Aalto-yliopisto
Perustieteiden korkeakoulu

Optimisation for biodiesel production and analysis of capillarity expansion of suppliers

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15.06.2022

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Biodiesel

- Renewable, environmentally friendly
- Effect on food price
- Raw materials for biodiesel production
  - Animal fats (AF)
  - Waste cooking oils (WCO)
  - PFAD

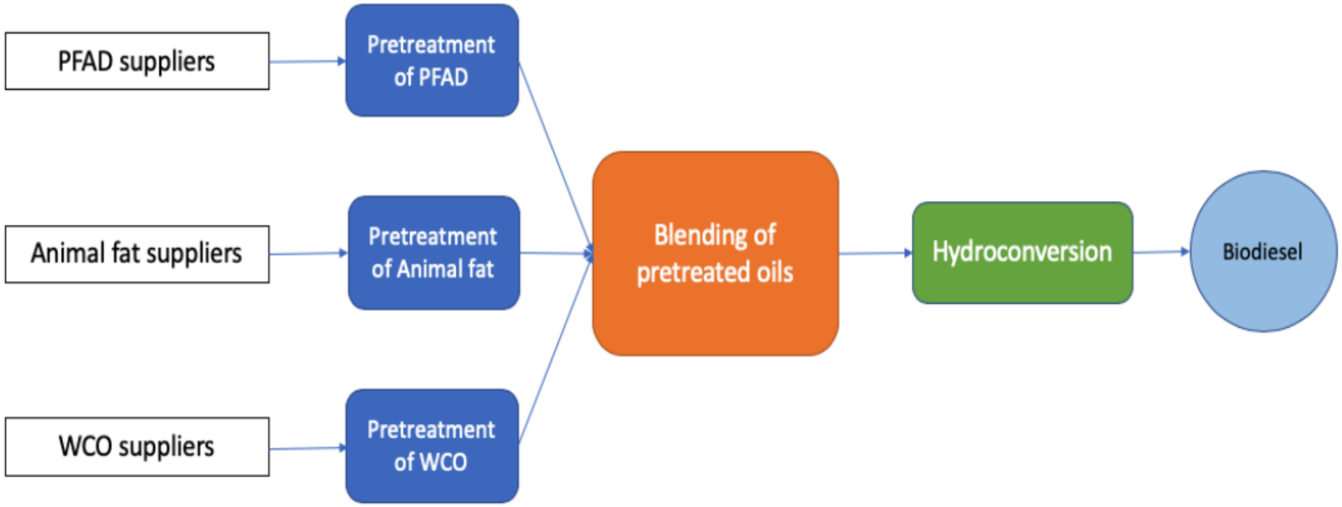
The problem

- Supply chain is complex
- The raw materials (biomass) come from many small suppliers
- Simple linear models are not accurate
  - Overbuying, inefficiency

