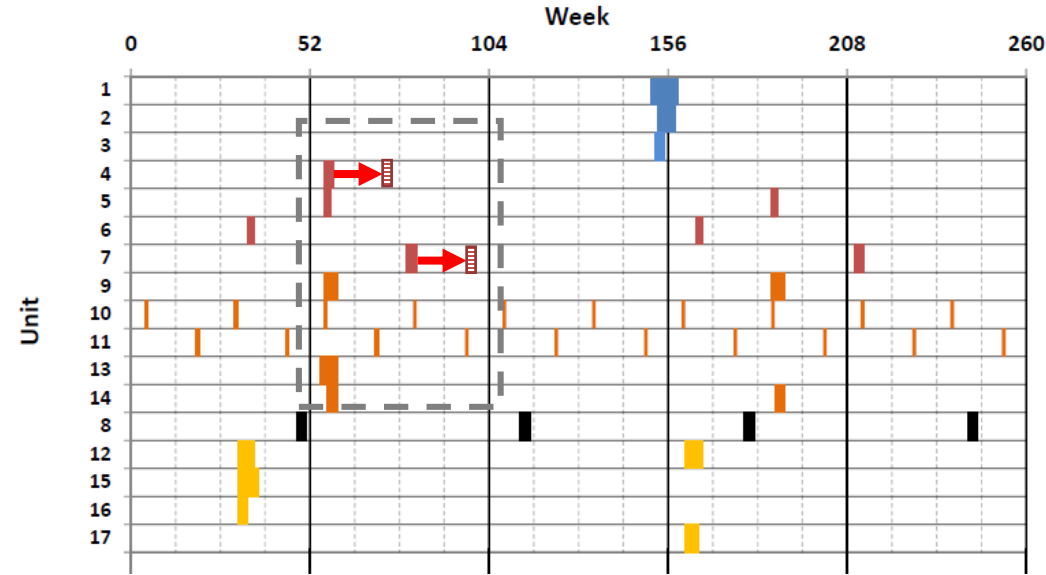


Flexible turnaround planning for integrated chemical sites



Amaran et al., 2015

Sreekanth Rajagopalan, Nick Sahinidis,
Satyajith Amaran, Anshul Agarwal, Scott Bury, John Wassick

Enterprise-Wide Optimization (EWO) Meeting, CAPD 2016

Turnaround rescheduling

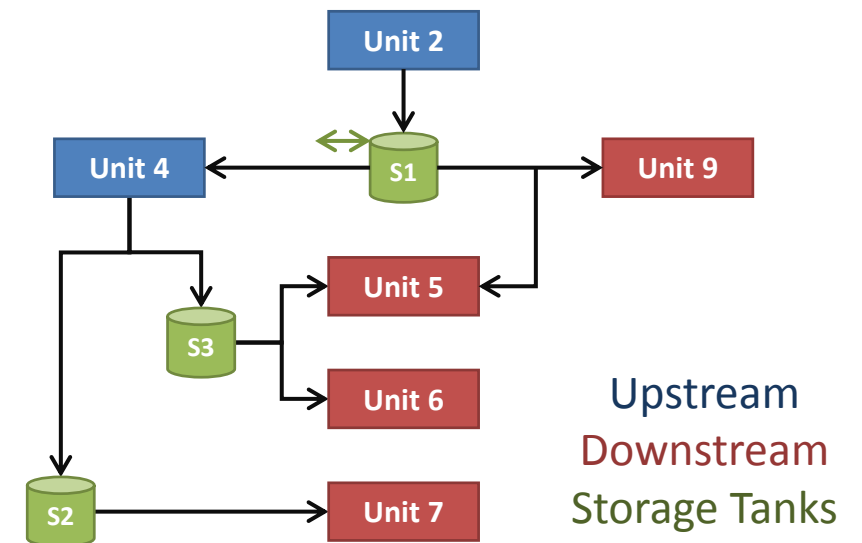
Motivation

- Respond to peak demands
 - High forecast during turnaround period
- Unfavorable market conditions
 - Foreseeable supply/demand variations
- Additional resource constraints
 - Availability of skilled workforce or process specific technical experts
- Continue operations
 - Performance exceeding expectations (less catalyst activity degradation, HEX fouling)

Problem statement

Given an integrated chemical sites network with a base turnaround schedule over the next 6-9 months,

