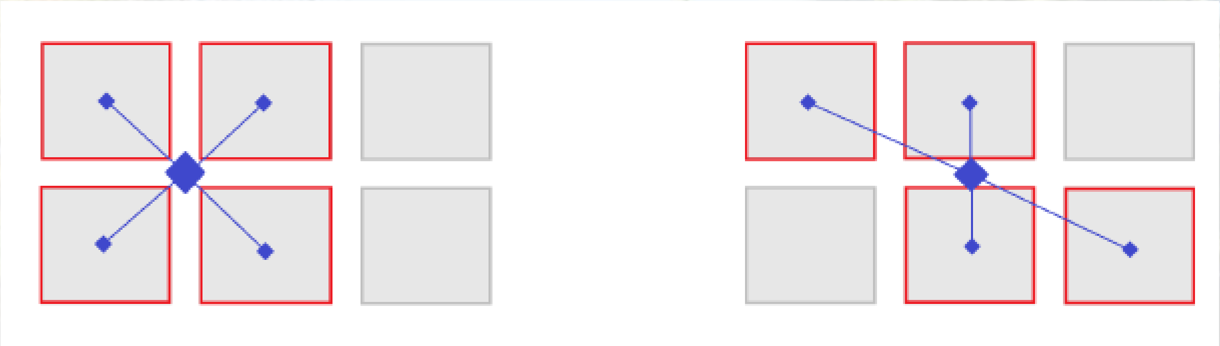
1. Each block belongs to a single segment

$$\sum_{s:m \in S} x_s = 1 \text{ for all } m \in M$$

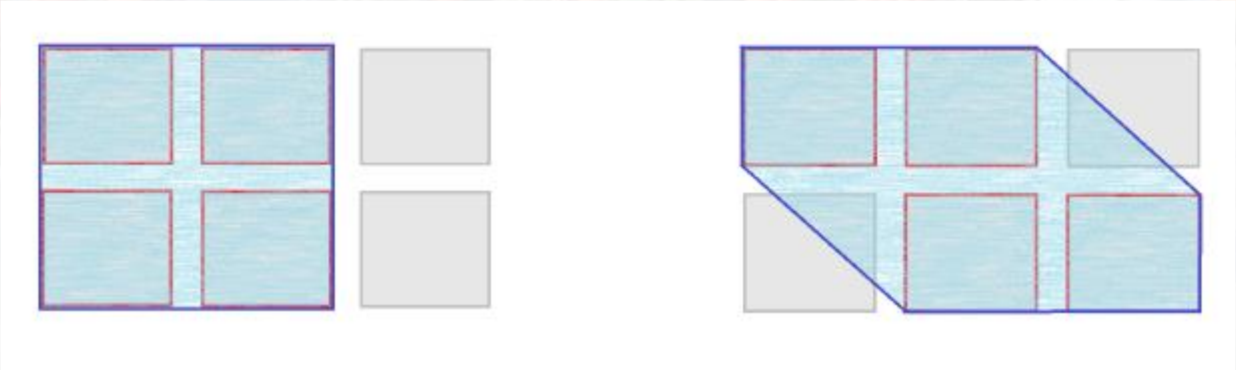
2. The number of segments must not exceed the number of available sweepers

$$\sum_{s \in S} x_s \leq available\_sweepers$$

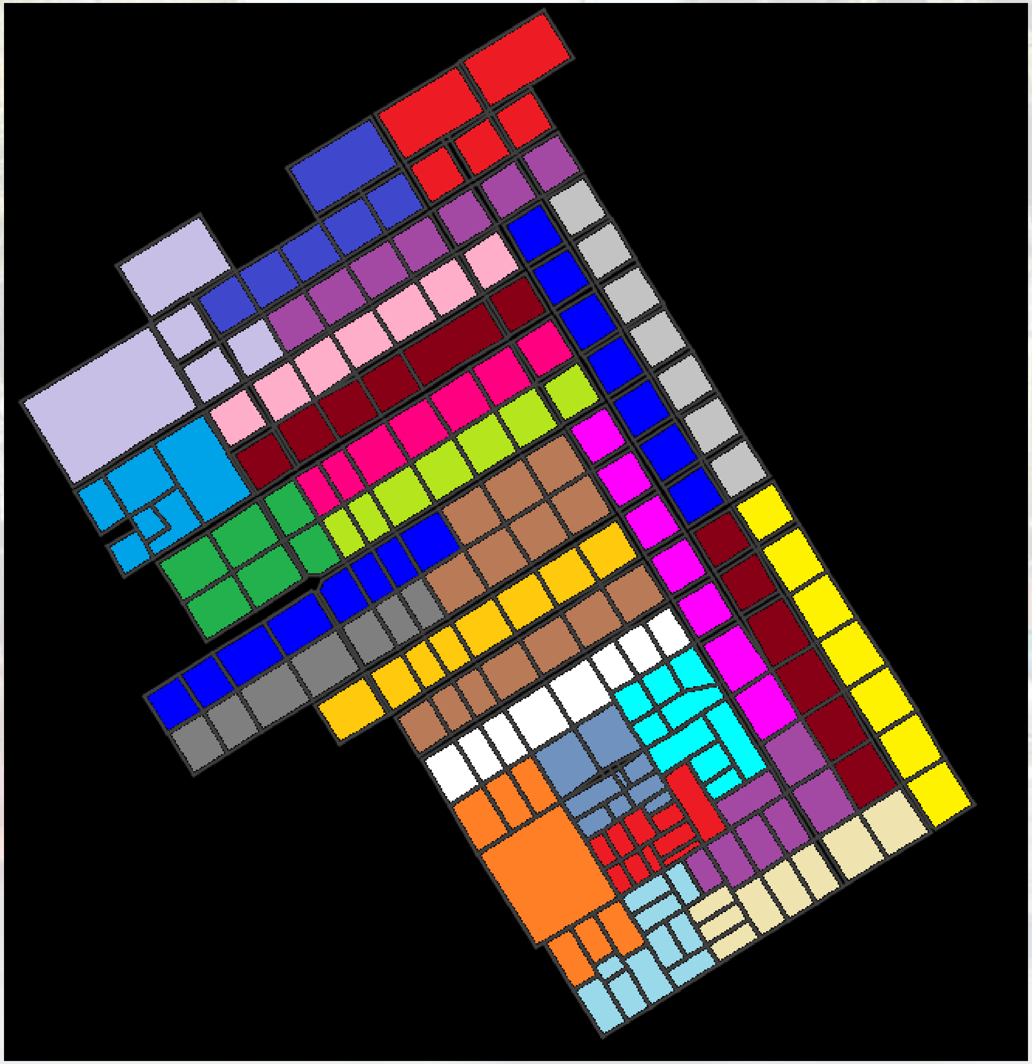
- Various types of evaluations were considered, settling finally on 2.2. below
- **Valuation 1:** Maximum distance from centre of mass



