Integrated Model for Production-Distribution Coordination in an Industrial Gases Supply-chain

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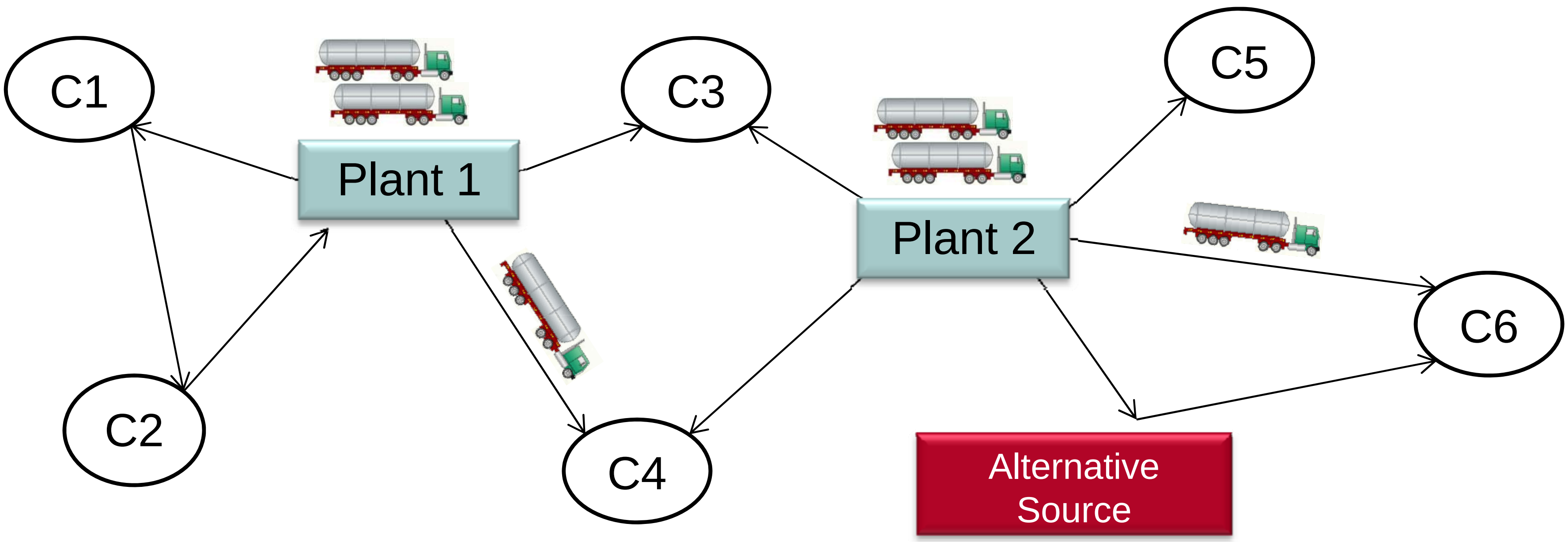
Background and Motivation

Industrial Gases Supply-Chain

- Multiple Plants and Multiple Products *(LIN, LOX etc.)*
- Over-the-fence, call-in and distributed customers *(some shared customers)*
- Storage facilities at production sites and customer locations