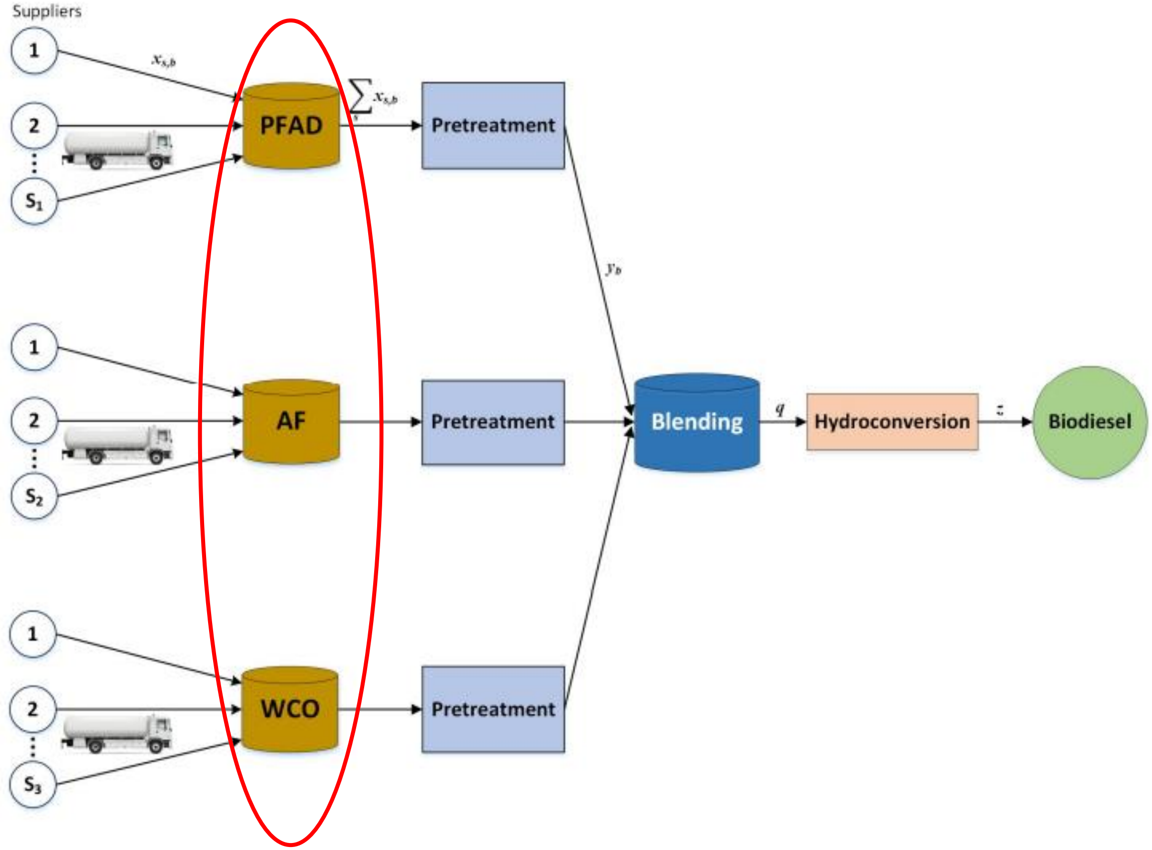
- Optimisation of the supply chain needed for an optimal purchase plan

Background

- Previous bachelor thesis with simple model



Supply chain model



Optimisation problem

- Minimise costs while satisfying the total demand
- Nonlinear and non-convex
  - Bilinear terms in equality constraints (3), (6)
- Computationally challenging
  - Nonlinear vs NMDT-linearised model

Mathematical formulation

$$
\begin{aligned}
\text{minimize} \quad & \sum_{s \in S_b} \sum_{b \in B} (CB_b + TC_{s,b} + PC_b) x_{s,b} + HC \times q && && (1) \\
\text{subject to:} \quad & \underline{X}_{s,b} \leq x_{s,b} \leq \overline{X}_{s,b}, && \forall s \in S_b, b \in B && (2) \\
\rightarrow \quad & \sum_{s \in S_b} \rho_{s,b} x_{s,b} = \sum_{s \in S_b} v_b x_{s,b}, && \forall b \in B, && (3) \\
& \underline{V_b} \leq v_b \leq \overline{V_b}, && \forall b \in B, && (4) \\
& y_b = \sum_{s \in S_b} \alpha_b x_{s,b}, && \forall b \in B, && (5) \\
\rightarrow \quad & \sum_{b \in B} v_b y_b = \rho q, && && (6) \\
& \underline{\rho} \leq \rho \leq \overline{\rho}, && && (7) \\
& \sum_{b \in B} y_b = q, && && (8) \\
& \alpha q = z, && && (9) \\
& z \geq D_{tot}. && && (10)
\end{aligned}
$$

