Multiscale Production Routing in Multicommodity Supply Chains

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Competitive supply chains require good **coordination of production and distribution operations**

- Motivated by the complexity in **industrial gas supply chains**

- **Production:**
  - Highly integrated production process
  - Restrictions on transitions
  - Time-sensitive electricity prices

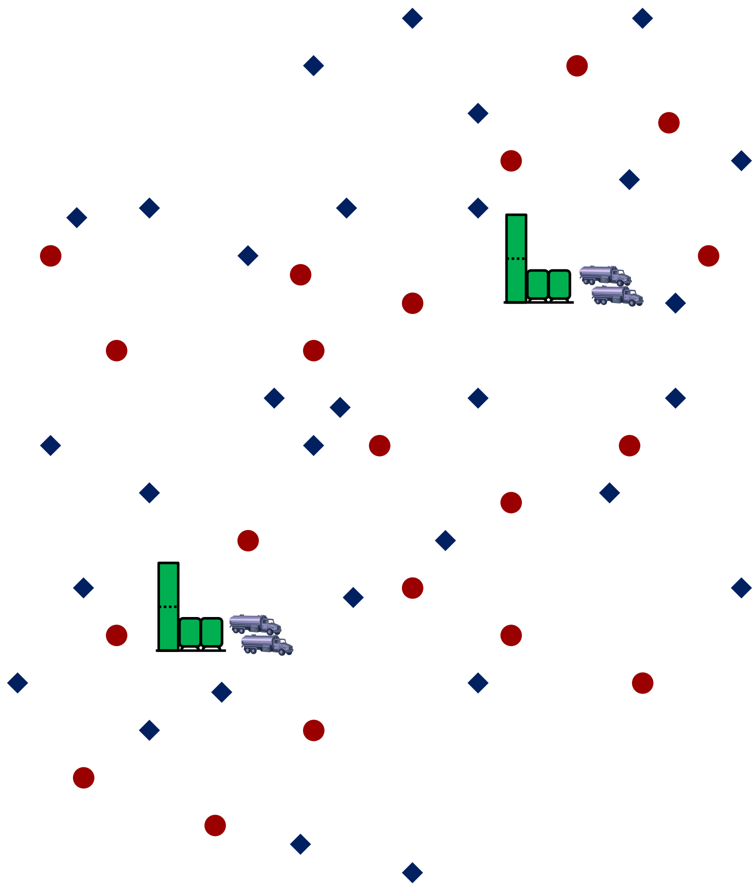
Requires detailed scheduling model

- **Distribution:**
  - Large network with hundreds of customers
  - Many customers can be visited by multiple plants
  - Vendor-managed inventory (VMI)

