SOLVING THE AUTOMATED VACUUM WASTE COLLECTION OPTIMIZATION PROBLEM

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System Description

System for the collection and transport of urban waste from drop off points (*inlets*) scattered through the served area to a central collection plant through a *closed network* of underground pipes using *air suction*.

An Automated Vacuum Waste Collection System (AVWCS) is modelled as:

$$\{\mathcal{T}, \mathcal{I}, \mathcal{F}, \mathcal{V}^a, \mathcal{V}^s\}$$

- $\mathcal{T}(\mathcal{N}, \mathcal{E})$ rooted binary tree:
  - Nodes ($\mathcal{N}$):
    1. The root node represents the waste collection facilities.
    2. The other nodes represent waste inlets ($\mathcal{I}$) or pipe junctions.
  - Edges ($\mathcal{E}$) correspon to pipes between nodes.
- $\mathcal{F}$ the set of fractions waste is divided into. *Typical fractions include organic refuse, paper, plastic and glass.*
- Air valves ($\mathcal{V}^a$), located at some inlets, create air streams able to empty downstream inlets.
- Sector valves ($\mathcal{V}^s$) are disposed along the tree in order to segment the whole tree structure, defining isolated sectors (s).

Inlets, Air Valves and Sectors

An inlet i can contain several separated waste fractions. We assign a different identifier for each I_i^f

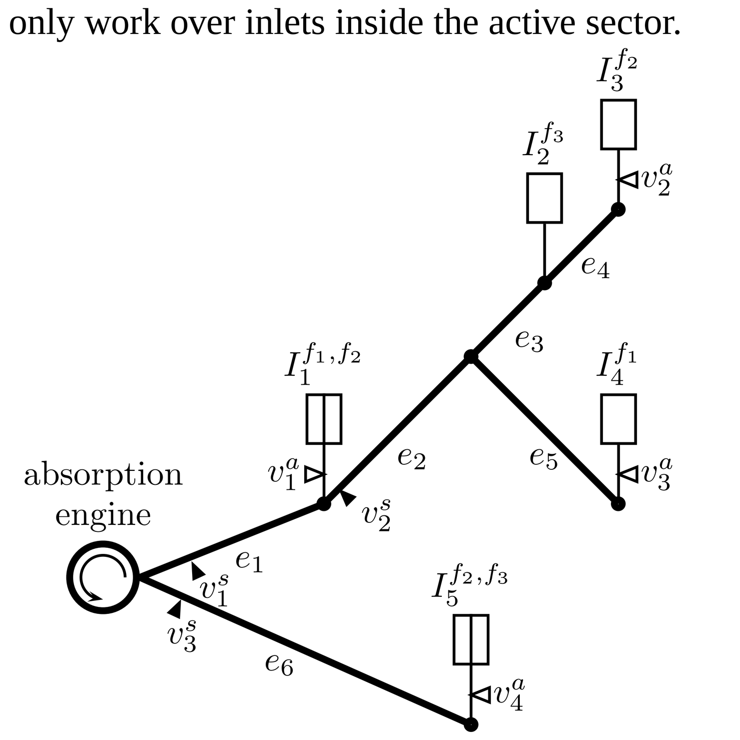
A configuration of open and closed sector valves defines a **sector**: Is the subtree that contains all the paths to the root that contain only open valves and at least an inlet.

The vacuum waste collection process can only work over inlets inside the active sector.

Sample configuration with:

- 3 types of fractions
- 5 inlets (2 with 2 types, so we will consider 7 inlets)
- 4 air valves
- 3 sector valves

Only 5 combinations of 8 in $\mathcal{V}^s$ are possible



Overall Functioning

At any time, a **subset of the inlets** can be selected to be emptied downstream to the collection facilities. Operation in two phases:

1. Transitory Phase: Adapt previous air speed to the selected sector.
2. Stationary Phase: Empty and transport each inlet waste, following a determined sequence order.