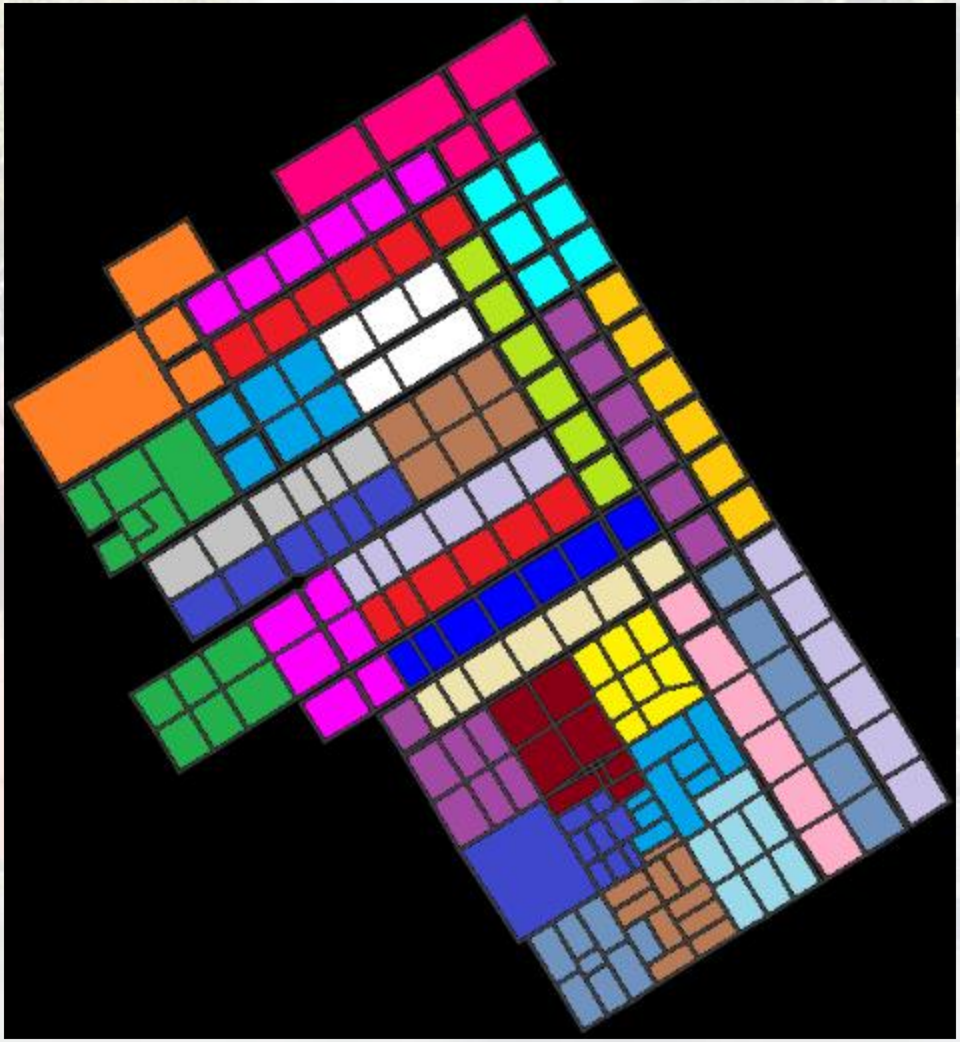
- **Valuation 2:** Segment convexity, measured in two different ways:
  1. (Area of segment’s convex hull)/(Real area of segment)
  2. Area of segment’s convex hull less real area of segment