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Purpose of the thesis

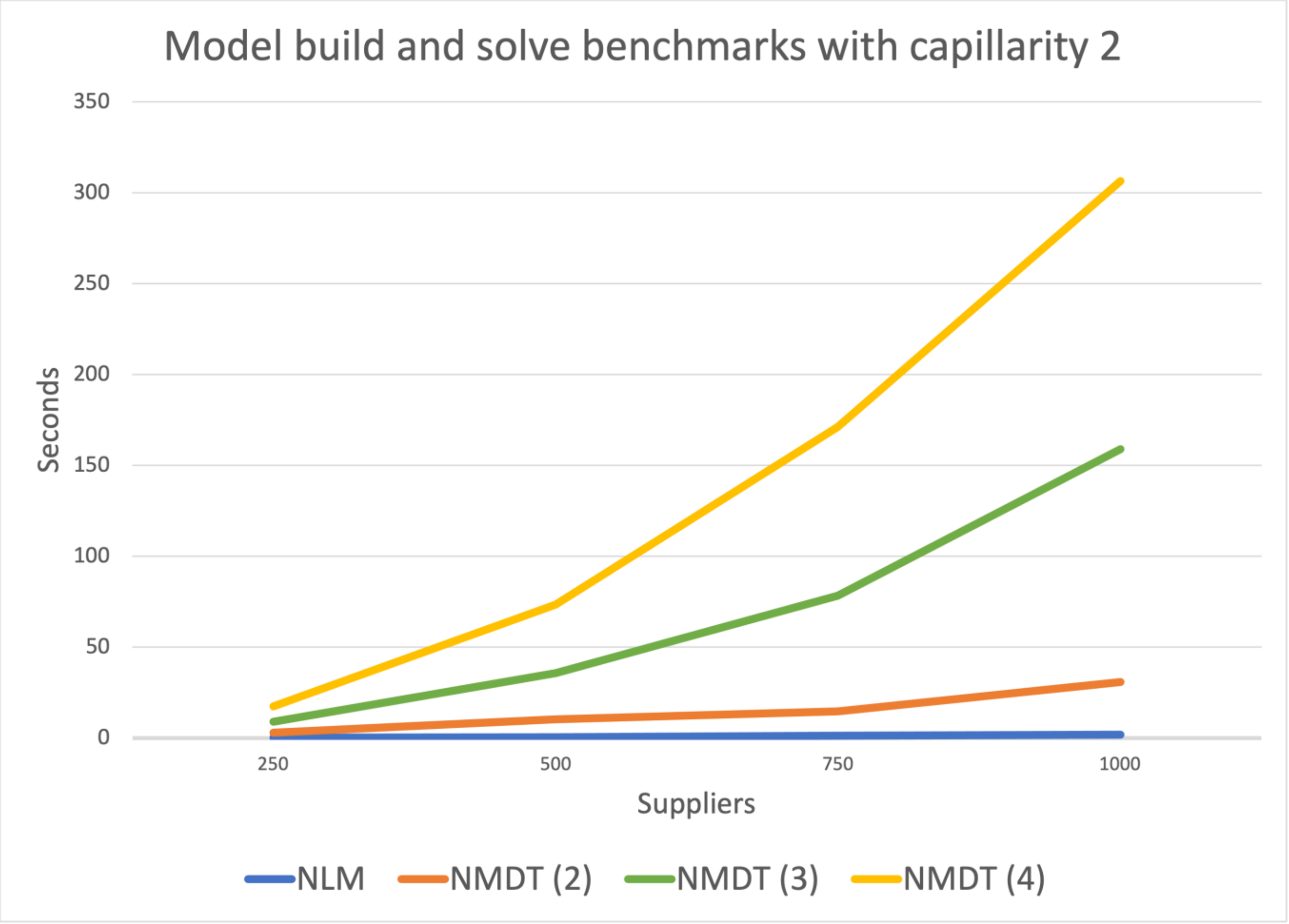
- Determine the best model and solver for precision and efficiency
  - Nonlinear model with Gurobi’s nonlinear solver
  - NMDT-linearised model with Gurobi’s linear solver
- Examine the effects of capillarity expansion of WCO suppliers
- Analysis of results and comparison to previous models

