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Snap4Waste: An integrated dynamic system for optimal waste collection management

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SNAP4CITY

Why Waste Collection Needs a Smarter Model

Waste management is no longer only a disposal problem - it is a mobility, cost, and sustainability problem.

635 Mt	1,999 Mt	3,539 Mt
Global Waste — 1965	Global Waste — 2015	Projected by 2050

- Urbanization, population growth, tourism, and consumption increase volume and complexity.
- Collection and transportation generate high operational costs: trucks, staff, fuel, maintenance.
- Poor planning causes unnecessary trips, overflowing containers, illegal dumping, and lower service quality.
- IoT and routing optimization can reduce avoidable trips and improve resource allocation.

Problem and objective

Problem

- Traditional fixed schedules remain dominant but may collect non-full bins.
- Many solutions optimize only one layer: sensors, routing, dashboards, or PAYT.
- Urban operations must consider dynamic bin fill levels, vehicle limits, traffic conditions, and alarms.
- No real-time visibility into bin status or truck operations.

Objective

- Integrate IoT monitoring with dynamic route optimization.
- Deliver real-time KPIs, alarms, and dashboards.
- Reduce unnecessary trips and improve collection efficiency
- Support PAYT and multi-stakeholder roles.

Core research question

How can a city transform live waste data into reliable daily routes while monitoring execution and operational KPIs?

Literature Gap & Requirements Coverage

Existing solutions — Sensoneo, NextBillion AI, Nordsense, CollectMyWaste, and academic approaches — cover only **partial** functionality. Snap4Waste is the only system satisfying all **eight requirements (R1–R8)**.

R1–R2
Entities & Roles

R3–R4
Real-time Bin & Truck Data

R5
Dynamic Routing

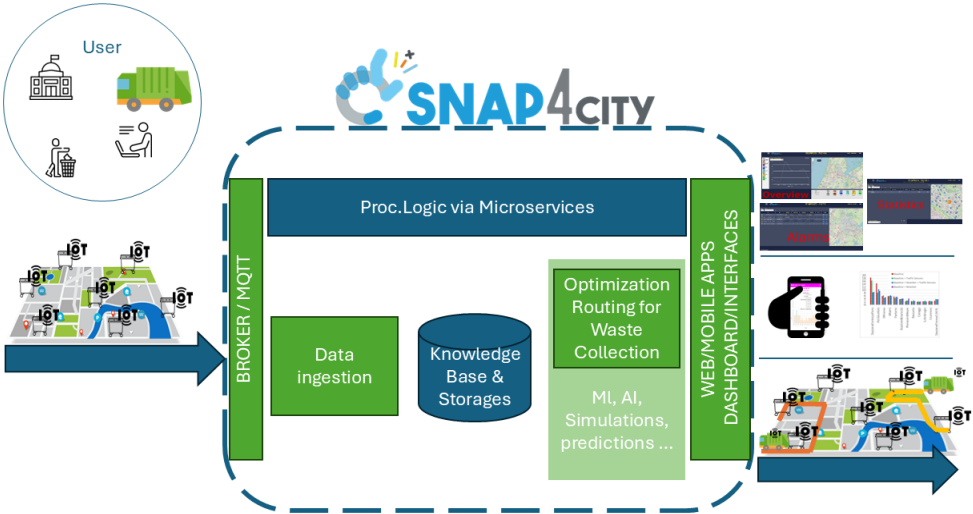
R6–R7
KPIs & Alarms

R8
PAYT Support

	R1 Entities	R2 Roles	R3 Bin Data	R4 Truck Data	R5 Routing	R6 KPIs	R7 Alarms	R8 PAYT
Sensoneo	✓	✓	✓			✓	✓	
NextBillion AI	✓		✓		✓	✓		
Nordsense	✓	✓	✓			✓		
CollectMyWaste	✓	✓	✓		✓	✓		
Academic Approaches	✓		✓		✓	✓	✓	
Snap4Waste	✓	✓	✓	✓	✓	✓	✓	✓

Snap4Waste is designed to satisfy every listed requirement, including PAYT and alarm management.