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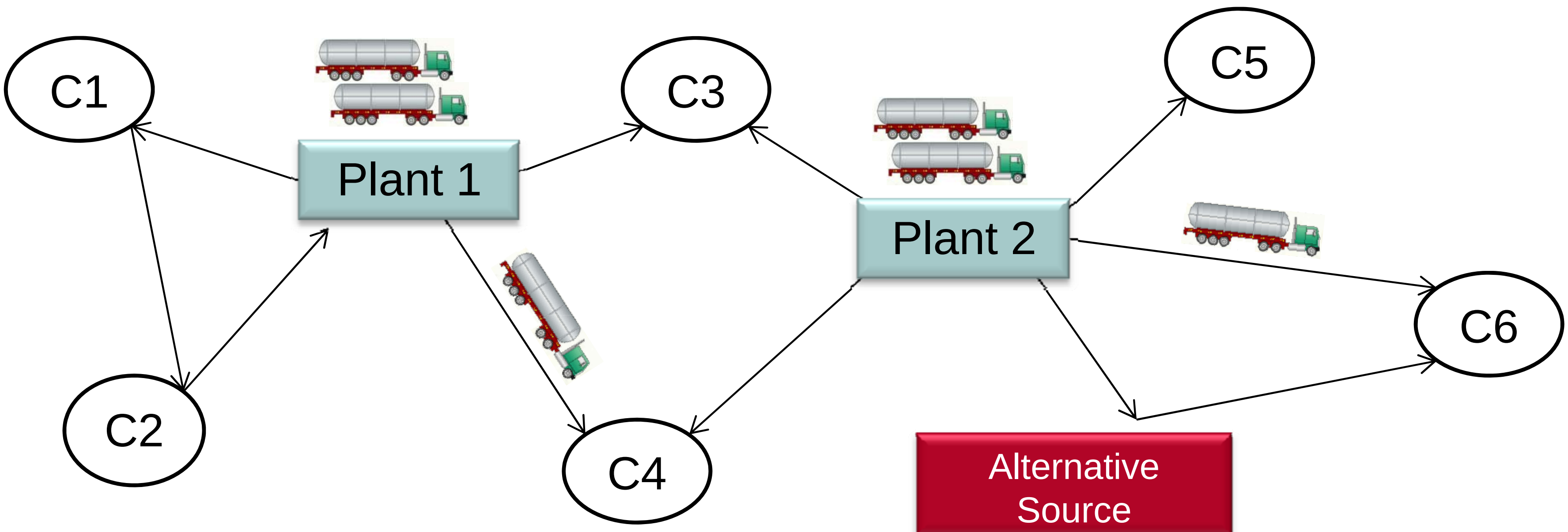

Goal

To quantify and access the savings associated with the
Production-Distribution Coordination at Operational Level
using an approximate model

Problem Statement and Main Assumptions

Given

- **Plants , Operating Modes and Respective Production limits**
- **Daily Electricity Prices (off-peak and peak)**
- **Customers and their demand/consumption profiles**
- **Max/Min inventory at production sites and customer locations**
- **Alternative sources and product availabilities**
- **Distances, Truck availability at the plants and truck capacities**
- **Fixed Planning Horizon (usually 1-2 weeks)**

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Decisions in each time period t

- **Production rates at each plant**
- **Inventory level at customer location and plants**
- **How much product to be delivered to each customer through which route**

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Objective Function

- Minimize total production and distribution cost over planning horizon

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Main Assumptions – Distribution Side

- Two time periods per day (peak and off-peak) are considered
- Trucks do not visit more than 4 customers in a single delivery

Mathematical Model (MILP)

Objective **Minimize total Production and Distribution Costs**

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Production Cost = Fixed Start-up cost
+ Variable production cost

Constraints on Production Side

- **Min/Max Production Capacity Constraints in each mode of operation**
- **Logic Constraints for switching between various modes of operation**
- **Max/Min Inventory limits at the production sites**
- **Plant Inventory Balance Constraints**
- **Demand satisfaction for pick-up customers**

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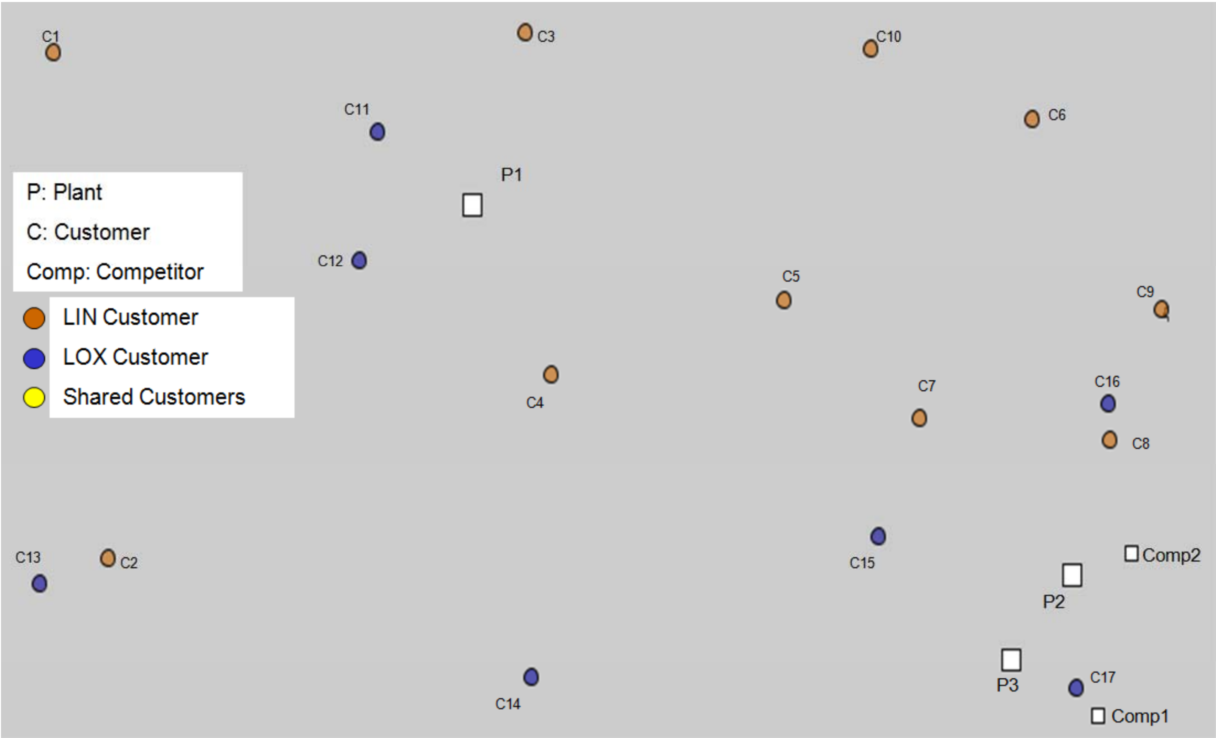
Distribution Cost = Cost of deliveries by trucks + purchases from competitors