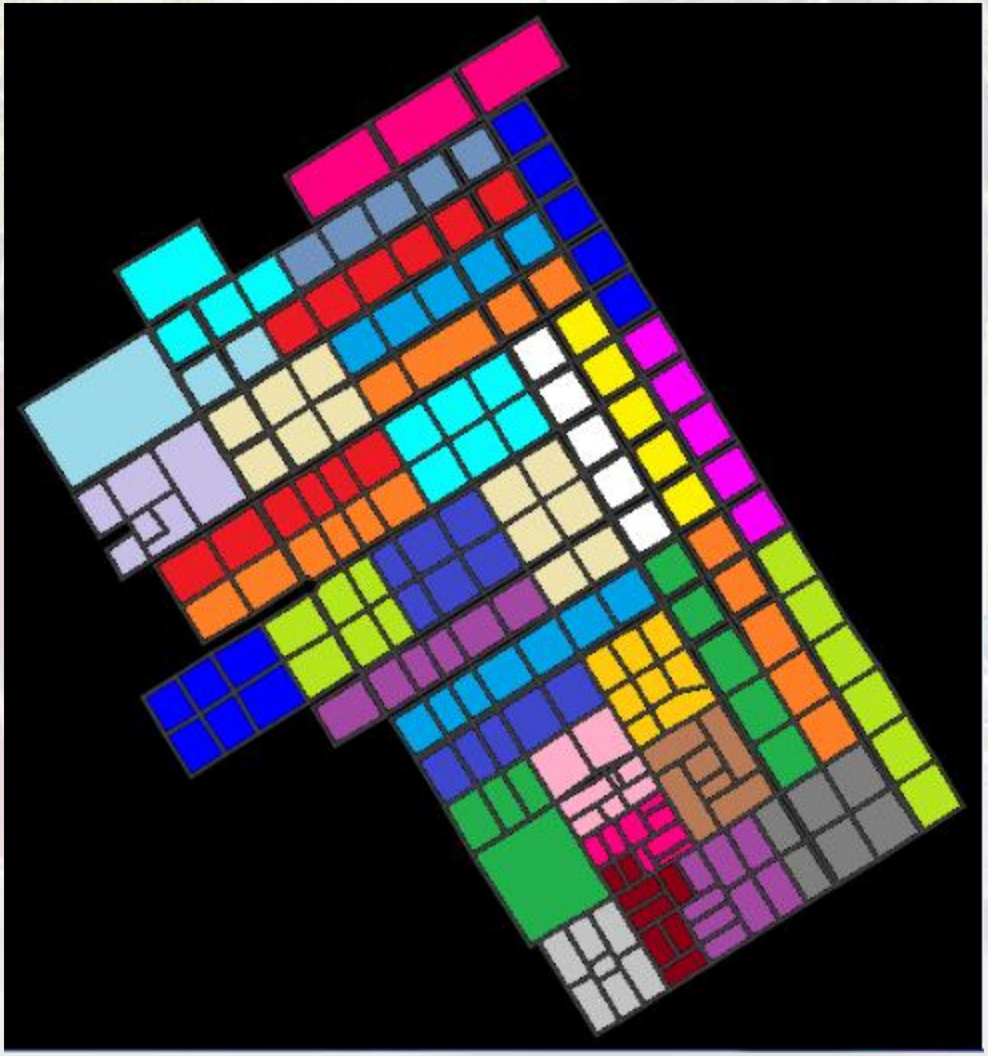
Results: Zone 1 with 28 sweepers



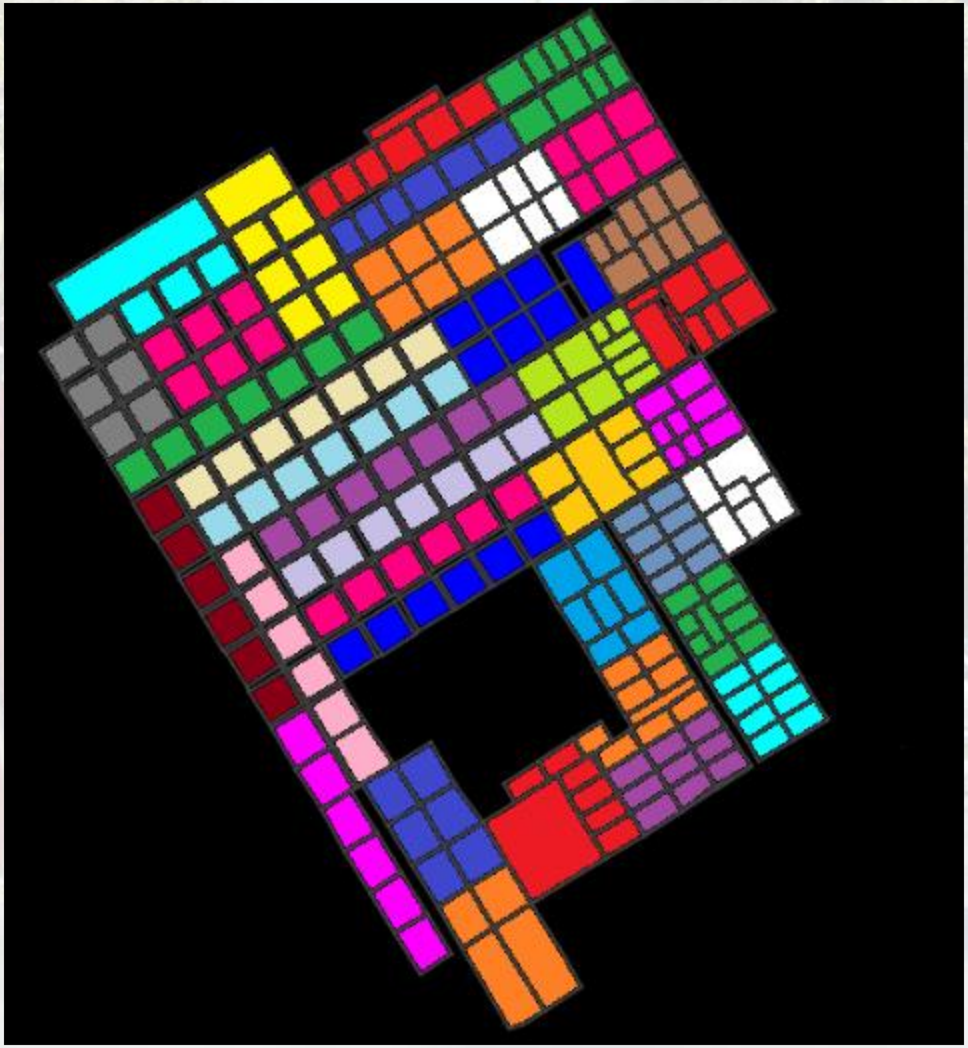
Results: Zone 1 with 31 sweepers



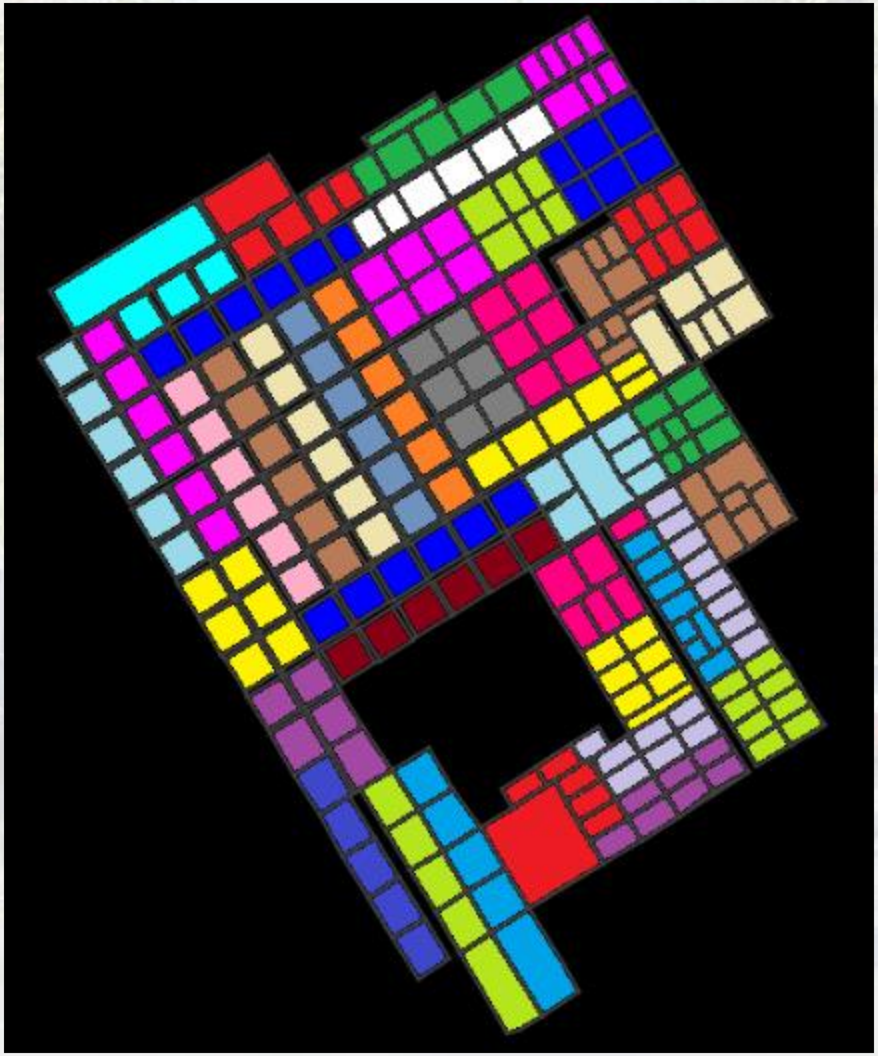
Results: Zone 1 with 35 sweepers



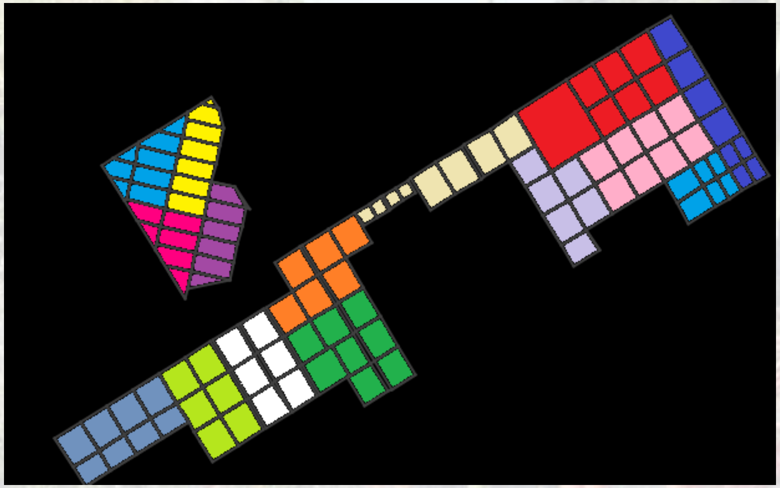
Results: Zone 2 with 36 sweepers

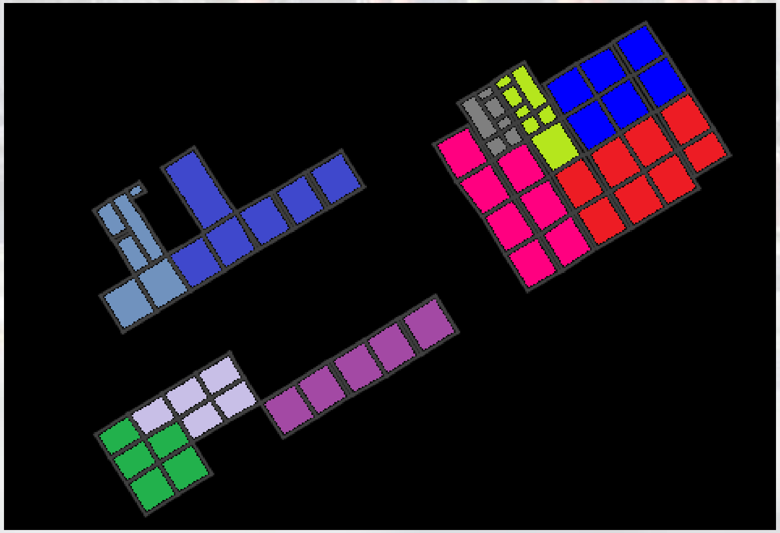


Results: Zone 2 with 40 sweepers

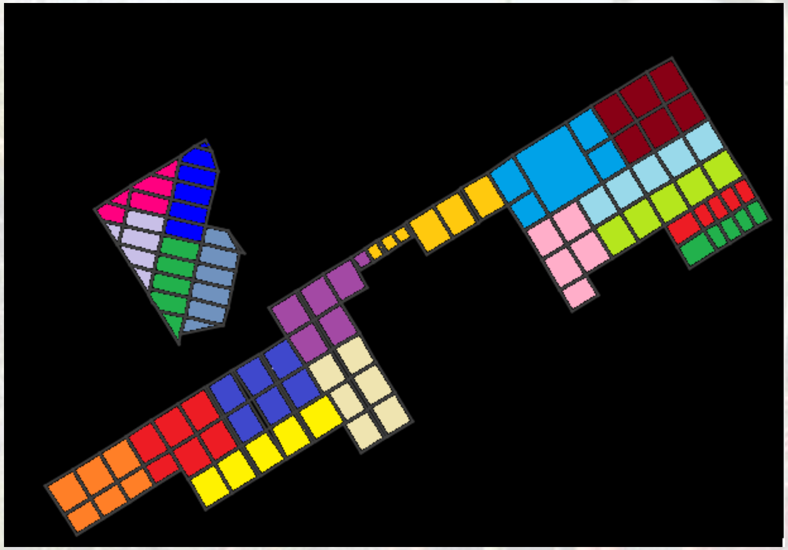


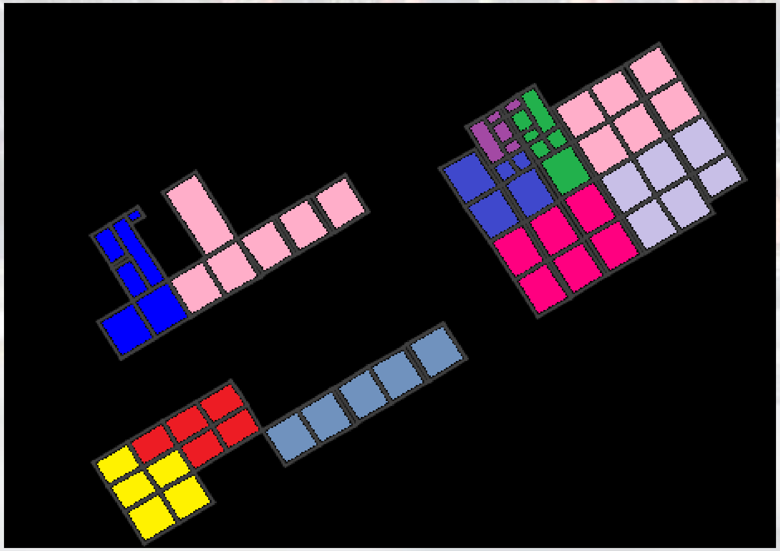
Results: Zone 3 with 20 sweepers





Results: Zone 3 with 25 sweepers





Parameters Used

Zone	Time frames of feasible segments (minutes)	Number of sweepers
1	320 - 400	28
1	300 - 360	31
1	240 - 350	35
2	260 - 360	36
2	240 - 300	40
3	240 - 320	20 (15 + 5)
3	200 - 260	25 (19 + 6)