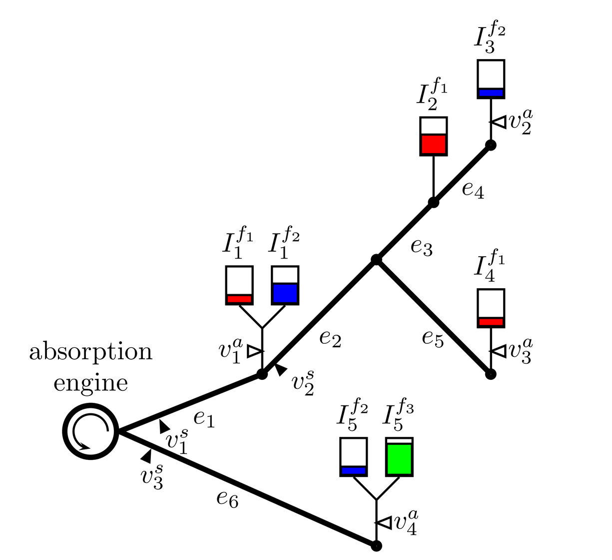
Conditions:

- The same waste fraction for the selected subset of inlets.
- Inlets with waste load above certain limit *should be* selected.
- Minimum air speed needed depends on the distance from selected inlets to the root and fraction type.
- There is a maximum air speed.
- An appropiate sector must be selected for the selected subset of inlets.

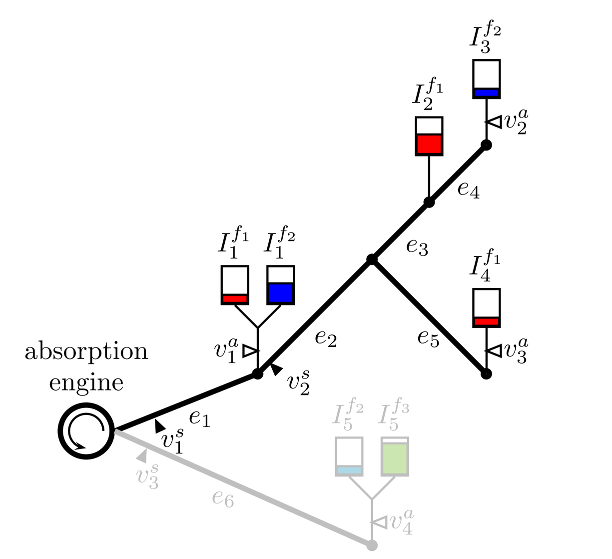
System Dynamics

Example of operation for a selected emptying sequence:

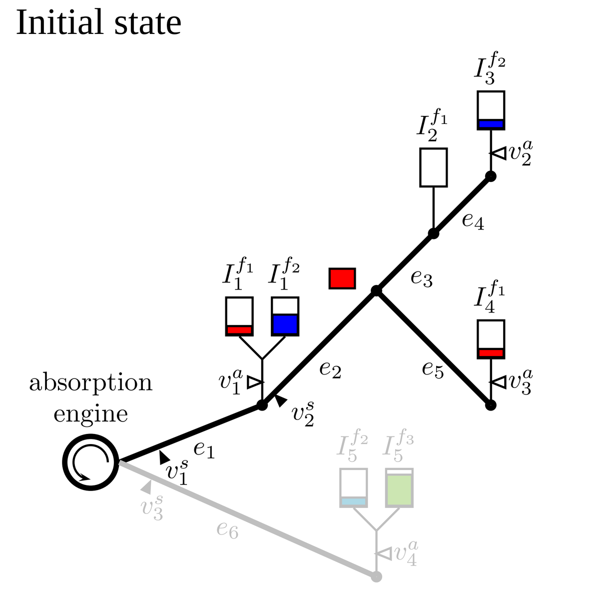
- Selected subset of inlets with fraction f_1: $\{I_2^{f_1}, I_4^{f_1}, I_1^{f_1}\}$, order: $[2, 4, 1]$
- Selected sector: $s_{1,2,\bar{3}}$ (contains the selected inlets)