Constraints on Distribution Side

- **Max/Min Inventory limits at the customer locations**
- **Customer Inventory Balance Constraints**
- **Truck Capacity constraints**
- **Material balance constraints for product pick-up and delivery points**
- **Max product purchase limit from competitor sources**

Small Test Case

- 3 Plants, 2 main products (LIN, LOX)
- 3 modes for each plant and respective capacities (Hi LOX, Hi LIN, shut-down)
- 17 customers (truck delivery), 42 pick-up customers, 2 alternative sources
- 14 time periods (peak and off-peak), 20 trucks (10 for LIN, 10 for LOX)
- Demands, min/max inventory, distances, electricity prices etc.



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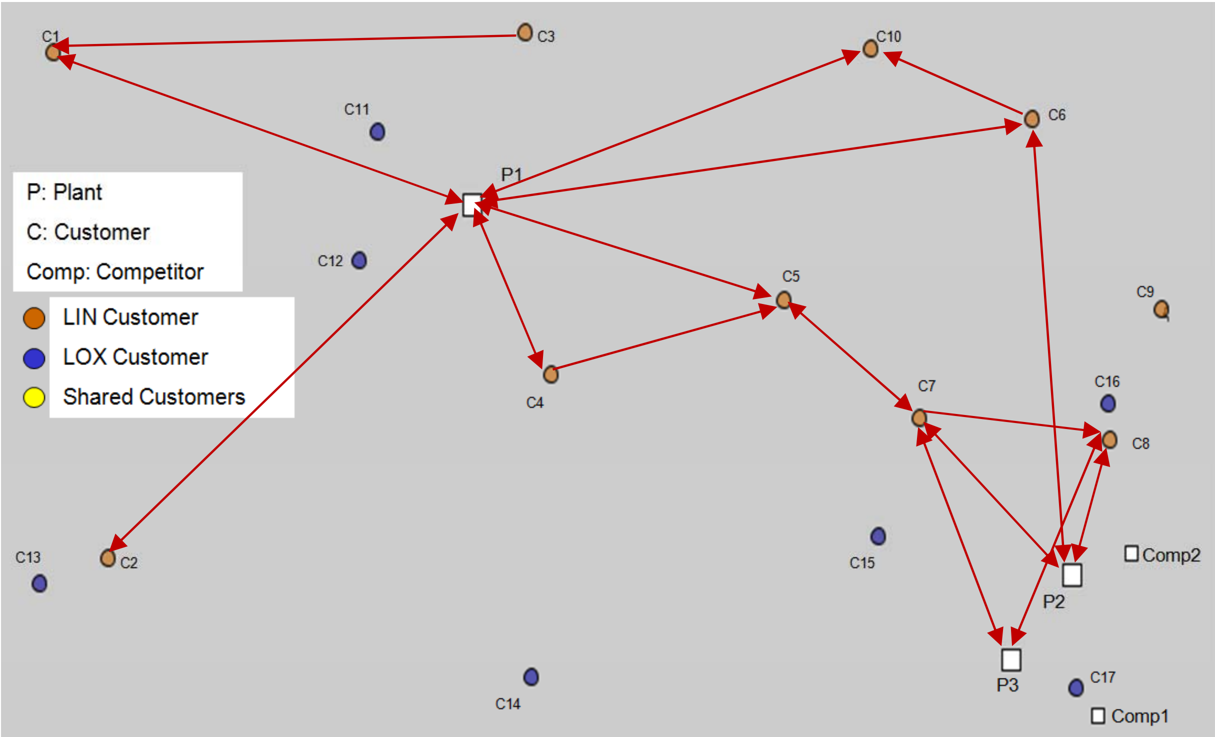