For all blocks in Zones 1 and 2, a difficulty level parameter was defined for each block side based on the assumption that it takes 11 minutes to sweep 100 metres.

For Zone 3, where the blocks are less “regular”, block sides were categorized by sweep times of 40, 50 or 60 minutes.

Differences between number of sweepers in manual assignment and model results

	Zone 1	Zone 2	Zone 3	Total
No. of sweepers with manual assignment	21	35	28	84
No. of sweepers indicated by model (av.)	30	38	23	91
Variation in no. of sweepers	+43%	+8%	-18%	+8%

Note that the results are in line with those expected by the Municipality, which estimated that 10 more sweepers were needed

Stage 2: Sweeper routes and leaf bag deposit points

- Start by solving the Chinese Postman Problem to determine which edges will be duplicated

$$\text{Minimize} \sum_{e \in E} c_e x_e$$

$$\text{s.t.} \quad \sum_{e \in E_i} a_{ie} x_e - 2w_i = b_i \ \forall i \in V$$

$$\mathrm{x}_e \in \mathbb{N}_0, e \in E;$$

$$\mathrm{w}_i \in \mathbb{N}_0, i \in V;$$

- Once the minimum is obtained, determine the order in which the block sides will be covered

Sweeper routes

- Before solving this model, determine the order in which sweepers cover block sides using the Hierholzer algorithm:

1. Begin by arbitrarily choosing a start node. From that point, construct a cycle C_1 covering all adjacent edges as they are eliminated. If it is Eulerian, the desired result has been obtained; if not, proceed to the next step.
2. Choose any node within C_1 that has uneliminated incident edges, thus obtaining cycle C_2.
3. Join the two cycles
4. If all of the edges have been eliminated, we have the desired result; otherwise, return to Step 2.