Case study

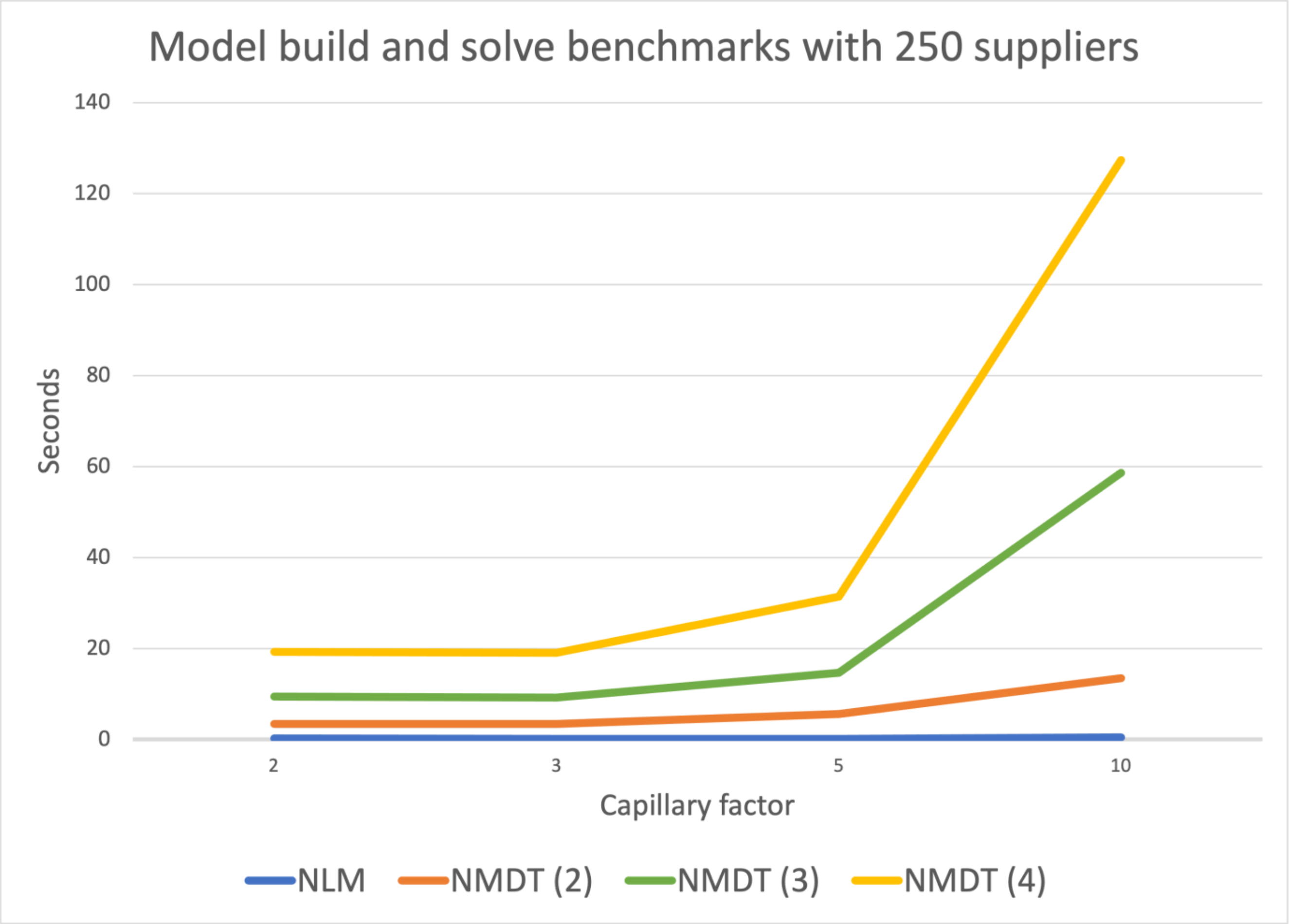
- Synthetic supply data generated with means and variances based on historical data
  - Transport distances, minimum and maximum production capacities, property values of biomasses

- Transform nonlinear model into NMDT-linearised model and perform benchmarks
- Expand WCO suppliers into many small suppliers and update data (capillarity)