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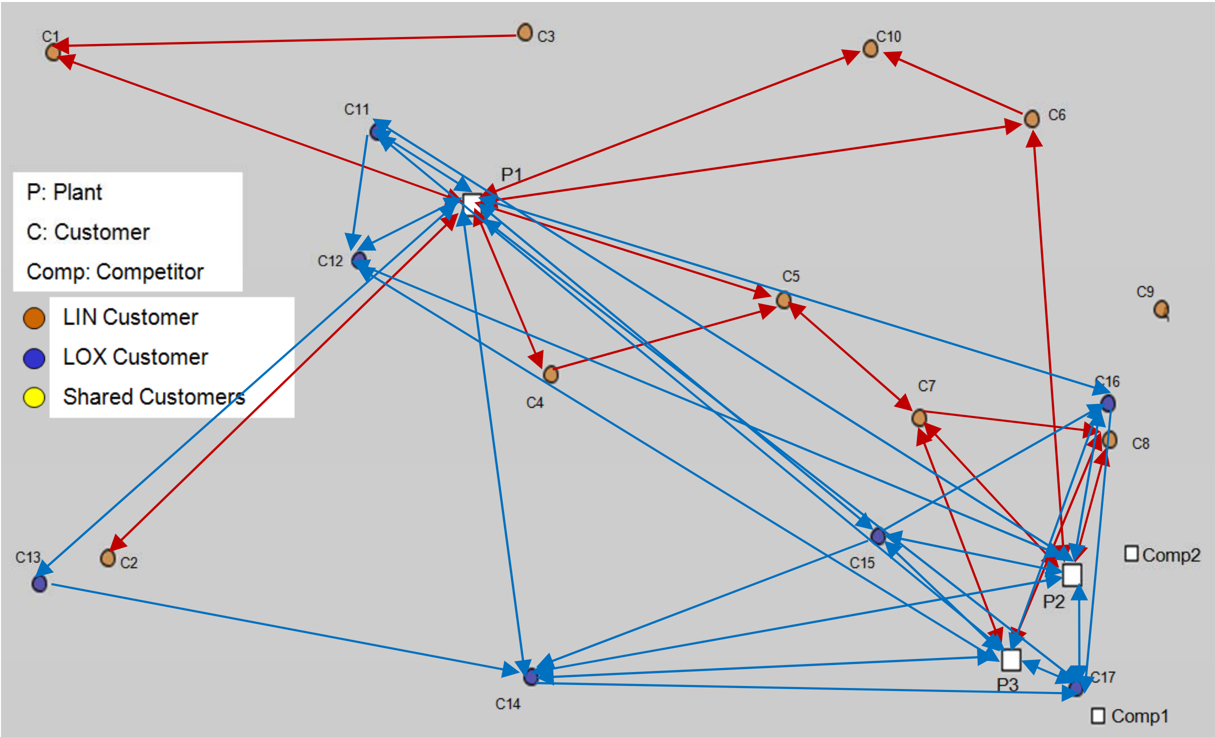