Have to consider routing and customer inventory

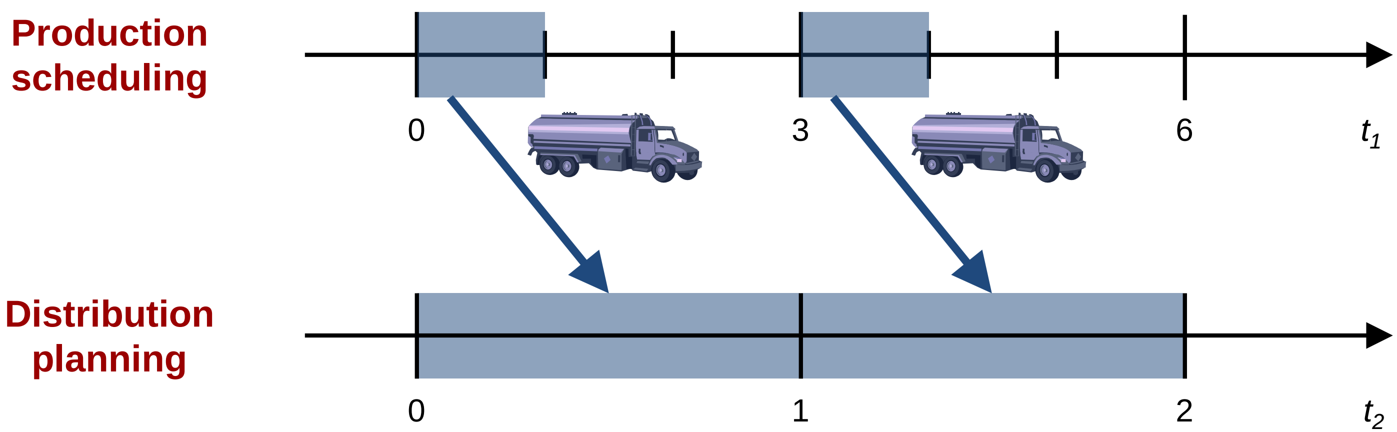
Problem Statement

- **Given:**
  - Set of plants $p \in P$ producing a set of products $i \in I$
  - Product-specific customers $c \in C_i$
  - Product-specific homogeneous vehicle fleets assigned to each plant
- **Determine:**
  - Detailed production schedule involving decisions regarding operating modes, production rates, and inventory
  - Tactical distribution plan involving plant-to-customer allocation decisions
  - No detailed routing decisions required, but need to guarantee feasibility in subsequent inventory routing problem



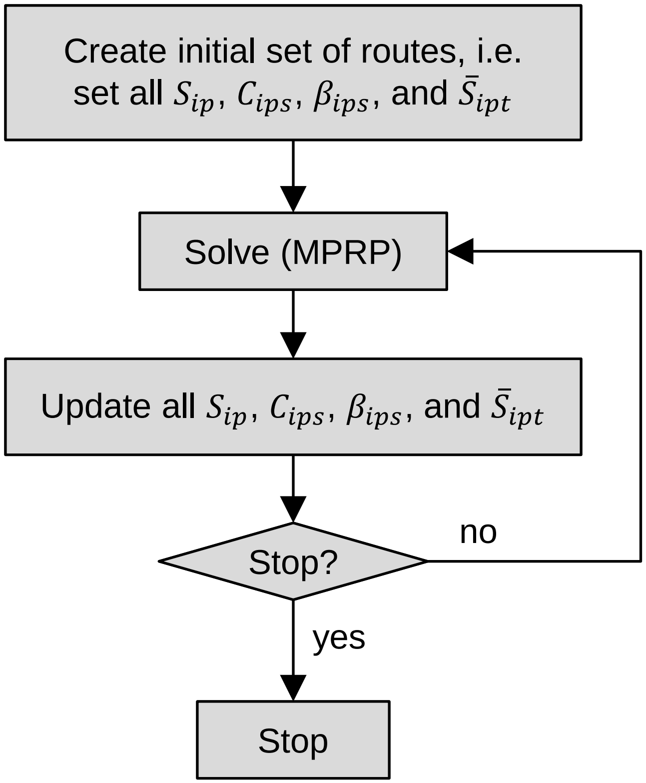
We propose an MILP formulation with two time scales

- Mode-based scheduling model with constraints on transitions[1]
- **Set-partitioning routing formulation[2]**
  - Select optimal routes from the set of possible routes, S_{ip}
  - Each route $s \in S_{ip}$ is defined by the set of customers that can be visited, C_{ips}, and the fixed distribution cost, β_{ips}
- **Two different time scales:**