Model efficiency benchmarks



Model efficiency benchmarks

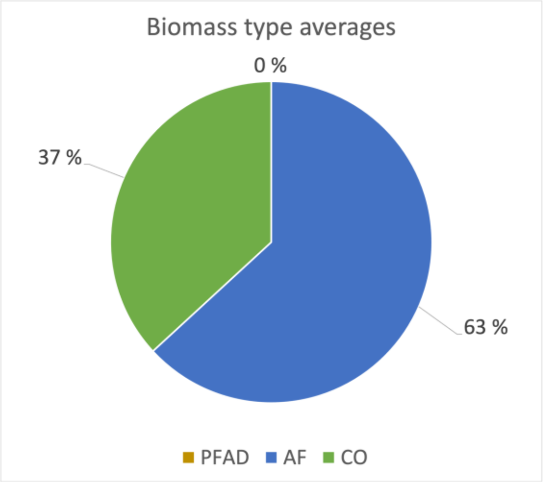


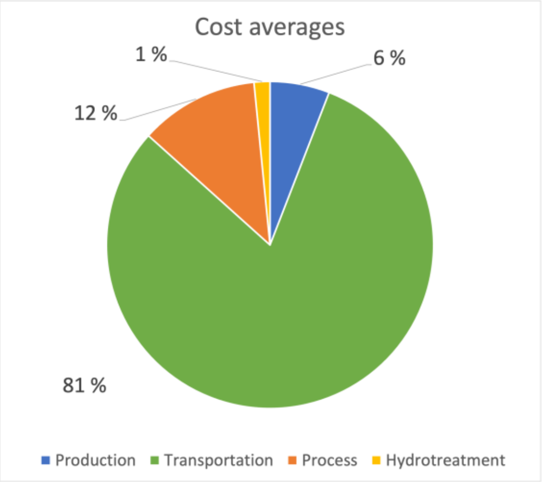
Final model

- 1000 suppliers
- 100 instances
- WCO expansion factors 2, 10
- Sweden/Germany: PFAD not allowed

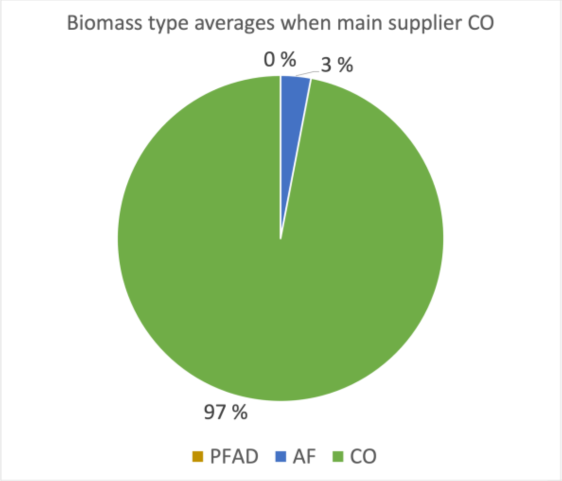
Biomass purchase plan with 1000 suppliers and capillarity expansion factor 2

