Applications on Stochastic Programming

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Main content

1. Supply Chain for Petroleum Production
2. Crude oil pumping schedule
3. Conclusions and References

Supply Chain for Petroleum Production (Oliveira and Hamacher 2012)

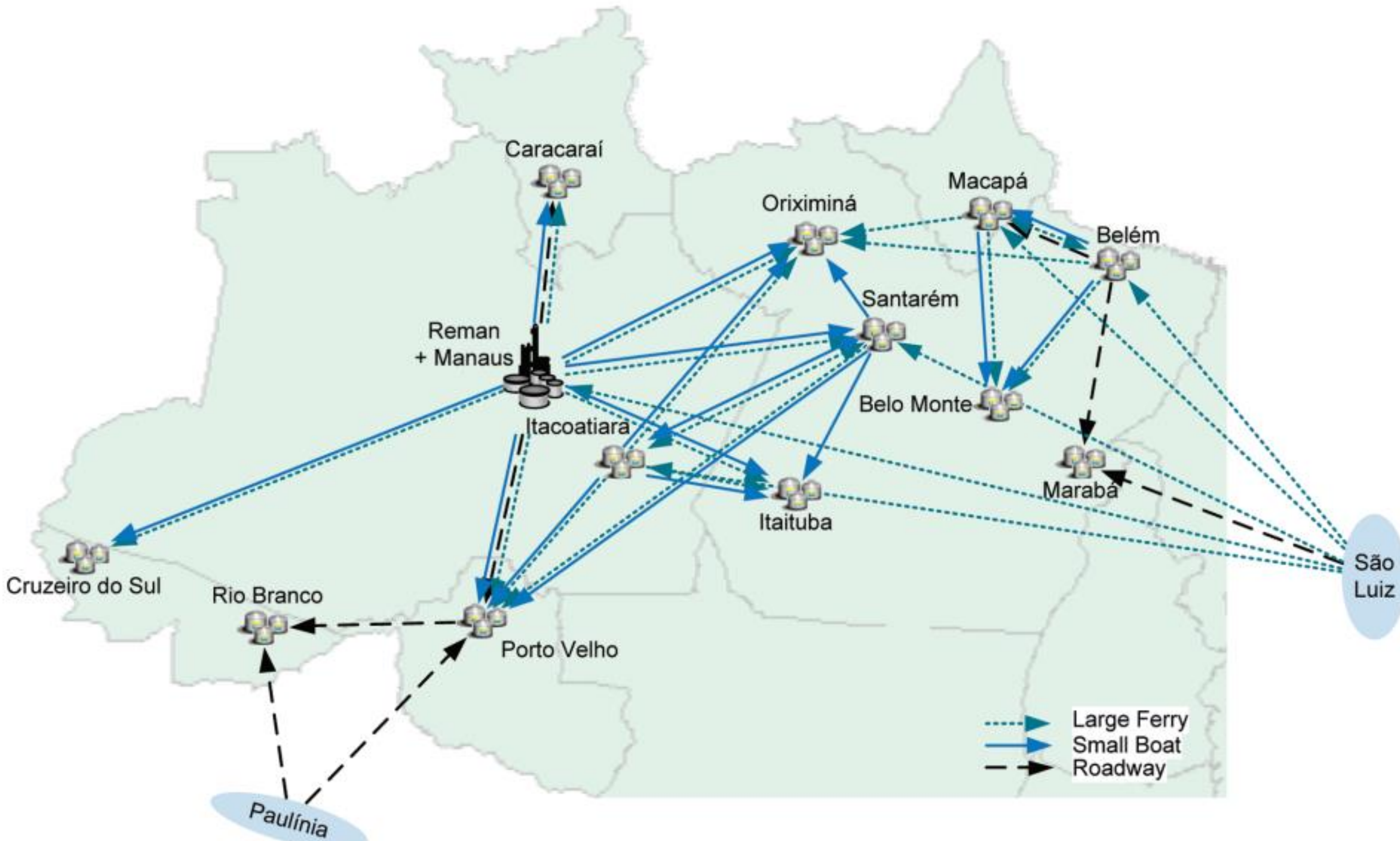
Problem Description

- **Logistic network for oil consists of bases and arcs**
  - Oil is produced in refineries
  - Product is distributed to bases in tanks
  - In bases constant loading and unloading of the tanks = tank rotation
  - Transportation through the sea, demurrage = delays in loading and unloading
- **Goal is to optimize both investments and distribution planning while satisfying the demand of bases**
- **Uncertainty in the demand**
- **Two-stage SP and sample average approximation (SAA)**