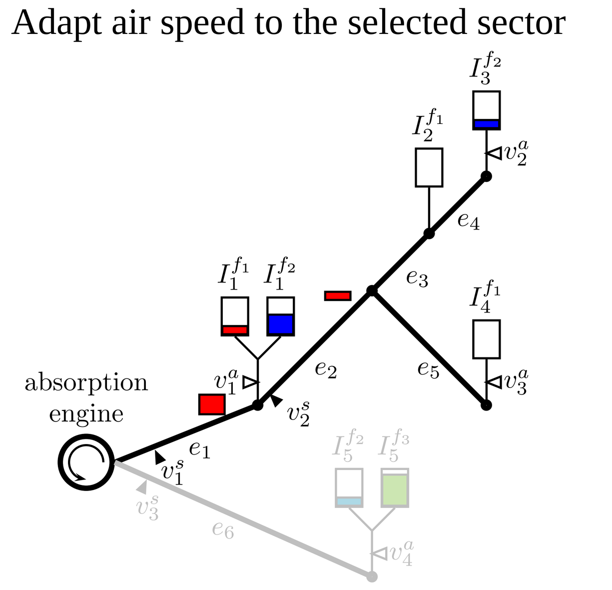
Initial state



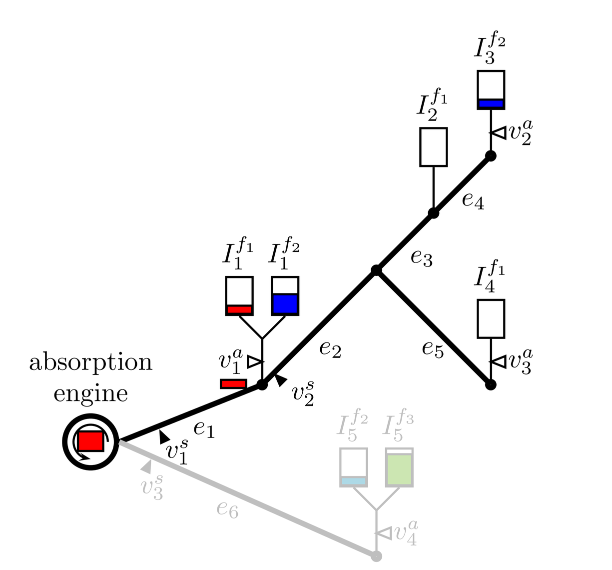
Adapt air speed to the selected sector



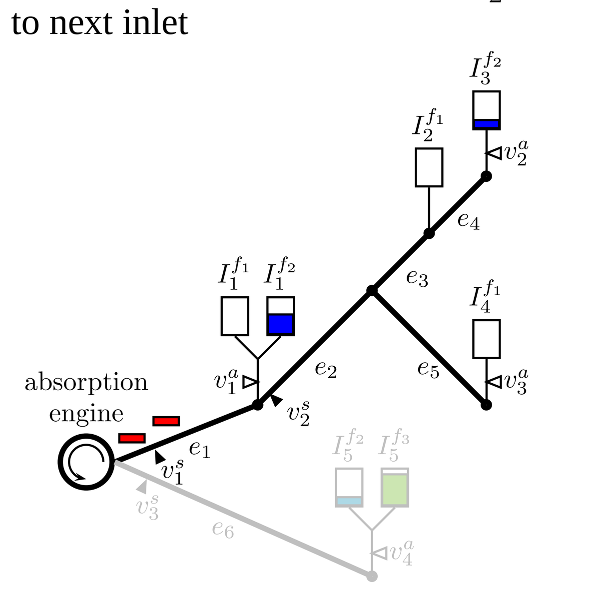
Empty and transport $I_2^{f_1}$ down to next junction



Empty and transport $I_4^{f_1}$ down to next junction and transport waste of $I_2^{f_1}$ down to next inlet



Transport waste of $I_2^{f_1}$ down to the root and transport waste of $I_4^{f_1}$ down to next inlet



Transport waste of $I_4^{f_1}$ down to the root and transport waste of $I_1^{f_1}$ down to the root

Optimization Problem

General Optimization problem

Find a set of emptying sequences and air speed operations, $\{\mathcal{E}_t^{f,s}\} \times \{v_t\}$, $0 \leq t \leq T$, for an operative period of time T, that minimizes the energy cost, $\sum_{t=0}^{T} f_c(t) \cdot \left(E_t^{tr} + E_t^{st}\right)$. The energy cost at time t contains two contributions: the energy needed to adapt the air speed to the new sector (E_t^{tr}) and the energy needed to execute the current emptying sequence (E_t^{st}).

Also, at the end of the period of time T, the residual load of inlet I_i^f should be below an upper bound.