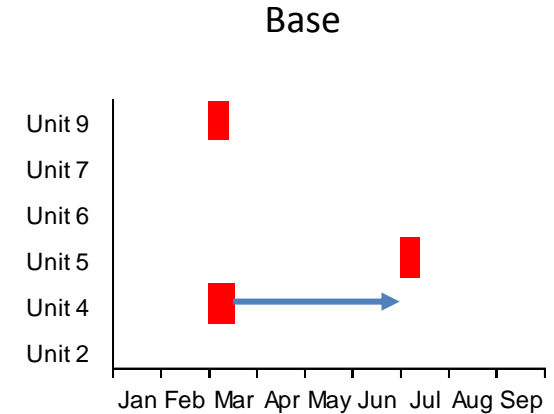
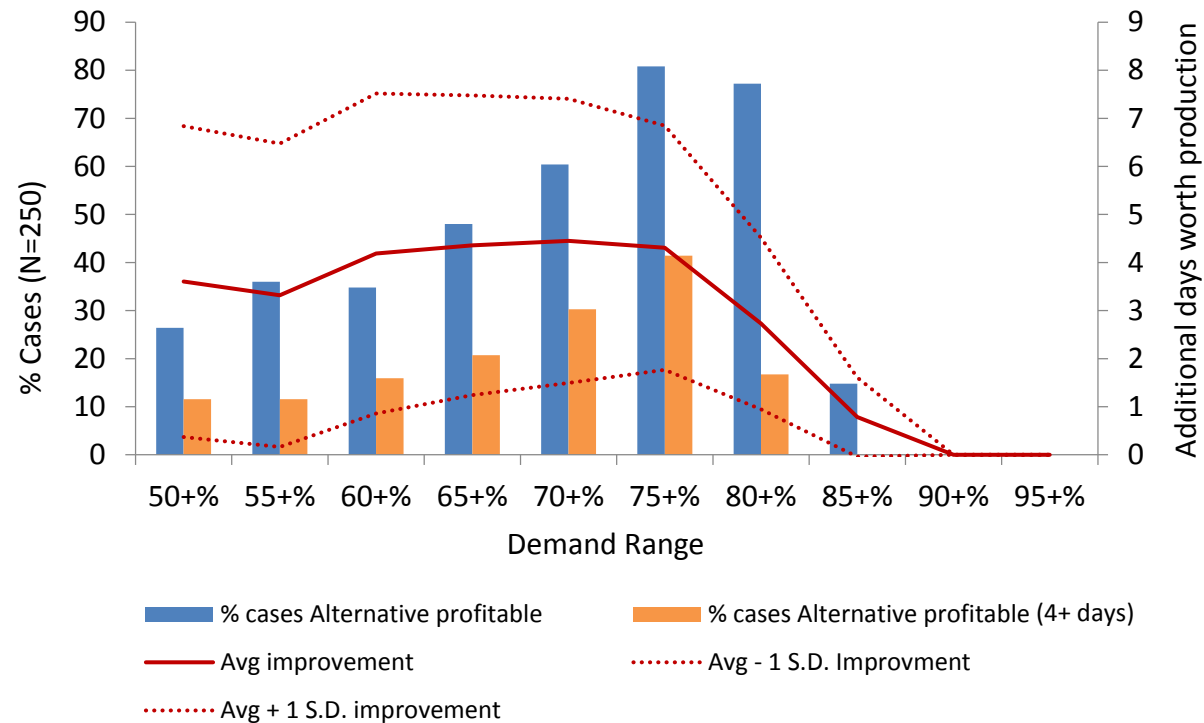
- Benefit of moving Unit 4 turnaround from March to July?
- Risk of loss in rescheduling?



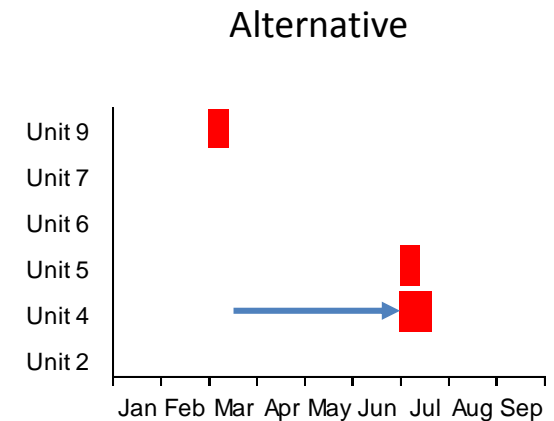
Potential benefits

Key factors

- Time value of money on costs and revenue
- Time to plan production and inventory better
- Integration effect