Case Study

- **Real case study in northern Brazil**
- **Four different products**
  - Diesel, gasoline, aviation fuel, fuel oil
- **13 bases**
  - 3 sea terminals
- **Four modes of transportation**
  - Waterway with large ferry or small boat, roadway, pipelines
- **Three types of investments**
  - Storage capacity, pumps and substations, new pier
  - Option for pipeline
- **Planning horizon 8 years divided to 32 quarterly periods**

Distribution network



(Oliveira and Hamacher 2012)

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First-Stage Problem

$$\min_{y,w} \quad \sum_{a,t} CKA_a^t y_a^t + \sum_{i,t} CKL_l^t w_l^t + E_\Omega[Q(y,w,\zeta)]$$

$$y_a^t, w_l^t \in \{0,1\}$$

Table 2. Investment Portfolio for Locations

		locations					
		Manaus	Macapá	Santarém	Belém	Cruzeiro do Sul	Itacoatiara
project type	diesel tankage	X	X	X	X	X	X
	gasoline tankage	X	X	X	X	X	X
	aviation fuel tankage	X	X	X	X	X	X
	fuel oil tankage	X		X	X		
	pumps and substations	X	X	X			X
	pier	X		X			

(Oliveira and Hamacher 2012)

Second-Stage Problem

$$\min_{xd,xi,v,z,zk,f,fk,i,e,s} \sum_{a,p,t} CFD_a^t xd_{a,p}^{t,\zeta} + \sum_{a,p,t} CFI_a^t xi_{a,p}^{t,\zeta}$$

$$+ \sum_{l,g,p\in g,t} CI_g \, v_{l,p}^{t,\zeta} + \sum_{l,g,t} CO_l^t \, z_{l,g}^{t,\zeta} + \sum_{l,g,t} COK_l^t \, zk_{l,g}^{t,\zeta}$$

$$+ \sum_{s,l,t} CS_{s,l}^t f_{s,l}^{t,\zeta} + \sum_{s,l,t} CSK_{s,l}^t fk_{s,l}^{t,\zeta}$$

$$+ \sum_{l,p,t} PI_{l,p}^t i_{l,p}^{t,\zeta} - \sum_{l,p,t} PE_{l,p}^t e_{l,p}^{t,\zeta} + \theta \sum_{l,p,t} s_{l,p}^{t,\zeta}$$

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Sample Average Approximation

- **Scenario generation:** $D_{l,p}^{t} = D_{l,p}^{t-1}\left[1 + \omega_p + \sigma_p\epsilon\right], t = 2, \dots, |T|$
- **Number of possible scenarios:** $N^{|P||L_B|} = \mathbf{2^{52}}$
- **Sample Average Approximation (SAA)**
  - M independent random samples of size N
- **New objective function:**

$$\widehat{g_N}(y, w) = \sum_{a,t} CKA_a^t y_a^t + \sum_{i,t} CKL_l^t w_l^t + \frac{1}{N}\sum_{n=1,\dots,N}[Q(y, w, \zeta^{\mathrm{n}})]$$

- **Choosing N: Consider trade-off between computational effort and the solution's quality**

Results

- **Approximate true measures with N=50**
  - N = 20, 30, 40 confidence levels 0.95, 0.975, 0.99 respectively on the estimation of required sample size

Table 3. Summary of the Size of the Model[a]

N	total variables	total constraints	average solution time (s)	standard deviation of solution time (s)
20	250 400	304 144	532.83	967.26
30	455 504	374 880	971.42	1500.20
40	606 864	499 360	1472.05	864.41

[a] 50 replications.

(Oliveira and Hamacher 2012)

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Results

- **Lower bound**
  - M =50
  - Stopping criteria: 1h or relative gap of 1%
- **Upper bound**
  - Select 3 best solutions from previous round
  - M = 1000

Table 4. Results of Experiments: Upper and Lower Statistical Limits

N		lower limit	upper limit
20	amount (10^6\$)	800.12	818.76
	standard deviation (10^6\$)	9.81	109.66
	percentage deviation	1.2%	13.40%
30	amount (10^6\$)	801.25	821.67
	standard deviation (10^6\$)	10.22	50.63
	percentage deviation	1.2%	6.20%
40	amount (10^6\$)	805.28	817.12
	standard deviation (10^6\$)	8.22	40.03
	percentage deviation	1.0%	4.90%