So far, we have been working only with **the problem of selecting an optimal emptying sequence for the state of the system on a given time slot** t.

Problem Modeling and Solving

We use a **Contraint Integer Programming (CIP)** model for the problem, where we use both linear constraints and logical constraints. We compute a total order for all the inlets in the system, and this ordering is used for any selected subset of inlets.

Variables:

- Boolean variables for:
  - Sector selection: one variable for each different sector
  - Inlet selection: one variable for each different (inlet,fraction)
  - Fraction selection: one variable for each different fraction
- One real valued variable for the operational air speed.

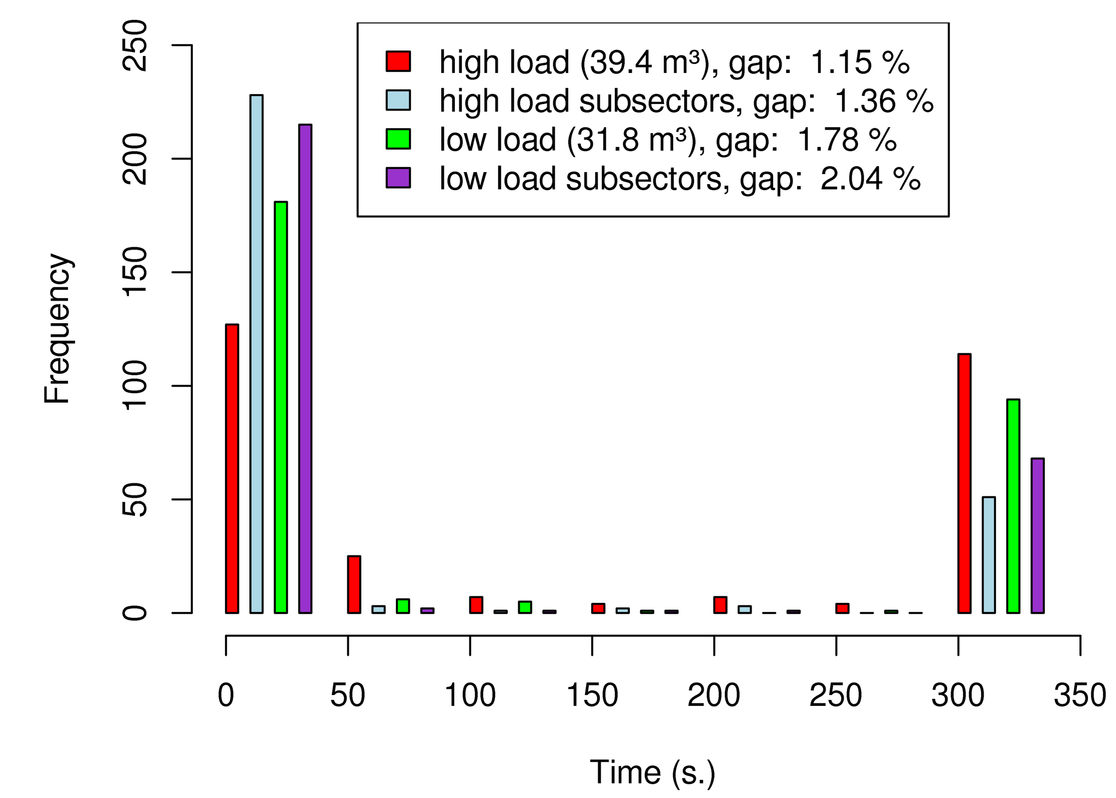
Constraints that the solution must satisfy:

- At most one active sector an at most one active fraction.
- Maximum transfer load per fraction below the plant operational limit.
- Operational air speed between the minimum needed for the selected inlets and the maximum operational speed.

Our objective function is to **minimize the energy consumption** plus the **penalty** for leaving unloaded inlets above a threshold of their capacity. The closer the load of an inlet to its capacity, the higher we set its penalty in the objective function.

Solving Real World Instances

Results obtained with SCIP solver, when solving problem instances obtained from data sets from a real waste collection plant.



We are able to solve even very critical scenarios within a few seconds. Some cases needed 5 minutes to be solved, but they can be solved with very **good suboptimal solutions** in seconds.

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