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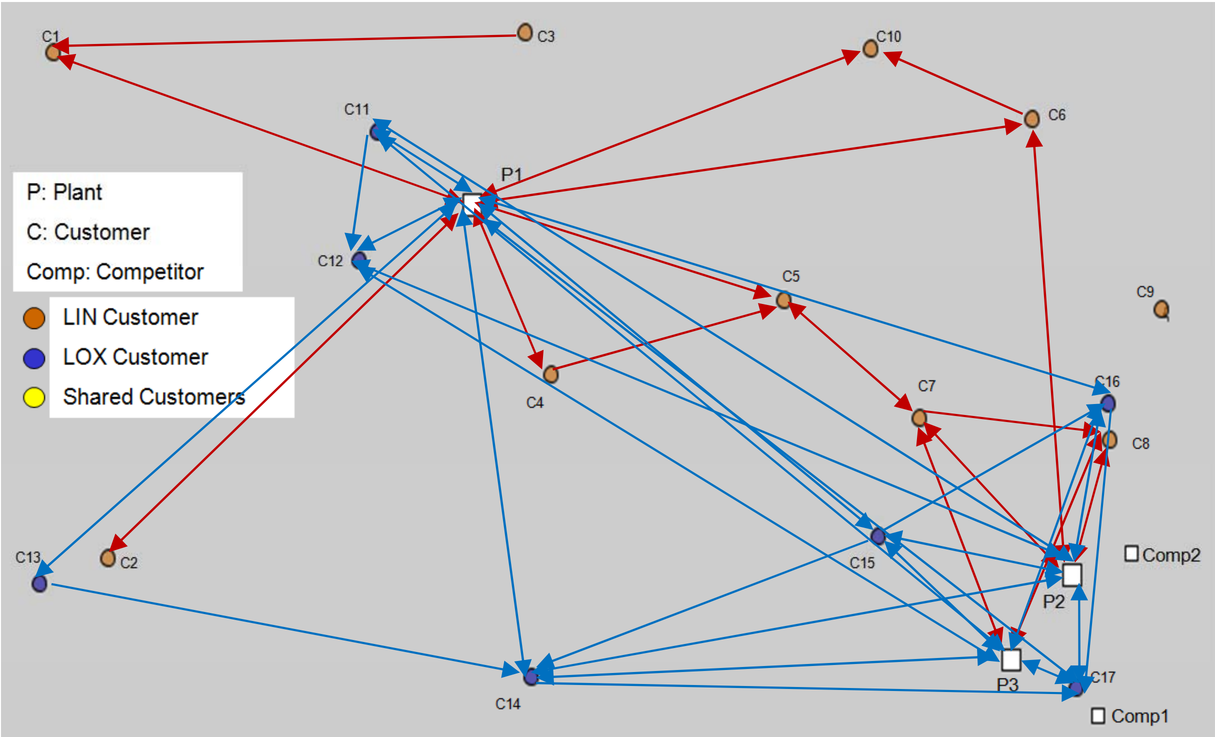

46 routes proposed

Small Test Case – Route Selection

The selection of the set of available routes is also a critical aspect to be considered.

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The same test case is solved but now using different sets of proposed routes.
Selection of routes based on plant assignments and ranking of minimum route distances.

- Route Set 1: *Initial 46 routes (10 shared customers)*
- Route Set 2: *65 routes (same plant-customer associations of Set 1)*
- Route Set 3: *73 routes (4 additional LIN customers at Plant 3, 14 shared customers)*
- Route Set 4: *249 routes (all customers served by all plants)*

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Distribution of routes per product and plant

Product	Plant	Set 1	Set 2	Set 3	Set 4
LIN	Plant 1	10	13	13	55
	Plant 2	5	9	9	55
	Plant 3	3	3	11	55
	Subtotal	18	25	33	165
LOX	Plant 1	10	14	14	28
	Plant 2	9	13	13	28
	Plant 3	9	13	13	28
	Subtotal	28	40	40	84
Total		46	65	73	249

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Route Set 4 = same routes for every plant (all customers)

Model Size and Computational Performance

Model size increases considerably with the number of routes proposed.

		Route Set 1	Route Set 2	Route Set 3	Route Set 4
Model Size	Binary variables	2,884	3,836	4,060	12,264
	Continuous variables	4,901	6,413	6,777	18,649
	Constraints	6,312	7,684	8,034	19,304
CPU results Time limit 10 min.	Nodes	190070	149026	52297	16155
	Iterations	2855097	1884368	1218652	615706
	Relative gap	1.6%	1.3%	1.4%	1.7%