Snap4Waste Architecture on Snap4City



Data model and operational entities

Bins

- Position, capacity, waste type
- Fill level and usage frequency
- Temperature and alarms
- Locker/fob events for PAYT

Trucks

- Vehicle capacity and class
- Route assignment
- Waste weight during loading
- Tracking and status data

Users and roles

- Administrators and operators
- Drivers and maintenance staff
- Common city users
- Commercial operators

The system can operate with sensor data from bins, data from trucks, or both for cross-checking and prediction.

PAYT support is enabled through bin lockers and fobs, or RFID-based bags, while remaining aligned with GDPR requirements.

Optimization workflow: from live status to daily routes

1. Collect data → 2. Select bins → **3. Optimize routes** → 4. Assign trucks → 5. Monitor

1

Real-Time Detection

IoT sensors continuously monitor fill levels across the city network

2

Prioritization

Bins above **70%** fill level are flagged; AI predicts those likely to reach **80%**

3

Route Enrichment

Nearby lower-priority bins are added to improve route efficiency

4

Optimized Dispatch

Drivers receive optimized daily routes — fewer trips, full coverage

Genetic Algorithm for Dynamic Routing

Snap4Waste uses a **genetic algorithm (GA)** to solve large-scale, multi-vehicle waste collection routing. Each **chromosome** encodes a complete set of vehicle-to-bin assignments. The fitness function jointly minimizes total operational cost and preserves population diversity, preventing premature convergence.

Tournament Selection

Competitive parent selection for high-quality offspring

Crossover & Mutation

Recombination and random variation across the population

Hard Constraints

Each bin visited once; truck capacity and working-time limits respected

Local Refinement Operators

After each GA generation, N/M-exchange and 2-OPT operators refine routes — removing suboptimal segments and reordering stops to reduce travel distance and operational cost.

Stopping Conditions

- Maximum generations reached
- No improvement over threshold iterations
- Minimum execution time satisfied

Multiple independent runs with different random seeds improve solution robustness and reduce stochastic variance.

Dataset & Case Study: Amsterdam

Snap4Waste was validated using **real operational data** from Amsterdam — not a synthetic benchmark. The city's smart-bin infrastructure provides sensor-driven fill-level readings across a heterogeneous urban waste network.

845K

Kg of Waste

Total volume in the test instance

120

Max Vehicles

Two vehicle classes available

4,621

Smart Bins

Across multiple waste types citywide

Operational Dashboards

Snap4Waste provides four integrated dashboards bridging optimization output and daily field operations.