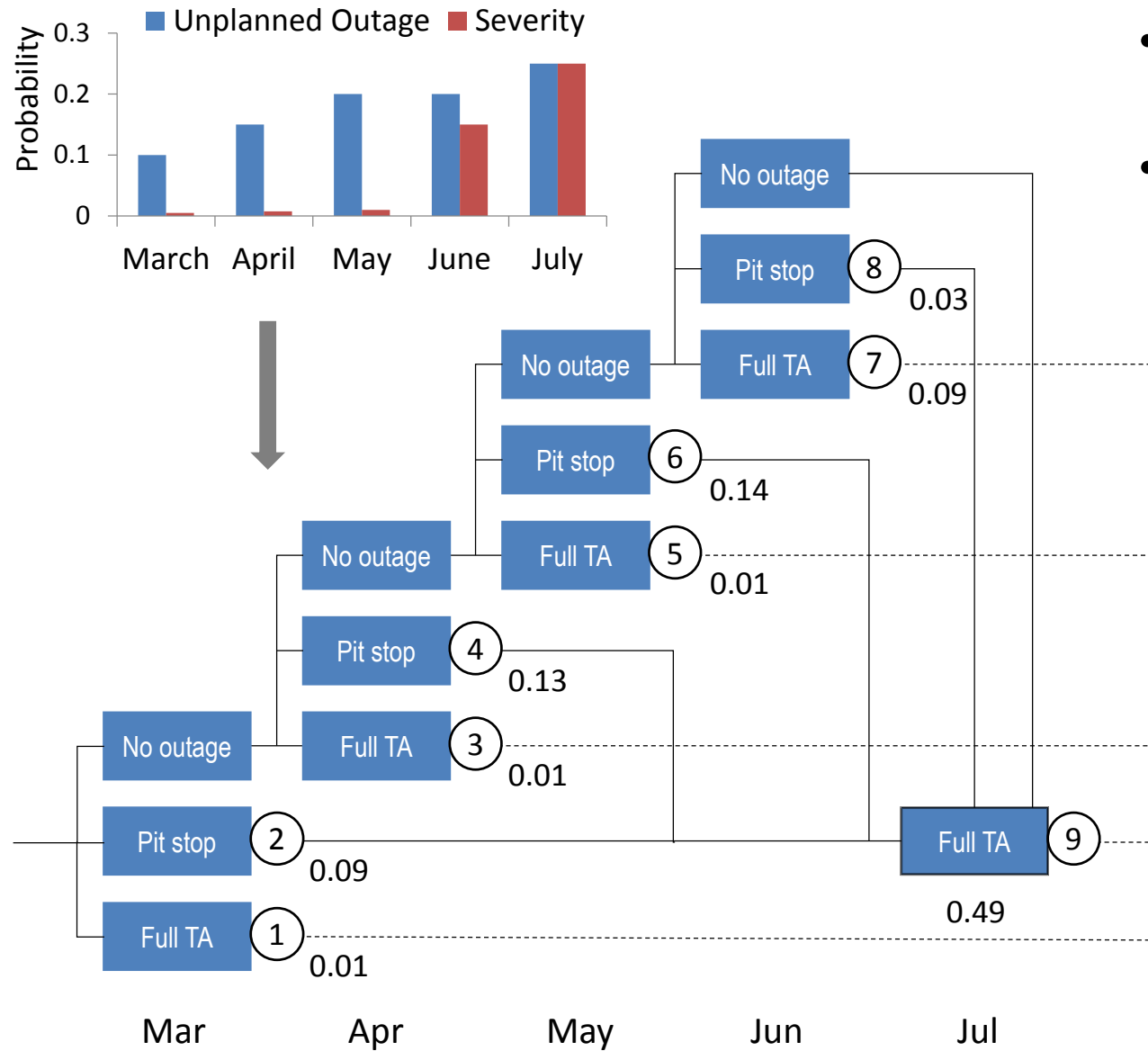


Unit 4 turnaround in March

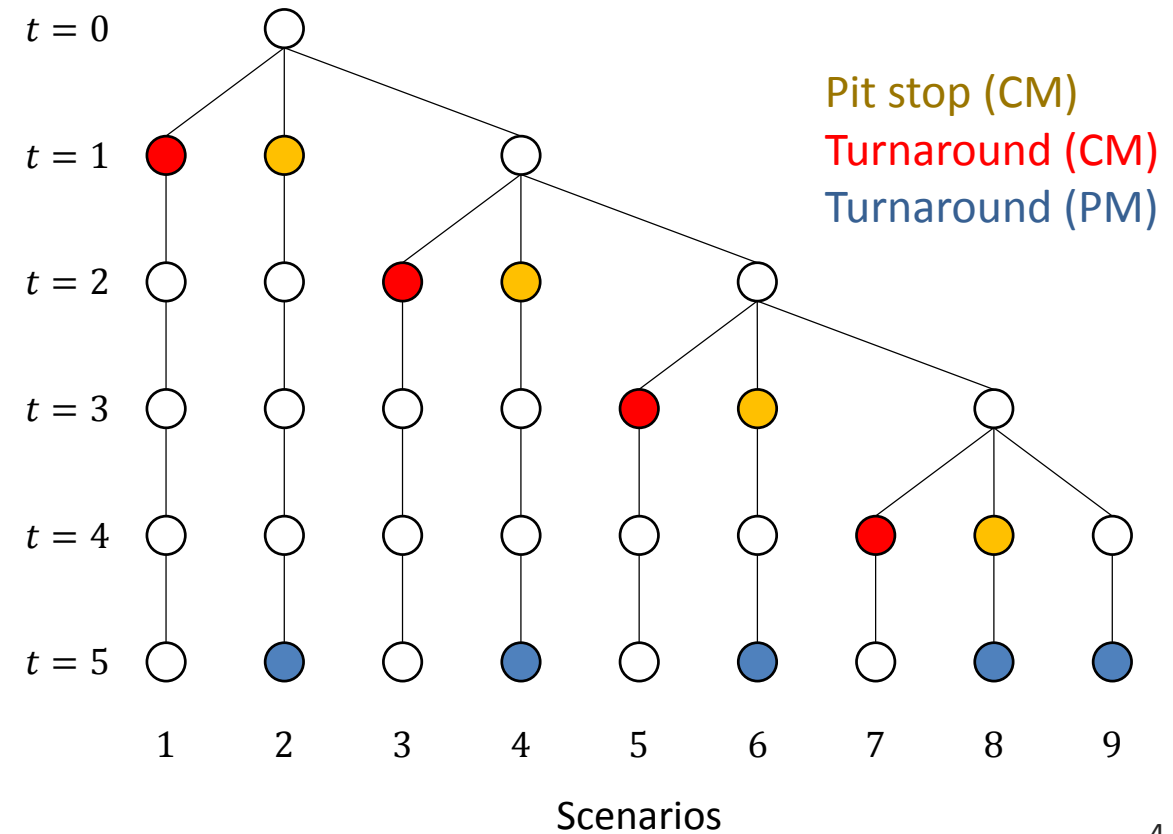


Unit 4 turnaround in July

Planning under uncertainty: unplanned outages



- Corrective maintenance decision policy: pit stop (minor) and turnaround (major)
- Reactive planning vs. anticipative planning



Stochastic programming model

max NPV	: expected value of all scenario profits
Flow balance	: material balance + stream ratio requirements