(Oliveira and Hamacher 2012)

Results

- **Optimality gap is not improving as N grows**
- **Variability of the gap is decreasing as N grows**

Table 5. Results of Experiments: Estimative of the Optimality Gap and Its Statistical Upper Limit

		gap		
N	solution number	value (10^6\$)	%	standard deviation (10^6\$)
20	1	19.61	2.40%	107.41
	2	26.4	3.20%	72.82
	3	18.64	2.30%	110.1
30	1	23.18	2.80%	63.73
	2	26.95	3.30%	82.4
	3	20.42	2.50%	51.57
40	1	17.38	2.10%	44.03
	2	11.83	1.40%	41.22
	3	14.85	1.80%	49.43

(Oliveira and Hamacher 2012)

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Results

- **Solutions have low variability**
- **Solutions can support decision making**
  - Santarém has strategic importance
  - Many of the considered investments were not relevant

Table 6. Investment Profiles of Solution 3 for $N = 20$, Solution 3 for $N = 30$, and Solution 2 for $N = 40$

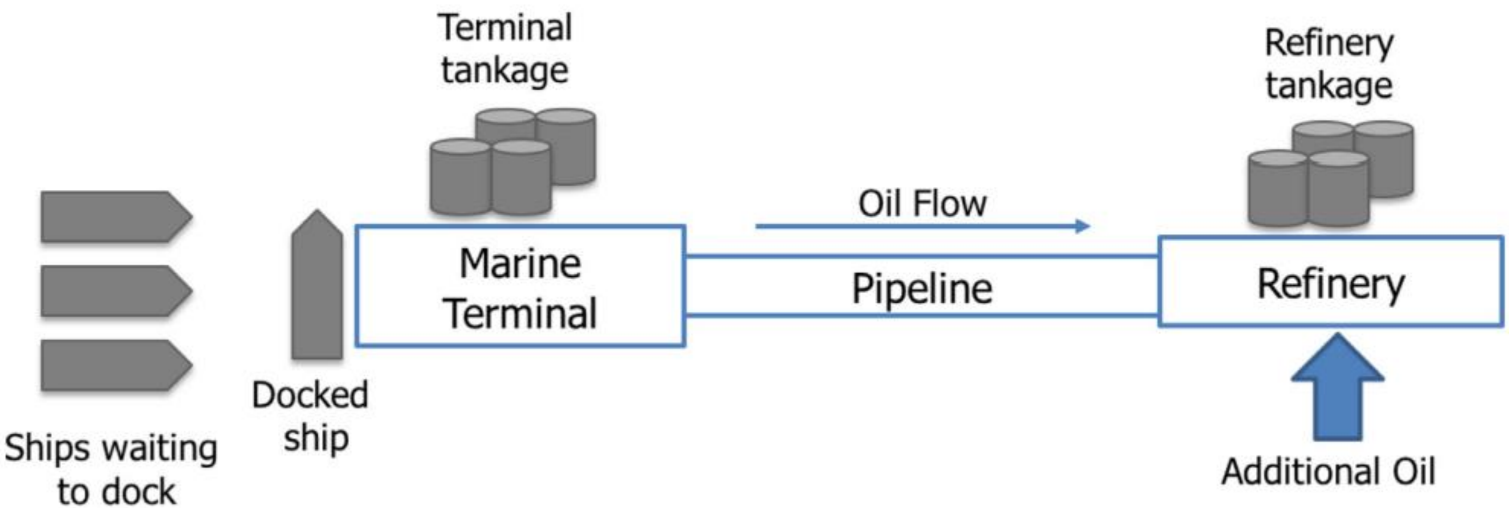
project	investment period		
	$N = 20$	$N = 30$	$N = 40$
Inv. Manaus Aviation Fuel	7	7	6
Inv. Santarem Diesel	21	16	17
Inv. Santarem Gasoline	24	22	16
Inv. Santarem Fuel Oil	1	1	1
Inv. Belém Diesel	29	24	27
Inv. Macapa BS	23	27	26

(Oliveira and Hamacher 2012)

Crude Oil Pumping Schedule (Oliveira et al. 2016)

Problem description

- **Oil is supplied through marine terminals**
  - Estimated time of arrival (ETA) is uncertain
- **Transport to refinery via pipelines**
- **Expensive pumping time between 6pm and 10pm**