We are now ready for the model that assigns leaf bag deposit points to corners subject to sweeper cart capacity.

Variables

- $x_j = 1$ ↔ if corner j is assigned as a deposit point
- $w_{ijt} = 1$ ↔ if sweeper i deposits leaves at point j at time t

Parameters

- $y_{iet} = 1$ ↔ if sweeper i visits block side e at time t
- $z_{ijt} = 1$ ↔ if sweeper i begins sweeping a block side starting at point j at time t

Objective function

Minimize the number of deposit points

$$\sum_{j \in V} x_j$$

Constraints

1. Sweeper cart capacity is sufficient for C curbs

$$\sum_{t \in [t_1, t_2]} \sum_{e \in E} a_e y_{iet} \leq C + C \sum_{t \in [t_1, t_2]} \sum_{j \in V} w_{ijt}$$

$$\forall i \in B, \forall t_1 < t_2, t_1 + C + max\_replied\_edges + 1 > t_2$$

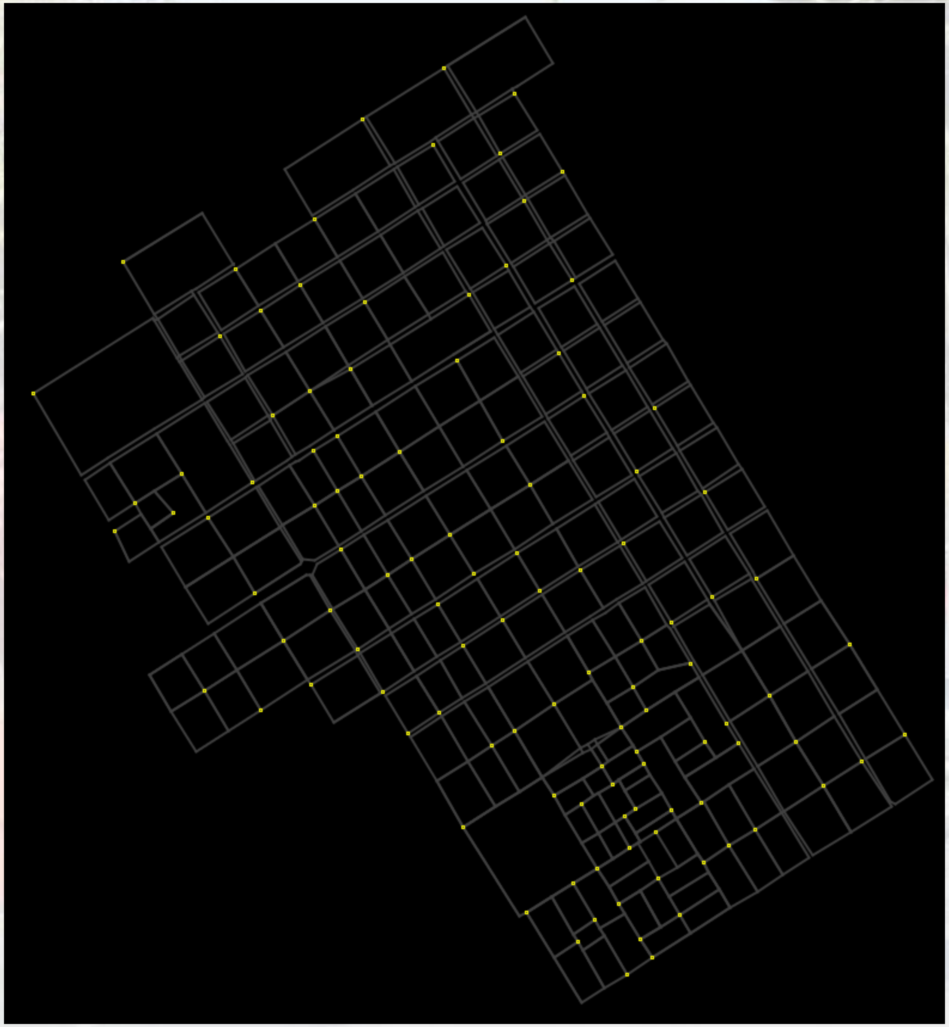
2. If a sweeper deposits leaves at point j at time t, he or she must have visited that point at that moment

$$w_{ijt} \leq \sum_{k \in N'(j)} z_{ikt}, \forall i \in B, \forall j \in V, \forall t \in T$$