Demand constraints	: upper bound (deterministic, monthly timescale)
Turnaround constraints	: unit up or down for maintenance
Capacity constraints	: flow and storage tank bounds
Nonanticipativity constraints	: time-consistency and implementable decisions

Example: 11 nodes, 16 arcs, 3(1) turnarounds, 9 month horizon

- 72 time periods
- 33 stages (4-month reschedule window)
- 2 time periods per stage

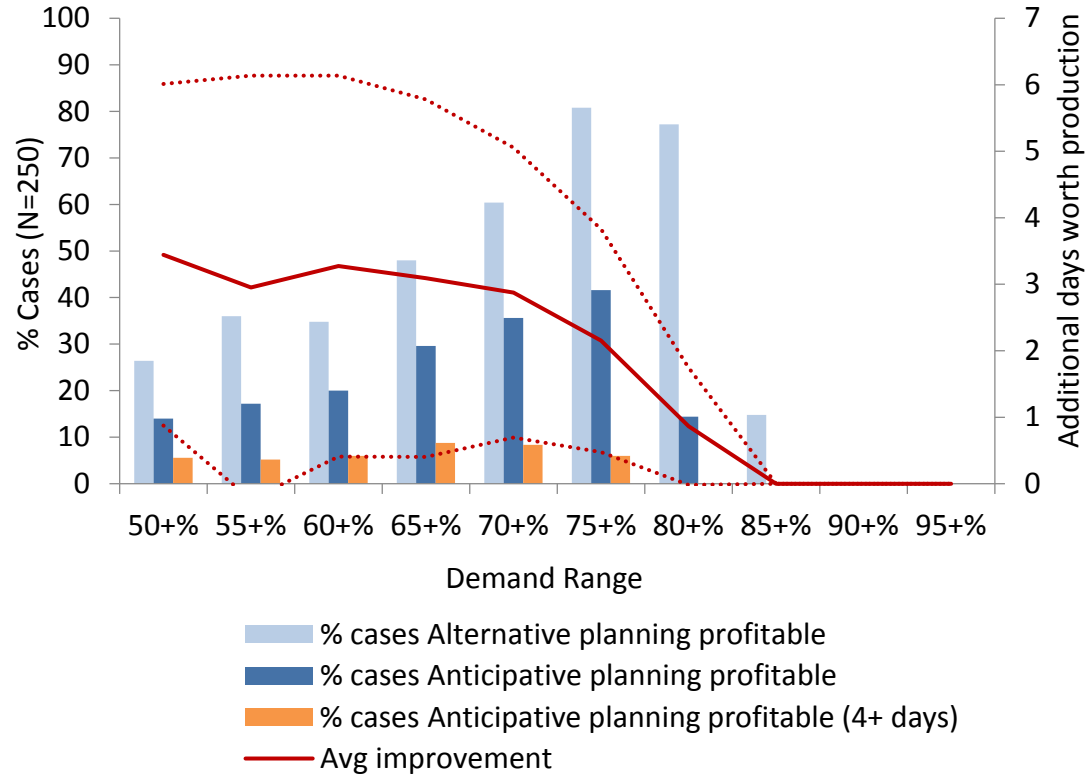
Model tractable to reliably reschedule single turnaround: stages ~ 2T