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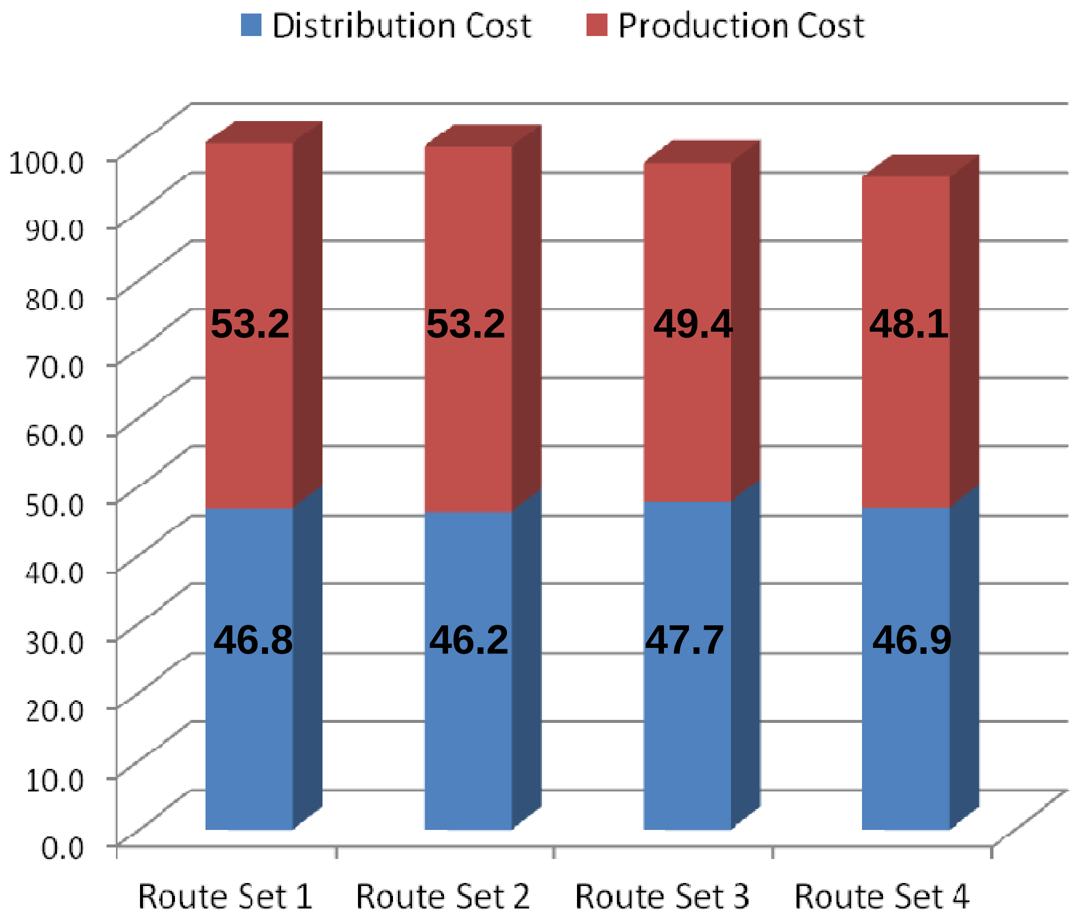
The model is able to find good solutions with small relative gaps (< 2%) in few CPU sec., even with large increases of the model size (and binary vars.)

However, the complexity of the problem is huge and the relative gap decreases slowly when more CPU time is provided.

Impact of Route Selection on Total Cost

Economic benefits obtained through better selection of proposed routes.