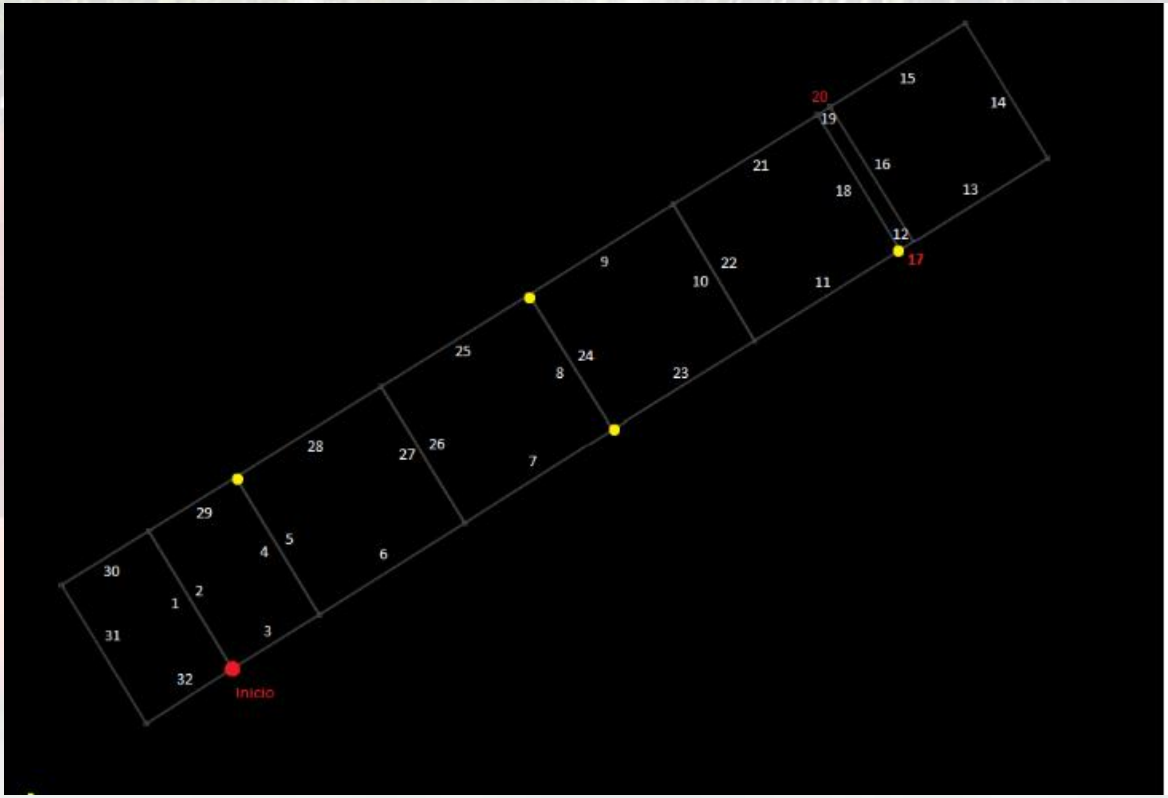
3. If a sweeper deposits leaves at a corner, it must be a deposit point

$$x_j \geq w_{ijt}, \forall j \in V, \forall i \in V, \forall t \in T$$

Results: Stage 2 (Zone 1)



- The number of deposit points was reduced from 240 under the manual assignments to 111 using the model results (almost 54 % fewer)
- Example of a sweeper route:



Stage 3: Truck Routing

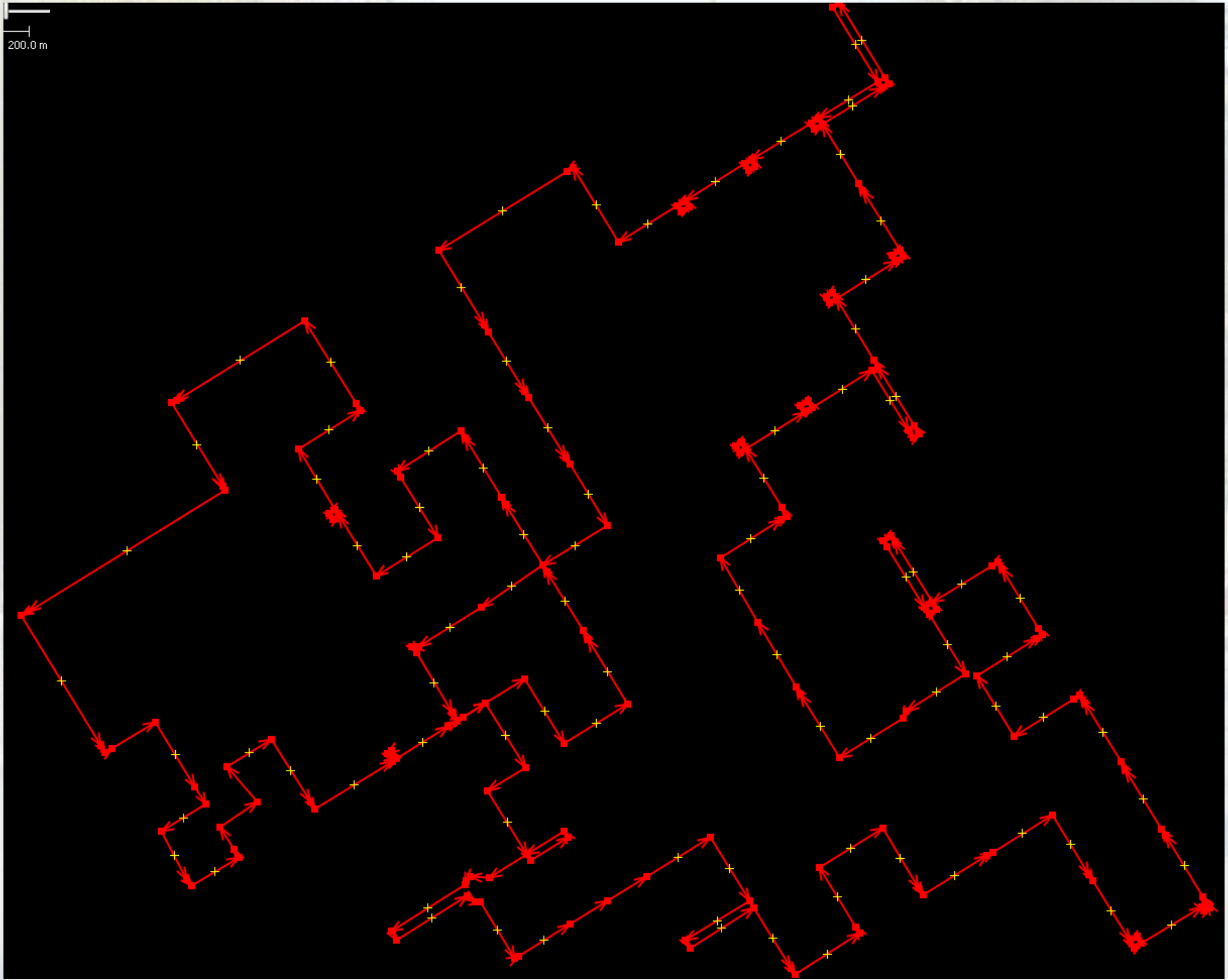
- Reduction of distance travelled by leaf bag collection truck
- Problem solved as an asymmetric TSP using Corcorde software