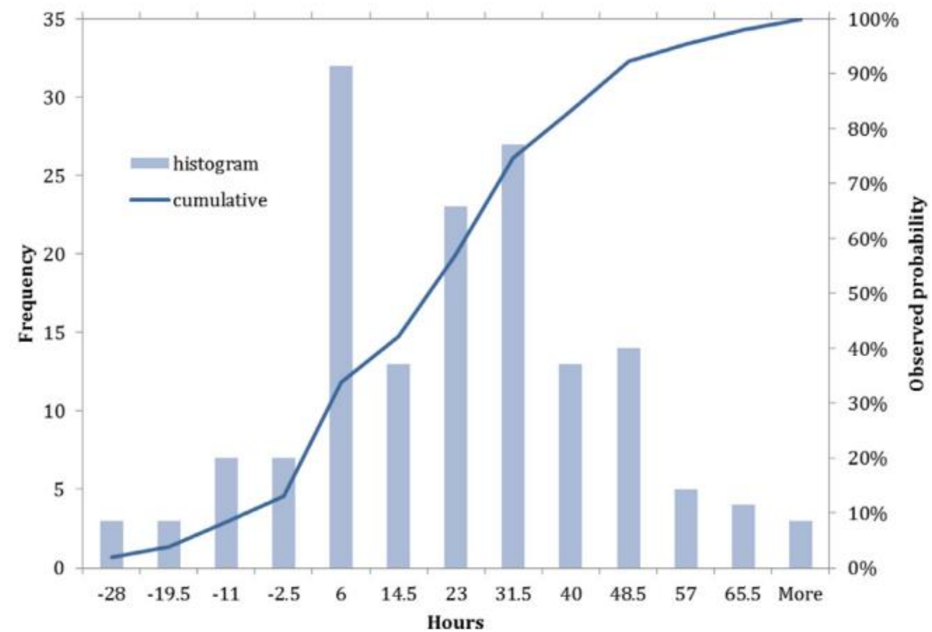
(Oliveira et al. 2016)

Model Formulation

- **Two-stage SP**
- **First-stage decisions before we know the exact arrival times of the vessels**
  - Pumping schedule → refinery's inventory level, pumping during critical time
- **Second-stage decisions after we know arrival times**
  - Terminal activities
- **Objective to minimize operational costs such that the demand of refinery is fulfilled**
  - Costs: demurrage, product transference, penalty costs

Scenario Generation

- **Deviations follow normal distribution**
- **Scenario generation**
  - Generate samples
  - Scenario reduction
  - Solve SP using reduced scenario tree
- **How many samples?**
- **How many scenarios in the reduced scenario tree?**



Histogram for the deviations around ETA

(Oliveira et al. 2016)