Solution time for deterministic equivalent of SP is < 2 sec

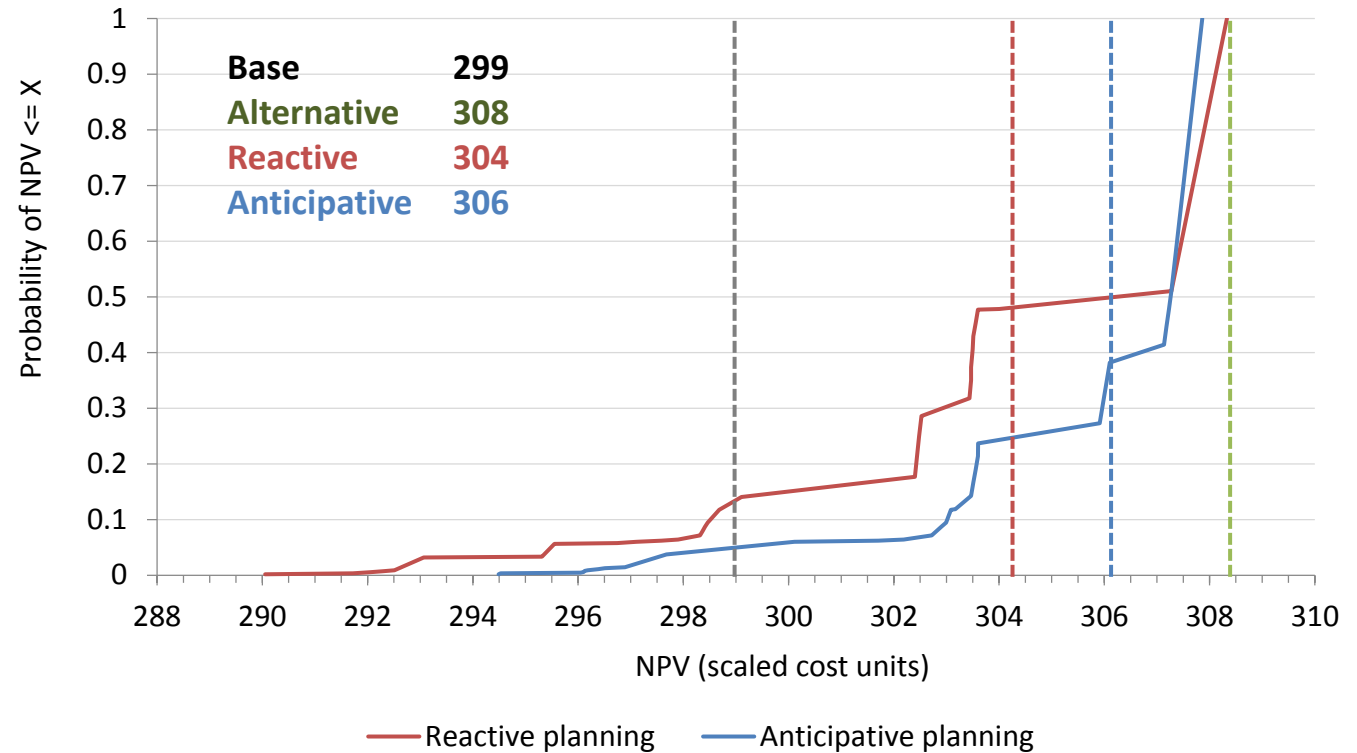
	Base	Alternative	Reactive (sequential LPs)	Anticipative (multistage SP)
variables	1,408	1,408	27,648	54,736
constraints	1,987	1,987	38,435	434,035
non-zeros	5,441	5,441	105,281	916,513