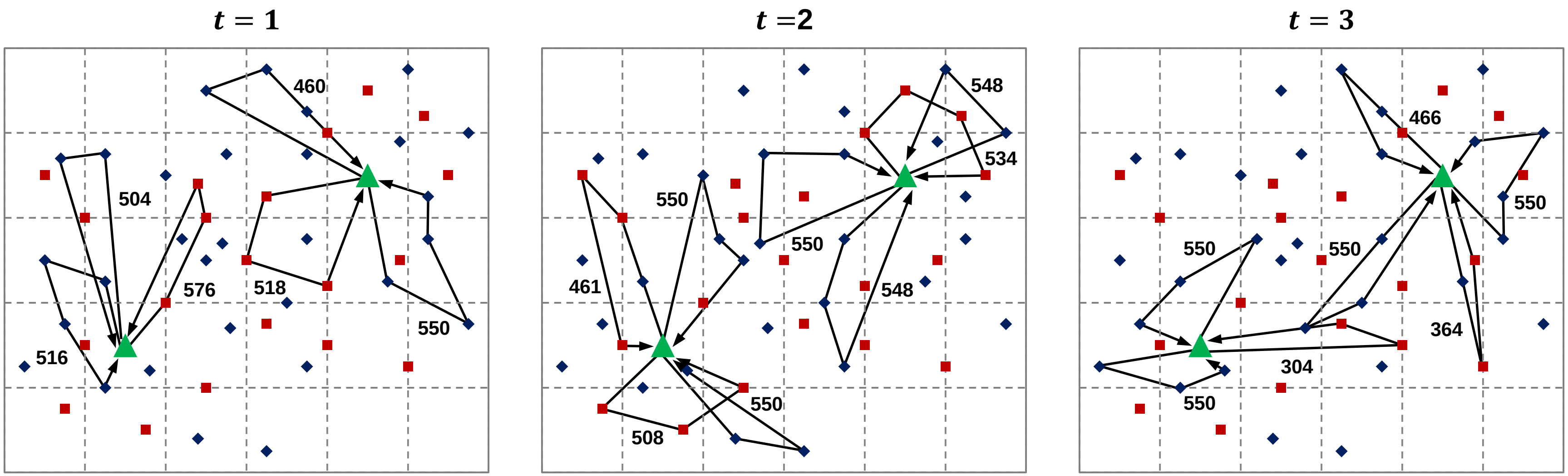
1. Z. et al. (2016). *Computers & Chemical Engineering, 84,* 382-393.
2. Marchetti et al. (2014). *Computers & Chemical Engineering, 69,* 39-58.

For solving large-scale instances, we apply an **MILP-based heuristic with dynamic route generation**



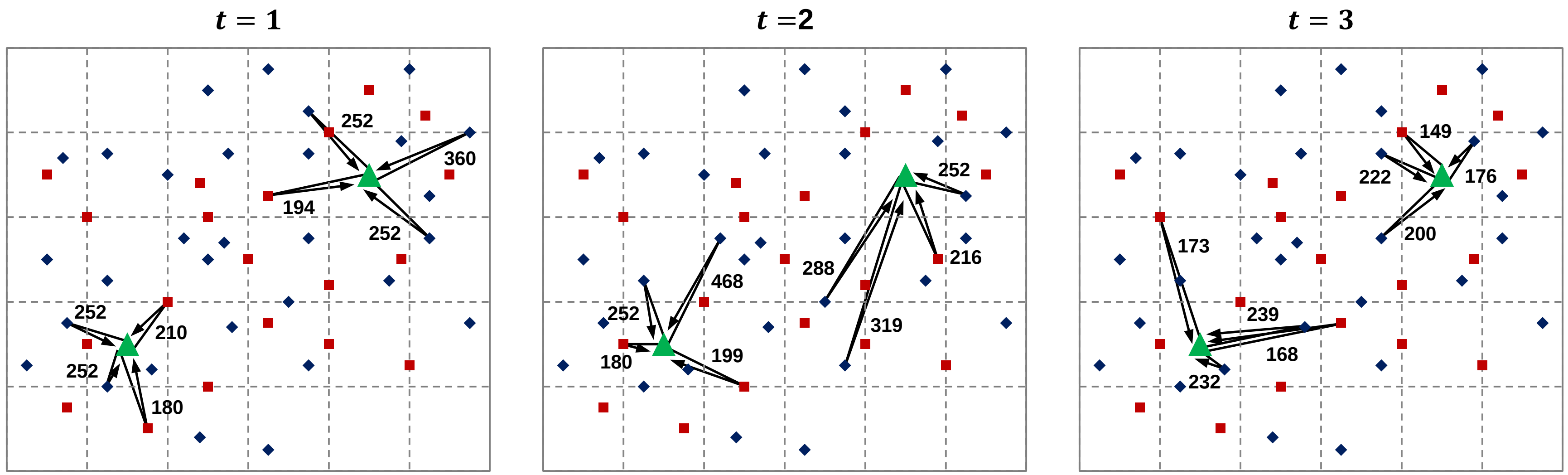
- Initialize with single-stop routes
- Solve (MPRP) to consider coordination between production and distribution decisions
- Identify new candidate routes based on local analysis, update set of possible routes
- Stop if time limit reached, no improvement made in multiple iterations, or no new routes generated
- **Main drawback: Cannot guarantee convergence to optimal solution**