Planning Dashboard

Set parameters, launch optimization, monitor KPIs

Route Management

Assign optimized routes to trucks and drivers

Alarm Dashboard

Track bin status, sensor faults, and critical events

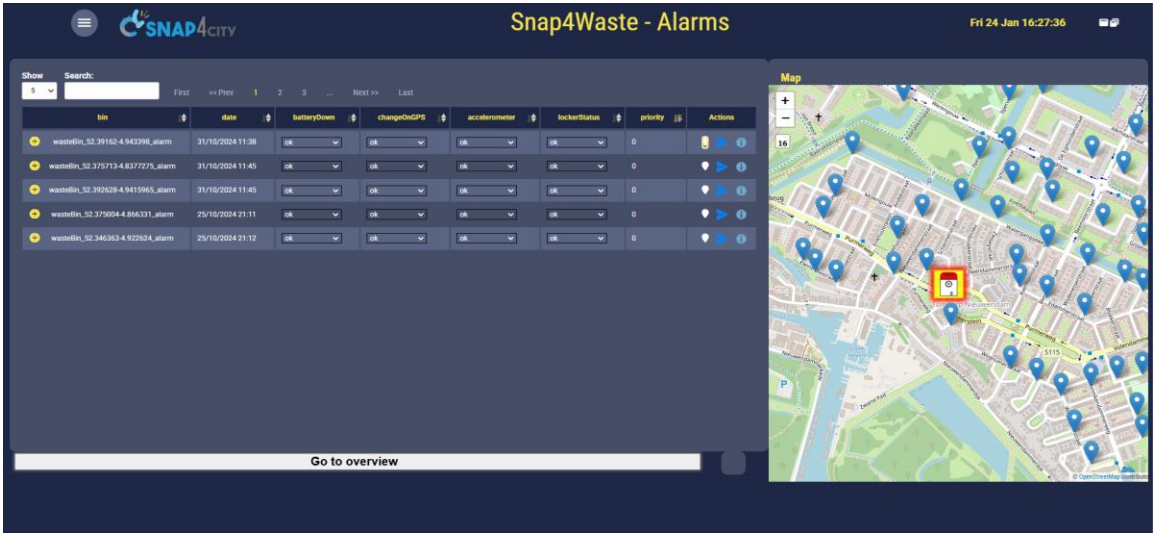
Statistics & Driver App

Collection KPIs, performance trends, and turn-by-turn navigation

Operational Dashboards

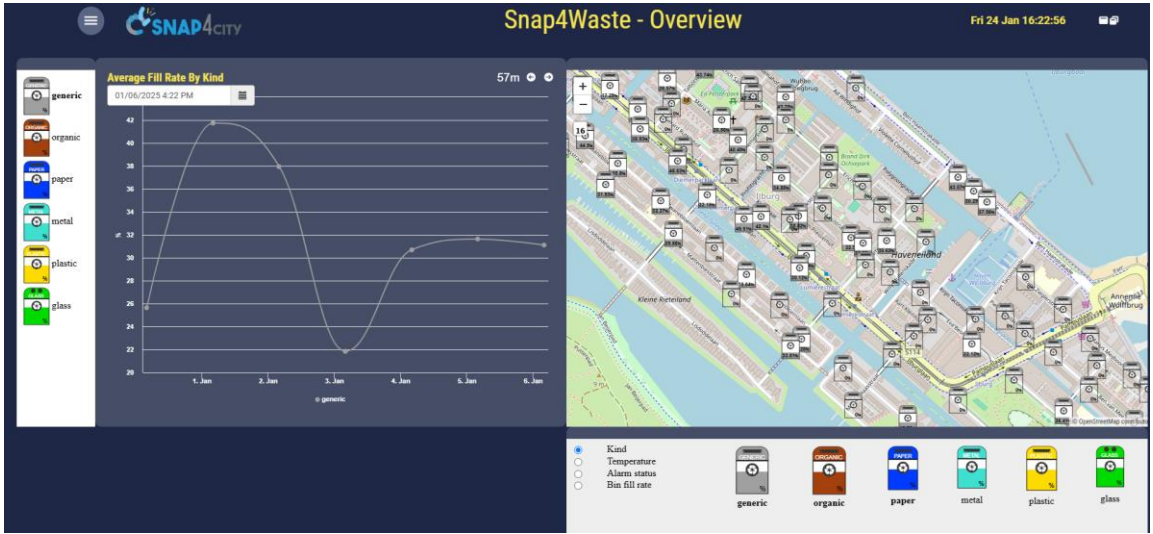
Operational Dashboards

Operational Dashboards

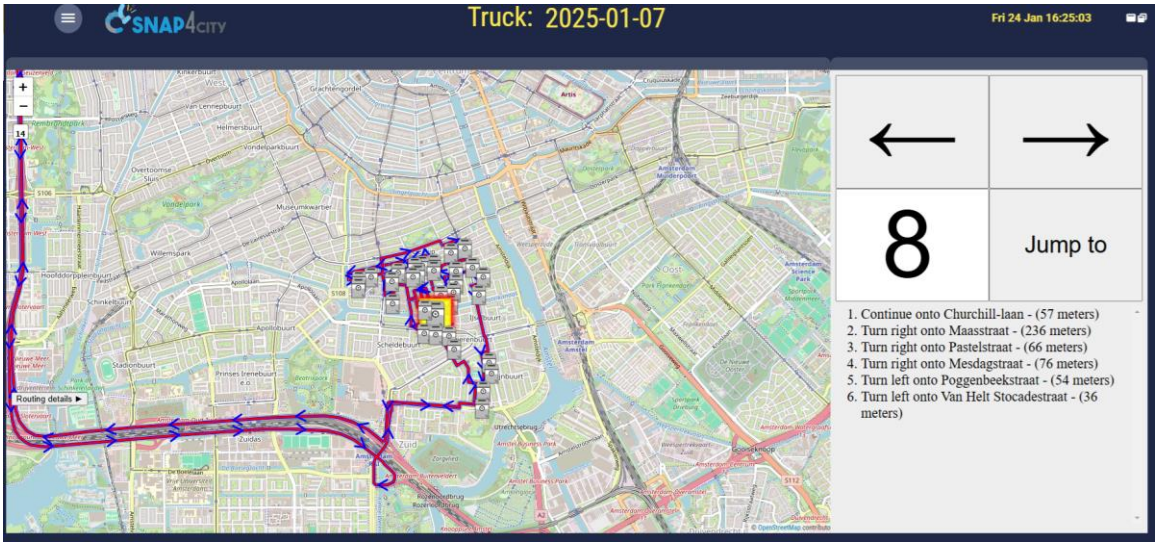


Operational Dashboards

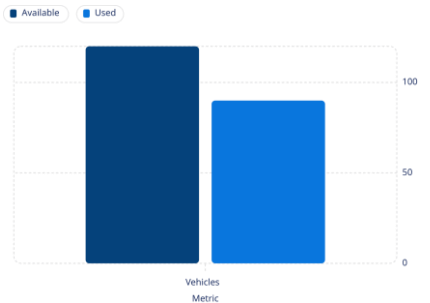
Operational Dashboards



Operational Dashboards



Optimization Results



4,621
bins in the instance

~845,000 kg
waste volume

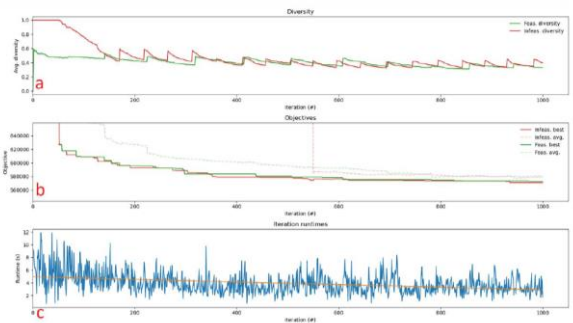
120
max vehicles

90
vehicles in solution

Key Outcomes

- 90 of 120 vehicles deployed — 25% fleet reduction
- Total travel time: ~572,000 seconds
- Solution time: ~4,000 seconds on Intel Xeon E5-2650 v4, parallelized over 32 cores

Three convergence curves track the run: population **diversity**, decreasing **total cost**, and **runtime per iteration**.



Contributions & Limitations

Contributions

- Integrated IoT-based waste management platform
- Dynamic routing with real-world urban constraints
- KPI dashboards and alarm management
- Support for PAYT and what-if scenario analysis

Limitations

- Dependence on reliable sensor and infrastructure data
- Computational cost for very large instances
- Predictive models require further field validation
- PAYT transparency and blockchain mechanisms remain future work

Snap4Waste shows how smart-city infrastructure can transform waste collection from fixed schedules into data-driven, dynamic, and monitorable operations.

Future work: better waste-generation prediction, more dynamic AI planning, and secure transparent PAYT mechanisms.

Thanks for your attention

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