Potential reschedulable instances

NPV improvement: Anticipative vs Base



Risk profiles: cumulative distribution of profits

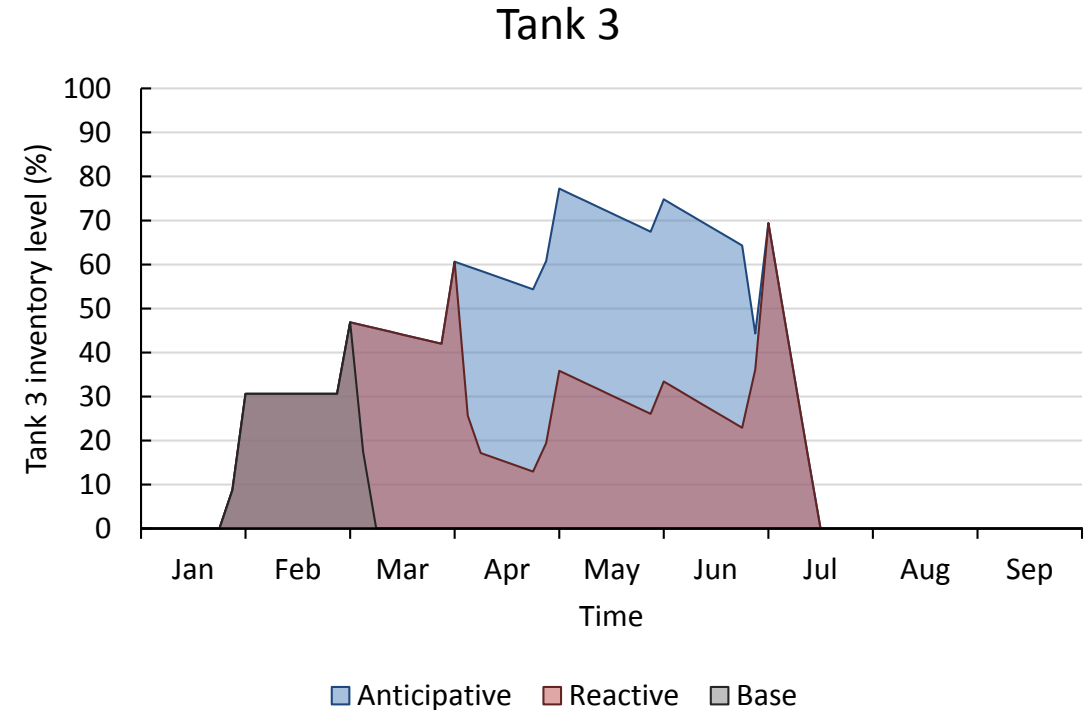
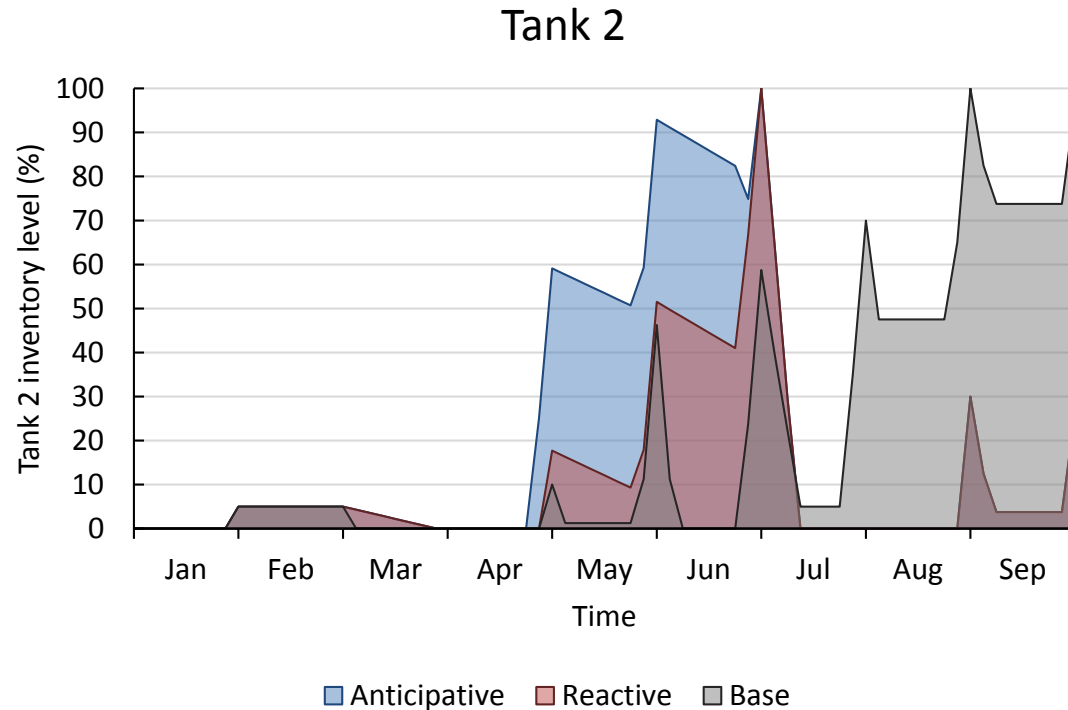