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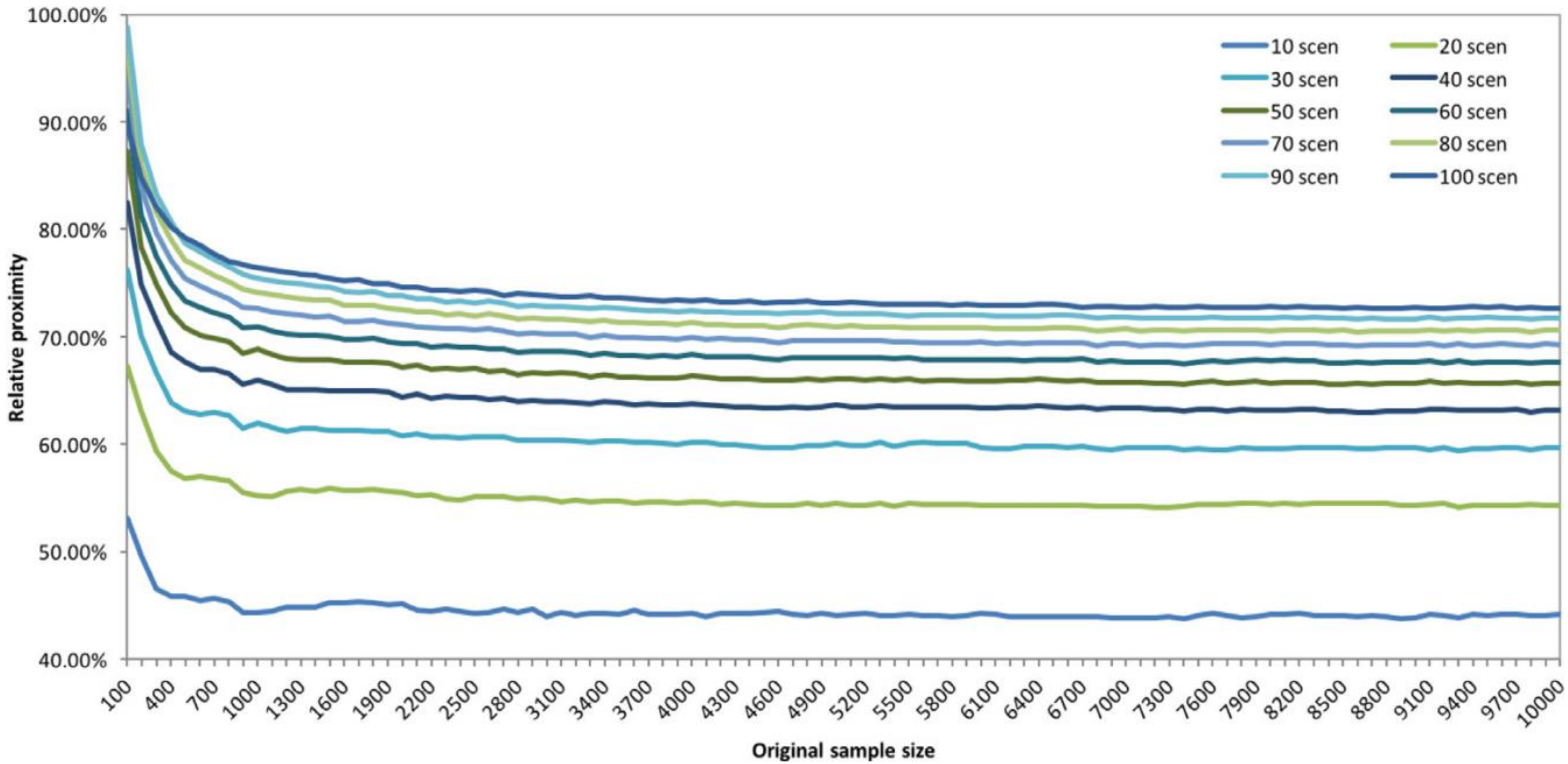
Scenario Generation



(Oliveira et al. 2016)

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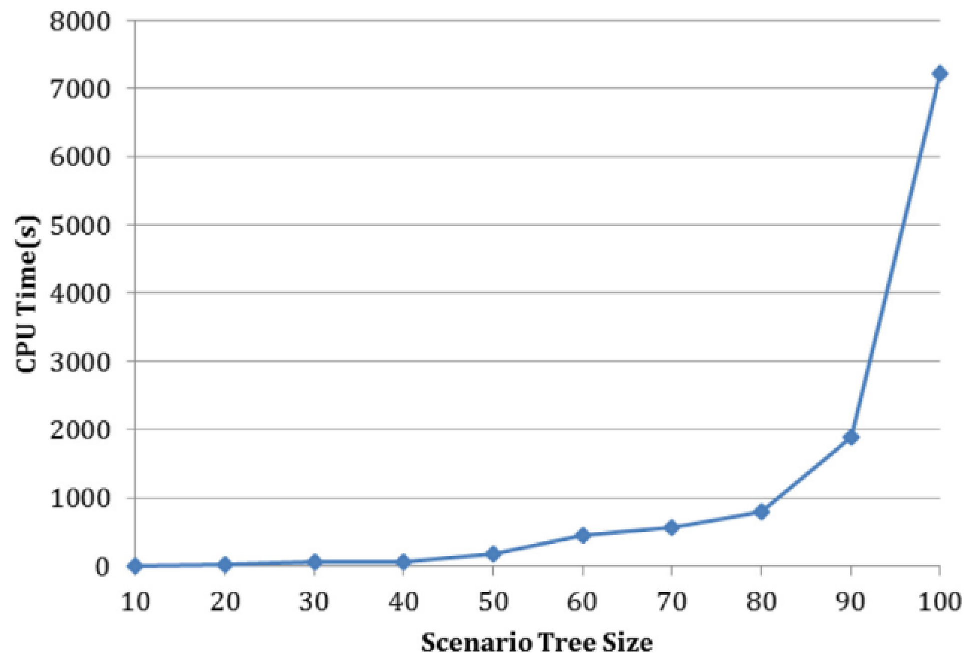
Results