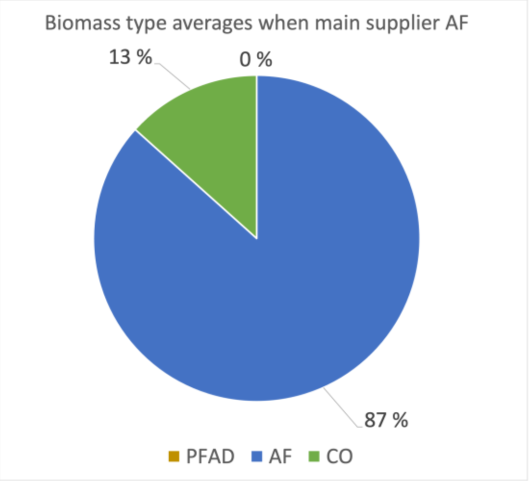
100 instances





29 instances

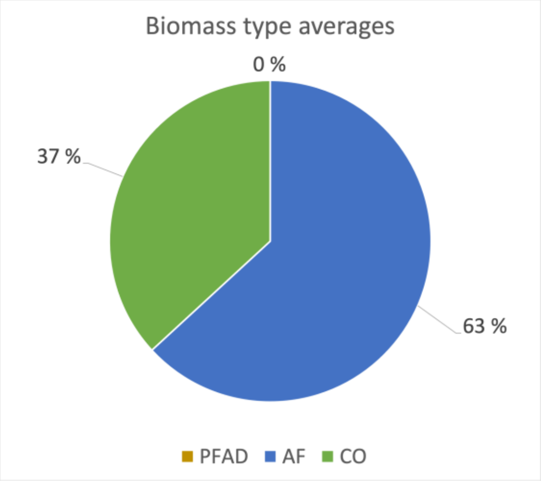


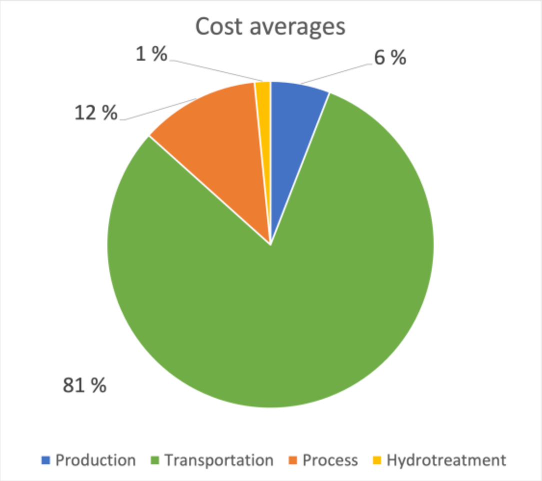


71 instances

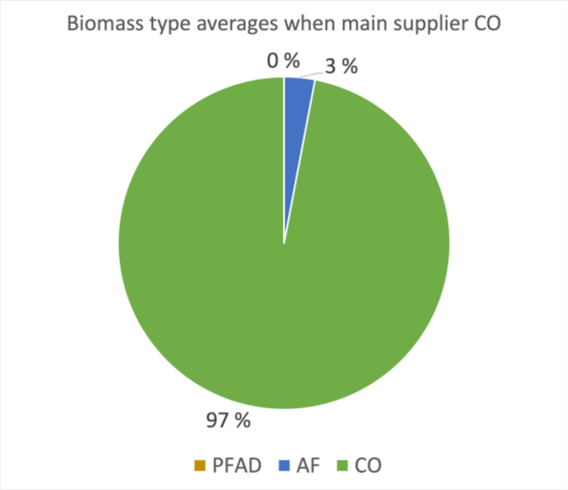
Biomass purchase plan with 1000 suppliers and capillarity expansion factor 10

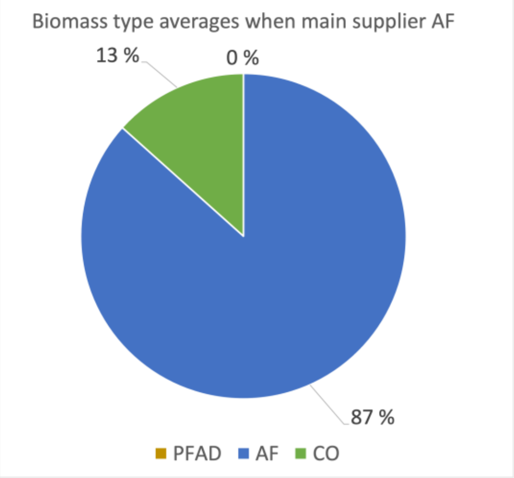
50 instances





19 instances





31 instances

Results

- 1000 suppliers with capillarity expansion factor 2

	AF	WCO	Total biomass	Quality of blend	Production cost	Transportation cost	Total cost
All instances (100)	1 097,2	640,3	1 737,5	0,86	598 950,6	8 215 500,0	10 174 100,0
CO instances (29)	50,4	1 632,0	1 682,4	0,85	428 151,4	12 375 862,1	14 110 344,8
AF instances (71)	1 524,8	235,2	1 760,0	0,87	668 713,6	6 516 197,2	8 566 338,0

- 1000 suppliers with capillarity expansion factor 10

	AF	WCO	Total biomass	Quality of blend	Production cost	Transportation cost	Total cost
All instances (50)	979,9	751,4	1 731,3	0,87	579 807,6	8 594 462,9	10 526 809,5
CO instances (19)	41,7	1 640,2	1 681,9	0,85	426 739,0	12 218 735,8	13 949 426,9
AF instances (31)	1 554,9	206,7	1 761,6	0,88	673 623,9	6 373 134,3	8 429 076,3

Conclusions

- Gurobi’s nonlinear solver most efficient
- The model is closer to real life supply chains
  - Initial blending included (nonlinear, non-convex)
- Capillarity expansion of WCO suppliers is not a problem
- PFAD is not necessary
- High variability in optimal solutions

Conclusions

- Suppliers have uncertainty in production capacity
  - Seasonality, restaurant customers, etc.
- Deterministic model does not take into account the uncertainty in supply
- Implement robust model