- 10-30% instances can be reliably rescheduled
- More than 4 days worth production recovery in about 5% cases

- Anticipative planning model provides a flexible production and inventory plan that is less risky
- 5% chance of loss vs. 10% from reactive planning

Additional inventory to hedge against uncertainties

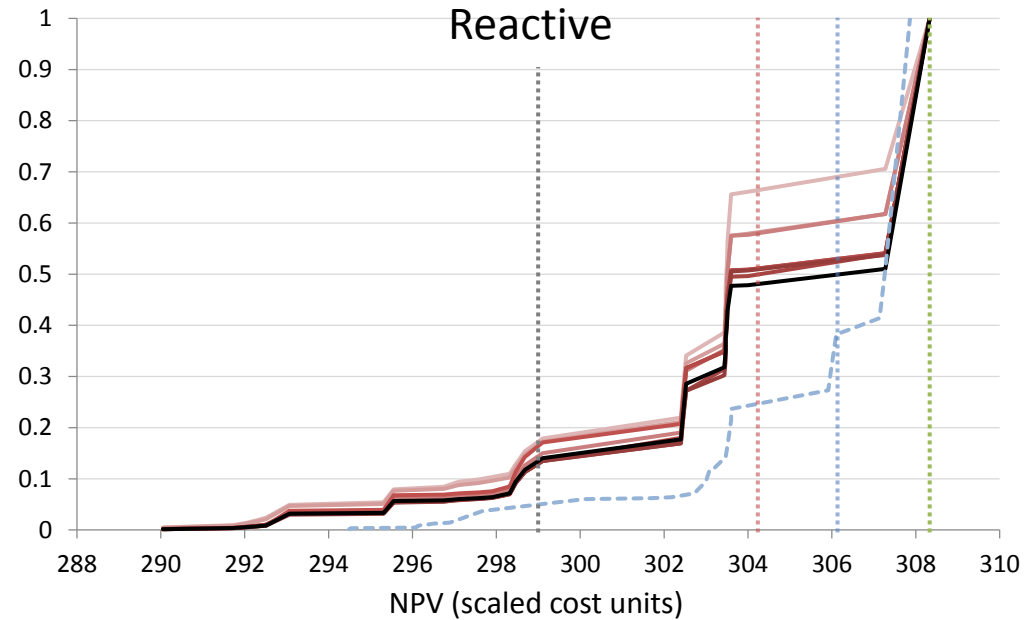
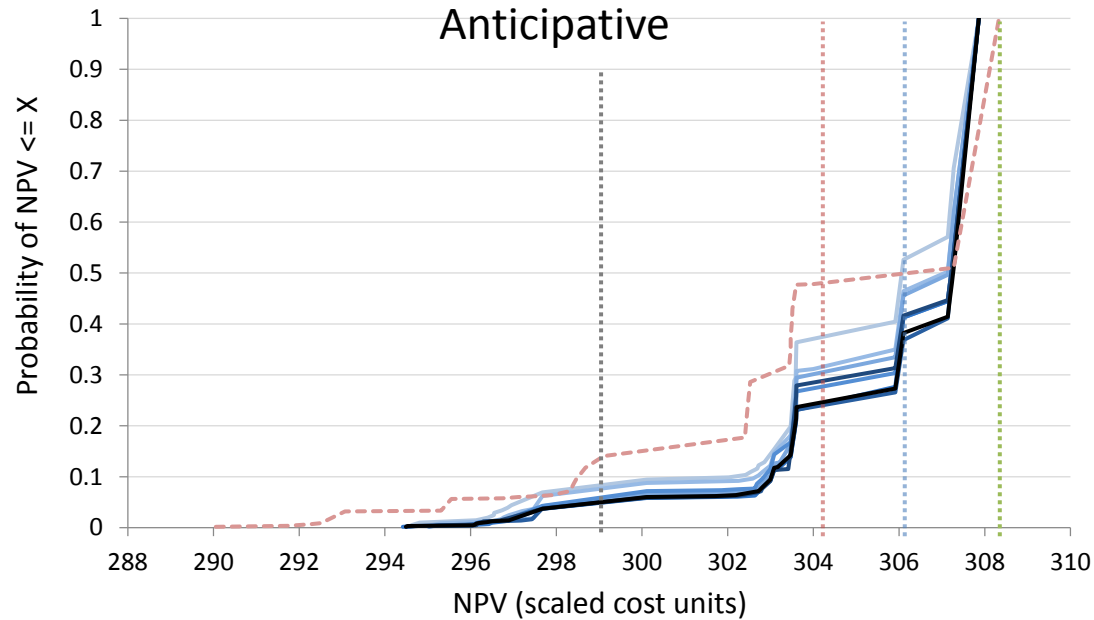
Inventory with time for tanks 2 and 3 for the (final) scenario corresponding to no outages



