RETHINKING WASTE TRACK

SortLedger AI

Smart Waste-Contamination Auditor, Diversion-ROI & 2-Opt Route Optimizer

Turning municipal & campus recycling streams from MRF rejection liabilities into verified climate & budget savings.

12-Class Audit Engine

PET, HDPE, Aluminum, OCC, Glass, Compost, E-Waste, Battery, Film, Foam, Soiled, and Mixed Trash modeling.

2-Opt Smart Routing

Fill-threshold filtering (>=65%) + Nearest-Neighbor + 2-opt local search cuts diesel mileage & fleet CO2e.

Zero-NaN Compliance

RFC-4180 CSV & JSON audit ledgers + annualized municipal budget ROI simulator. 25/25 Vitest assertions pass.

01 / PROBLEM STATEMENT

Why Municipal & Campus Recycling Loses Money Today

1. MRF Contamination Rejection Cliffs

Single-stream loads exceeding ~12% contamination (plastic film, EPS foam, food-soiled paper) face steep MRF surcharges and 65%+ recovery loss.

One stray lithium battery in a compactor truck creates an immediate thermal/fire hazard.

2. Blind Static Daily Collection Routes

Fixed daily truck schedules service bins that are only 20-40% full, burning 0.42 L/km of diesel and unnecessary crew hours.

Without 2-opt path optimization, overlapping cross-district loops inflate fleet emissions.

3. Disconnected Spreadsheets Hide True Diversion ROI

Sustainability officers track tonnage in one sheet, tipping fees in another, and fleet fuel in a third. SortLedger AI unifies contamination risk, commodity recovery ($/ton), EPA-WARM CO2e factors, and 2-opt collection routing into one deterministic, auditable decision engine.

02 / CORE ENGINE

Deterministic 12-Class Contamination & CO2e Auditor

Clean Divertible Streams

- Aluminum ($1,480/t, 9.11 tCO2e)
- HDPE #2 ($420/t, 0.87 tCO2e)
- PET #1 ($310/t, 1.13 tCO2e)
- Cardboard ($115/t, 3.12 tCO2e)
- Glass ($28/t, 0.28 tCO2e)
- Compost ($18/t, 0.56 tCO2e)

Full tipping-fee savings ($68/t) when contamination <= 12%.

MRF Contaminants & MSW

- Film-Plastic (disc tangler)
- EPS Styrofoam (non-MRF)
- Food-Soiled Paper (grease)
- Mixed-Trash (residual MSW)

Triggers sorting surcharge >5% and MRF rejection cliff >12%, cutting recyclable recovery efficiency down to 35%.

Critical Hazard Flagging

- Battery (CRITICAL): Flags thermal/fire risk + $150 base + $18/kg surcharge.
- E-Waste (HIGH): Flags toxic heavy metals + $75 base + $6/kg surcharge.

All inputs guarded against NaN, Infinity & negatives.

Smart-Fill Filtering + 2-Opt Local Search

Algorithmic Pipeline

1. Filter bins by fill level >= threshold (default 65%).
2. Construct initial tour via Nearest-Neighbor.
3. Apply 2-opt edge-swap local search until
   zero crossing edges remain.
4. Supports Euclidean (km) & Haversine (lat/lon).

Verified 12-Bin District Benchmark

- Static Daily Route: 44.27 km (all 12 bins)
- Smart-Fill (>=65%) + 2-Opt: 32.00 km (8 bins)
- Distance Saved: 12.27 km (27.7% reduction)
- Diesel Saved: 5.15 L/run (13.81 kg CO2e)
- Strict monotonicity: smart <= nn <= static.

Why 2-Opt Matters for Municipal Fleets

Heavy refuse trucks average ~0.42 L diesel/km (2.68 kg CO2e/L). Eliminating 27.7% of wasted collection mileage across a 14-truck fleet (260 days/yr) cuts 18,746 L of diesel and 50.3 metric tons of tailpipe CO2e annually before counting landfill diversion savings.

Dark-Emerald Sustainability Ops Console

Live Bin Stream Inspector

- Instant preset switching:
  - North Campus Single-Stream
  - Residence Hall Move-Out Spike
  - Downtown Commercial Corridor

- Adjust any of the 12 material weights in kg and watch MRF rejection alerts, hazard banners, net load value, and CO2e avoided update in real time.

2D District Map & Budget Simulator

- Interactive Fill-Threshold Slider (0-95%) redraws the 2D SVG district map live, contrasting Static Daily (dashed) vs 2-Opt Smart Route (emerald solid).

- Annualized Municipal ROI Simulator: Tune fleet size, tipping fee, diesel, crew hourly rate, and platform cost with 1-click CSV & JSON export.

05 / CLIMATE & BUDGET IMPACT

Quantified Municipal ROI (14-Truck Fleet Simulation)

Annual Diversion Value

Tipping + Commodity:
$1,168,476 / yr

Driven by aluminum, OCC cardboard, and avoided $68/t tipping.

Fleet Fuel & Labor

Fuel + Crew Saved:
$100,089 / yr

27.7% route reduction frees crew hours for targeted bin audits.

Climate Impact

Total CO2e Avoided:
8,534 tCO2e / yr

Combines EPA-WARM material recovery + tailpipe diesel cuts.

Zero-Backend Auditability

Every simulation produces a deterministic Audit ID (e.g., SL-XXXXXXXX) and exports RFC-4180 compliant CSV and structured JSON ledgers for municipal finance, ESG reporting, and state waste-diversion grant compliance.

TypeScript Architecture & 25-Test Vitest Suite

Clean Modular Codebase

- src/waste/contaminationAuditor.ts
  12-class engine, hazard flags, MRF cliffs.
- src/waste/routeOptimizer.ts
  Euclidean + Haversine, NN + 2-opt.
- src/waste/auditLedger.ts
  RFC-4180 CSV, JSON, ROI simulator.
- Strict TypeScript (tsc --noEmit) + Vite.

25/25 Automated Vitest Proofs

- Weight & share conservation across all 12 material classes.
- Battery/E-Waste hazard & penalty jumps.
- 2-opt uncrossing & monotonicity proofs.
- Haversine Earth-arc distance checks.
- NaN, Infinity, & negative input guards.
- RFC-4180 CSV quote/comma escaping.
- Headless Chrome QA: 0 console errors.

07 / NEXT STEPS & LINKS

Deployment, Open-Source Repo & Next Milestones

Near-Term Roadmap

- Edge ultrasonic bin-fill MQTT ingestion for live campus compactor telemetry.
- Camera-based MRF tipping-floor classification feeding into SortLedger.
- Multi-depot Capacitated VRP (CVRP) with truck payload weight constraints.

Live Artifacts

- GitHub Repo (MIT): alphonshhhomenicmtu/sortledger-waste-ai
- Live Web Console: alphonshhhomenicmtu.github.io/sortledger-waste-ai/
- Deck PDF: .../sortledger-deck.pdf

Thank You — SortLedger AI

Cleaner recycling streams. Shorter collection routes. Verifiable municipal ROI.
Ready to deploy on any campus or city waste district today.