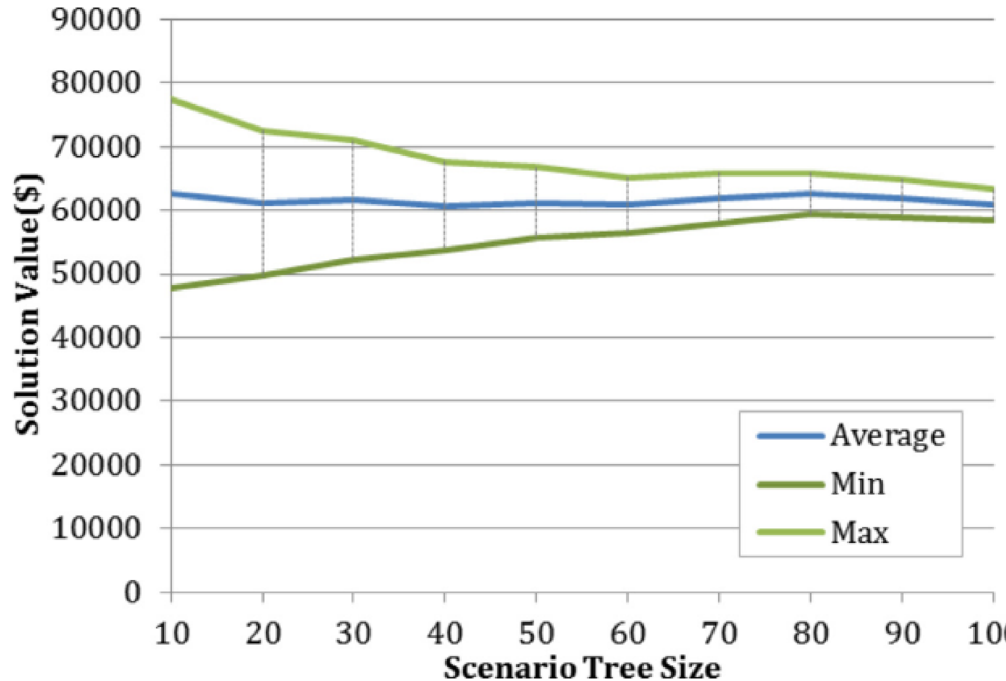
- **Time horizon of seven days, time periods of 2 hours = 84 time periods**
- **Two different classes of oil: light and heavy**
- **Three vessels, each with different ETA**
    - ETA: 6, 22, 56
- **Sample size 10 000, 50 distinct scenario samples**



(Oliveira et al. 2016)

Results

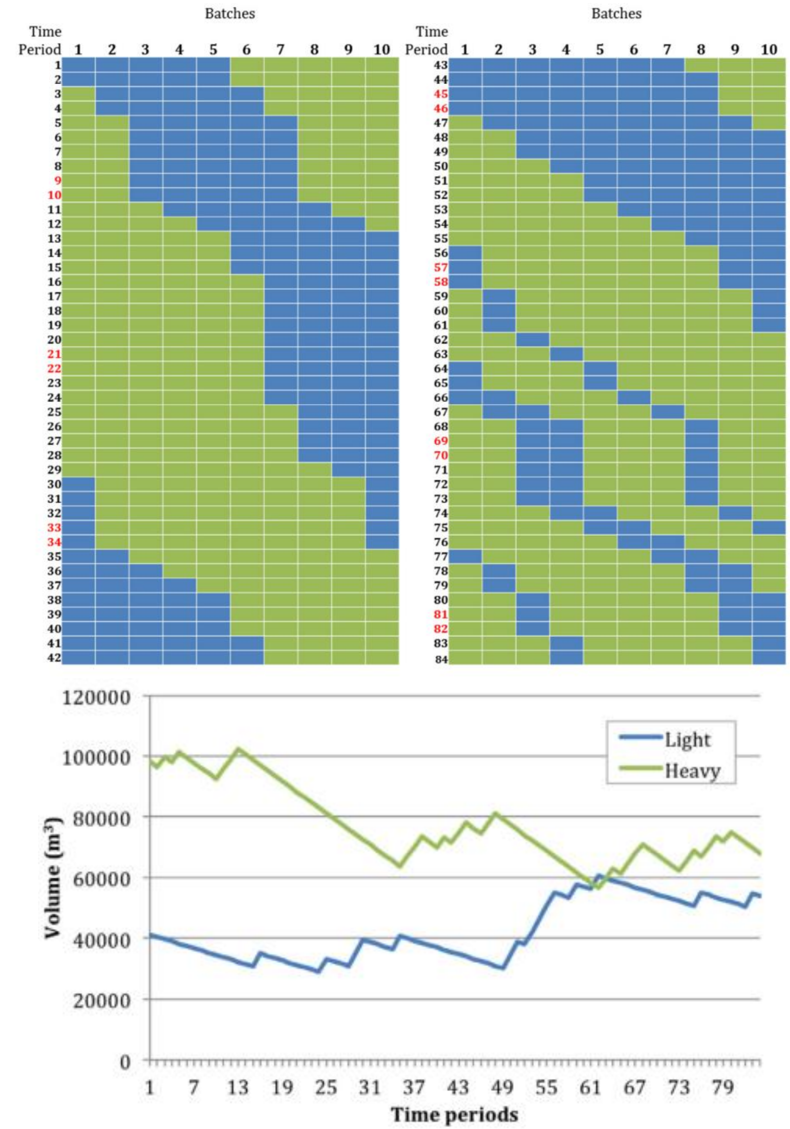
- **Size of the scenario tree hardly affects the average solution**
- **With larger tree size we have less variability**
    - In-sample stability