- Anticipative plan recommends more inventory to hedge against future uncertainties
- Small premium of 0.5 scaled cost units incurred from additional holding cost

Sensitivity to outage probabilities

What if outage probabilities data is underestimated?

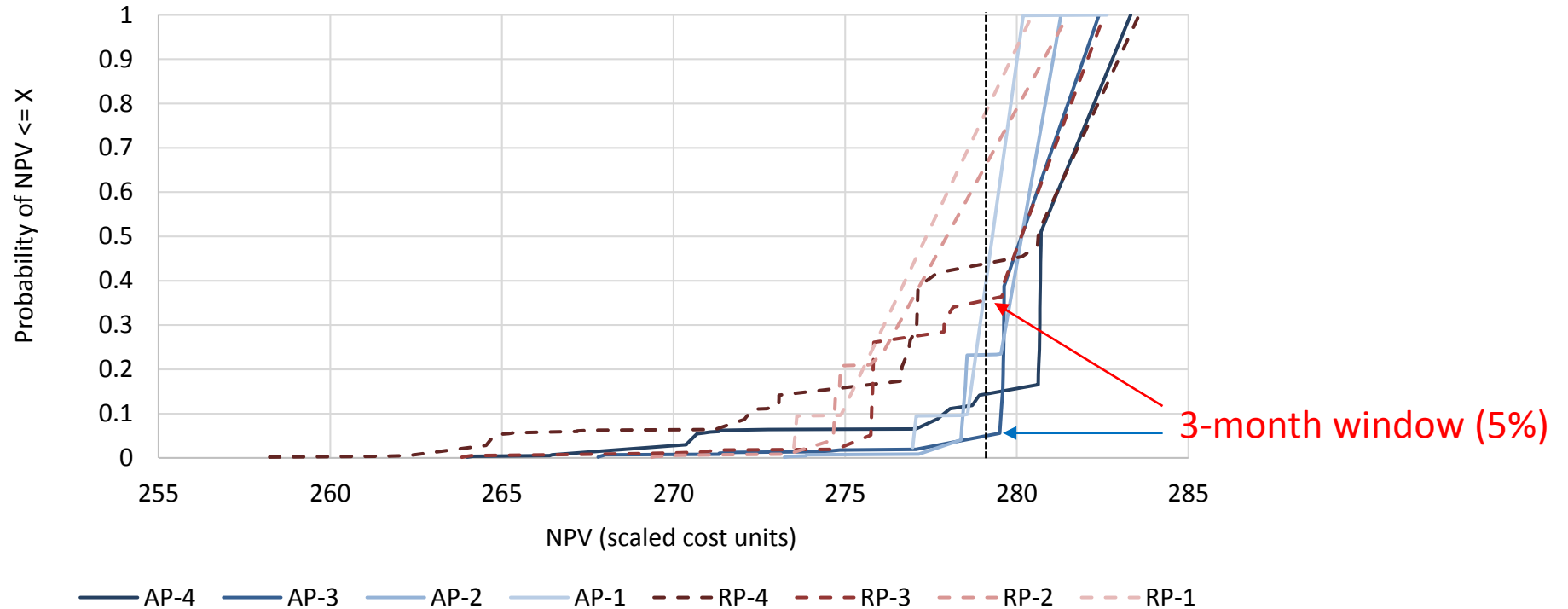


[7 different profiles. Dark to light :: best- to worst- case]

- Change in probability of loss compared to base schedule is within 5%
- Anticipative planning model values reschedule more than best-case reactive plan

Sensitivity to reschedule time window

Effect of reschedule time (1 to 4 months) for decreasing demands



- Short window (1-2 months) risky (25-35% chance of a loss) when demands not sufficiently low
- Long window (4 month) risky (15% chance of a loss) due to corrective maintenance costs

Conclusions

- Rescheduling a turnaround offers production recovery as high as 11-12 days
- Depends on demands as well as integration effects
- Anticipative planning model hedges against uncertainties due to outages at a small premium
- Timing of reschedule as well as performance condition of the unit affects potential cost benefits and risk of loss

Future work

- Optimal turnaround reschedule time window
- Simultaneous condition-based and risk-based turnaround planning
- Practical-scale networks