Illustrative Example: Optimal Solution



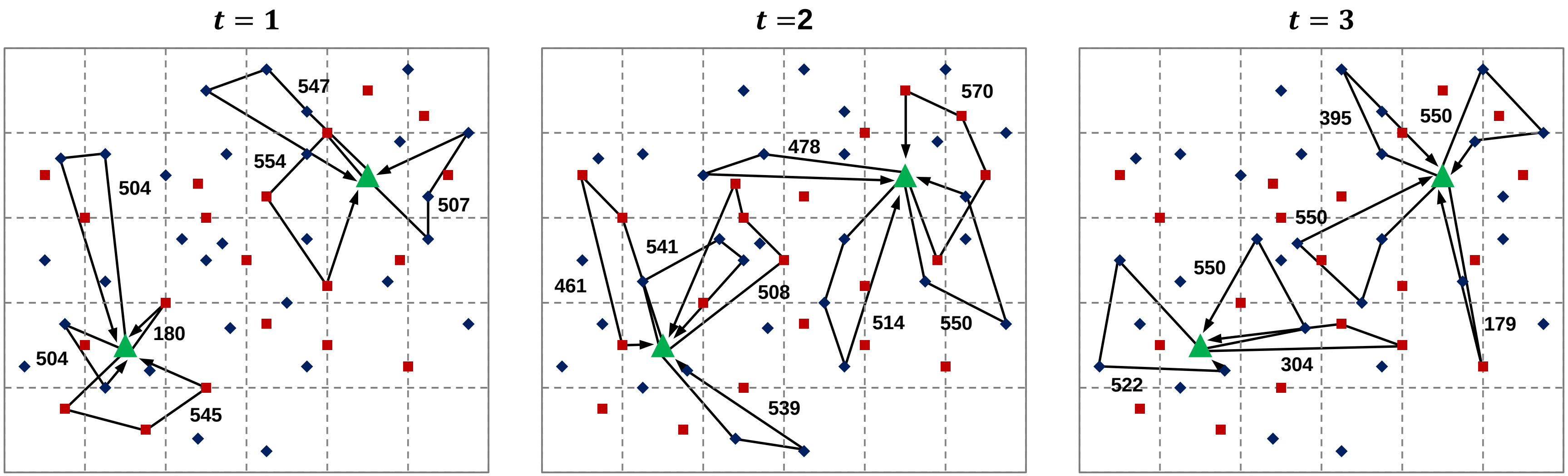
Total cost	41,646
Production cost	10,776
Purchasing cost	3430
Distribution cost	27,192
Inventory cost (plants)	95
Inventory cost (customers)	152

Illustrative Example: Iteration 1



Total cost	70,948
Production cost	8333
Purchasing cost	47,098
Distribution cost	12,288
Inventory cost (plants)	124
Inventory cost (customers)	106

Illustrative Example: Iteration 3



Total cost	42,796	41,646
Production cost	10,672	10,776
Purchasing cost	4598	3430
Distribution cost	27,276	27,192
Inventory cost (plants)	89	95
Inventory cost (customers)	161	152

Industrial Case Study

- **Problem specifications:**
  - 4 products (2 storable, 2 nonstorable), 2 plants, 238 customers
  - 4-week time horizon (168 level-1 time periods, 56 level-2 time periods)

	Heuristic One-Time Route Generation[1]	Historical Routes + Multiplant Assignment	Heuristic Dynamic Route Generation
# of Routes	263,928	173,544	9170*
# of Constraints	1,092,706	809,585	126,192*
# of Cont. Variables	838,232	645,760	131,344*
# of Bin. Variables	267,994	177,610	4066*
# of Iterations	1	1	4
Solution Time [h]	12	12	1
Objective Value	**370**	**100**	**91**
Lower Bound	267	84	

* largest case

1. Marchetti et al. (2014). *Computers & Chemical Engineering, 69,* 39-58.

Novelty and Readiness for Industrial Applications

- **Novelty of the work:**
  - Developed **multiscale** production routing formulation for multicommodity supply chains with **complex production facilities**
  - Proposed **MILP-based heuristic** solution method
  - Applied proposed framework to industrial-scale test case

- **Readiness for industrial implementation:**
  - Proposed framework will be tested on more real-world cases and compared with existing state-of-the-art solutions