(Oliveira et al. 2016)

Results

- **First-stage decision**
  - optimal schedule for pumping
  - refinery's inventory level
- **Inspecting second stage decisions help to understand impact of uncertainties**



(Oliveira et al. 2016)

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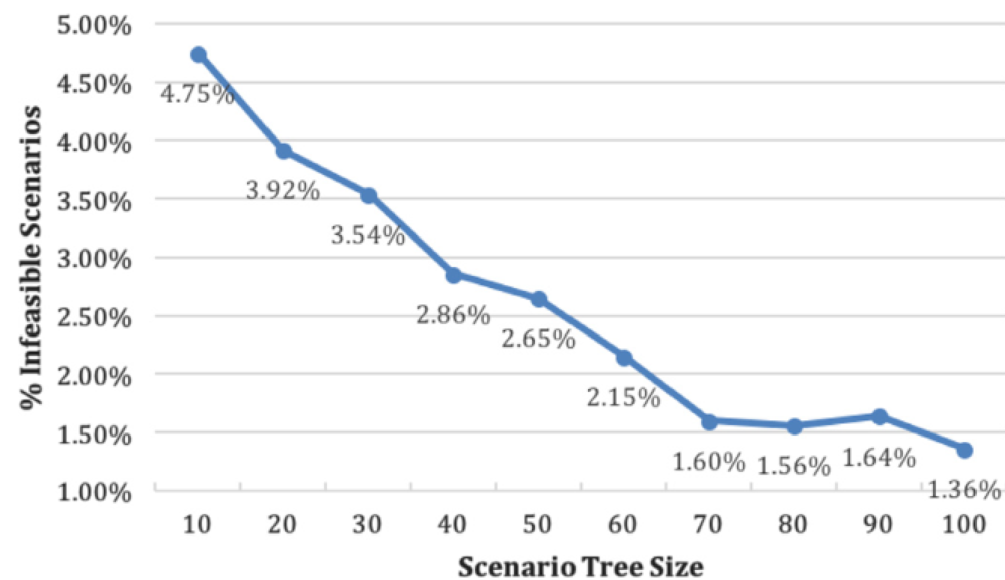
Results

- **Solution must be feasible in all considered scenarios**
- **Compare the chances of the solution being actually feasible**
    - VSS and EVPI are not good measures in this context
- **If problem is treated as deterministic, 90% of the samples are infeasible**



(Oliveira et al. 2016)

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Conclusions and References

Conclusions

- **We looked into applications of SP**
  - Supply Chain for Petroleum Production
  - Crude Oil Pumping Schedule
- **In both cases the computational efforts were reduced successfully**
  - Results were acceptable
- **Methods can be used to support decision making process**
  - Remember to validate results!

References

Oliveira and Hamacher (2012) - Optimization of the Petroleum Product Supply Chain under Uncertainty - A Case Study in Northern Brazil, Ind. Eng. Chem. Res. 2012, 51, 4279−4287

Oliveira et al. (2016) - A framework for crude oil scheduling in an integrated terminal-refinery system under supply uncertainty, European Journal of Operational Research 252 (2016) 635–645