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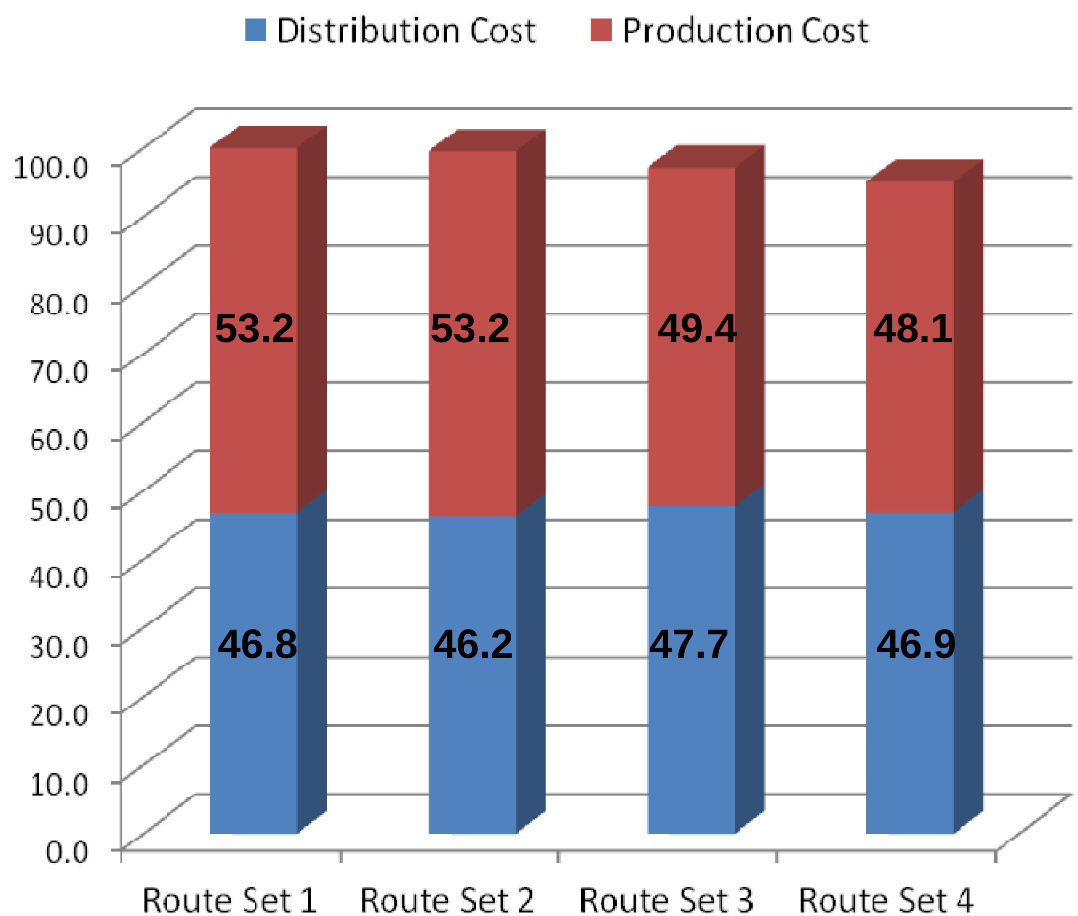
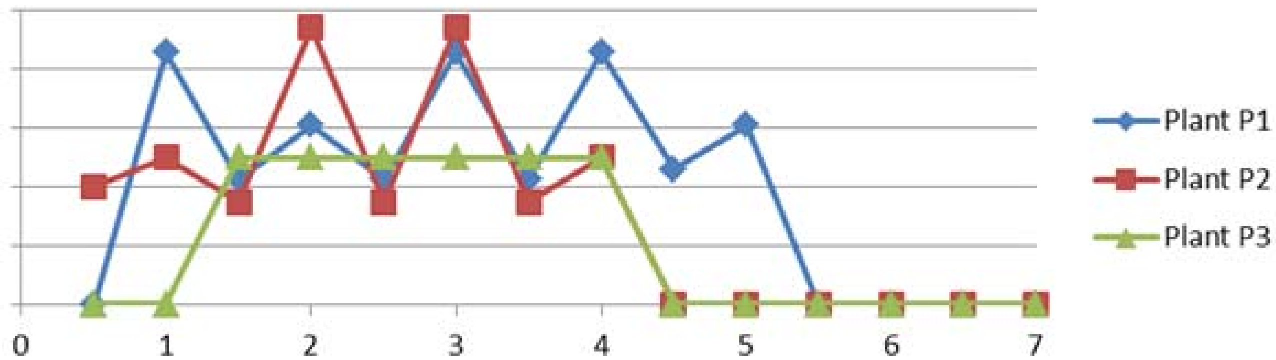


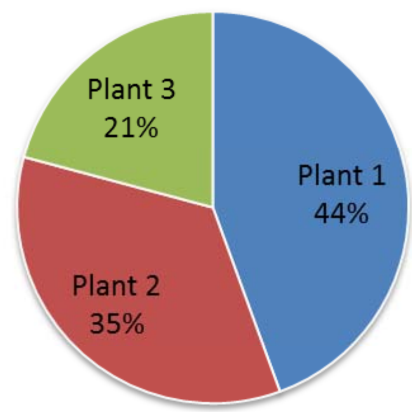
Savings	**(reference)**	**0.5 %**	**2.8 %**	**4.9 %**