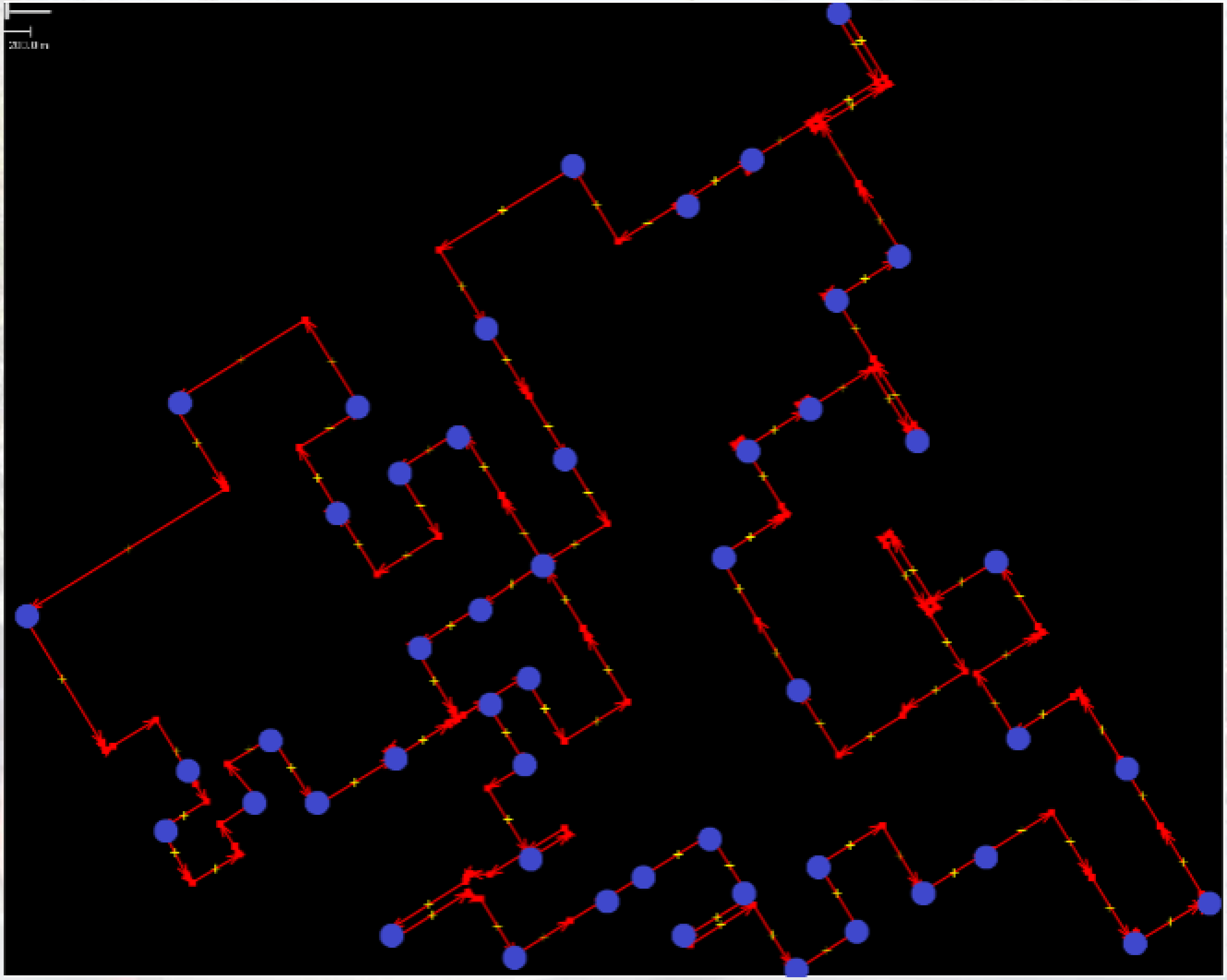
TSP

- Given N cities, the problem is to find the shortest route (permutation of cities)
- In formal terms, it consists in finding the shortest Hamiltonian circuit
- In an asymmetric problem, the weight of (i,j) is not necessarily the same as (j,i)

- Since there are two trucks per zone, divide the deposit points by a pre-process into two groups, north and south
- Start by constructing a directed graph, with modifications to take into account traffic regulations:
  - No U turns
  - No left turns at traffic lights
- Apply Dijkstra's algorithm to calculate the distances between the deposit points
- Since the Concorde software only solves symmetric TSP’s, we must first convert our asymmetric problem into a symmetric one.

Results: Stage 3, Zone 1 (North)





Results: Stage 3, Zone 1 (South)

- Under manual methods, the truck routes were full of zigzags
- Under the model, the trucks' combined routes in Zone 1 were reduced from 32.2 km to 28.4 km (savings of 12%)

Future Work

- Differentiate between sweepers by sweep speed
- Apply penalty for routes starting far from sweeper depot
- Associate difficulty level parameter with seasonal factors