Impact of Route Selection on Total Cost

Production load shifts to plant P3 because of lower electricity prices

Route Set 1 – LIN production rates





Production Cost % for each plant using Route Set 1

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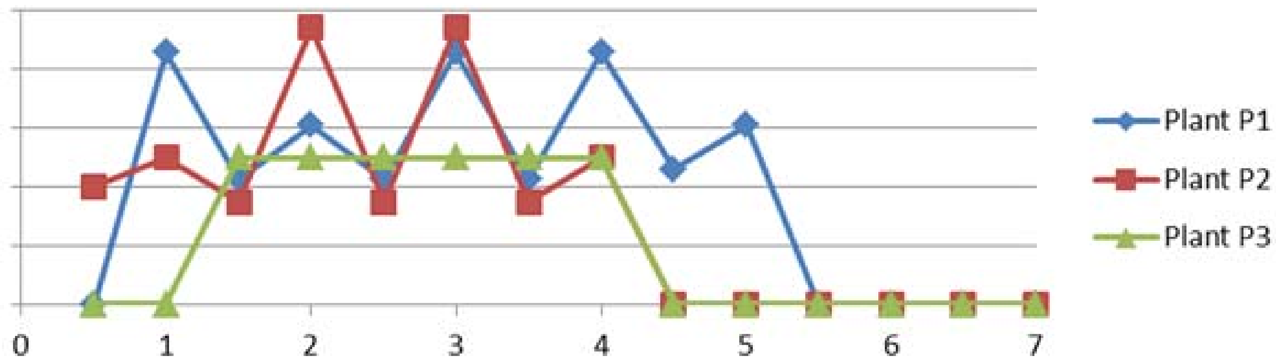
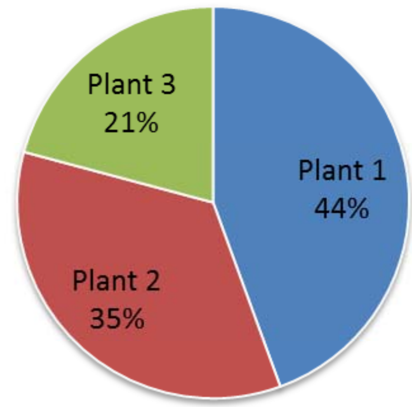
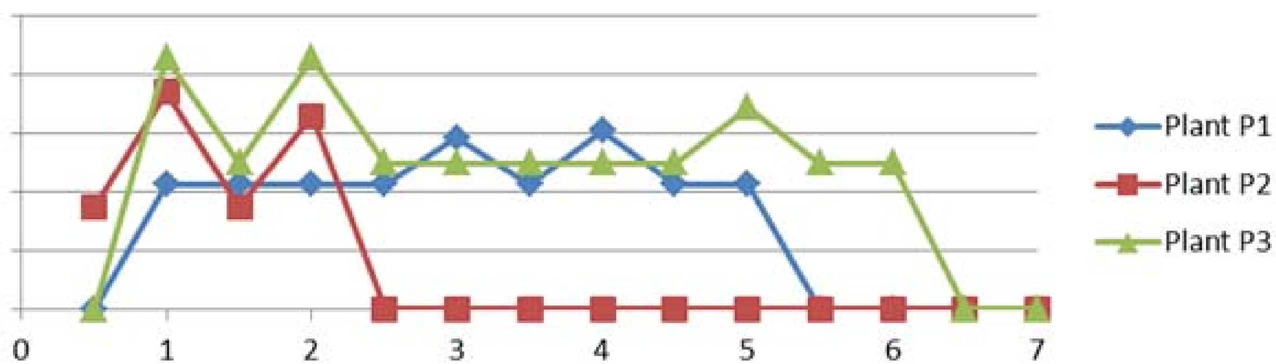
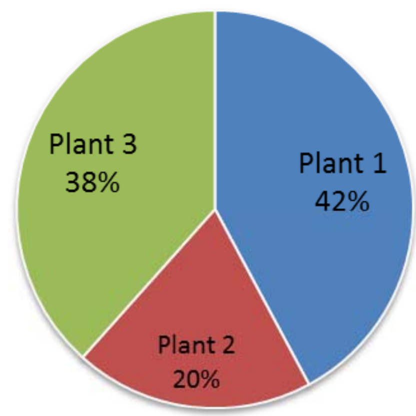




Production Cost % for each plant using Route Set 1

Route Set 4 – LIN production rates





Production Cost % for each plant using Route Set 4

Conclusions and Future Work

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- Proposed Simultaneous Production-Distribution MILP Model for optimal operational planning of industrial gases supply-chain
  - Multiproduct and multi-plant
  - Good quality solutions obtained with short CPU times
- Significant potential savings (~10%) can be obtained with a better production-distribution coordination.
- Plant-customer association and selection of routes are critical aspects to reduce the total cost of production and distribution (savings ~5%).

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Future work

- Model scalability: larger scale test cases *(work in progress)*
  - Standalone depots on distribution side
  - Clustering of customers
    - Cluster-to-cluster routes
    - Internal distribution cost inside clusters
- Improvements on Production Model