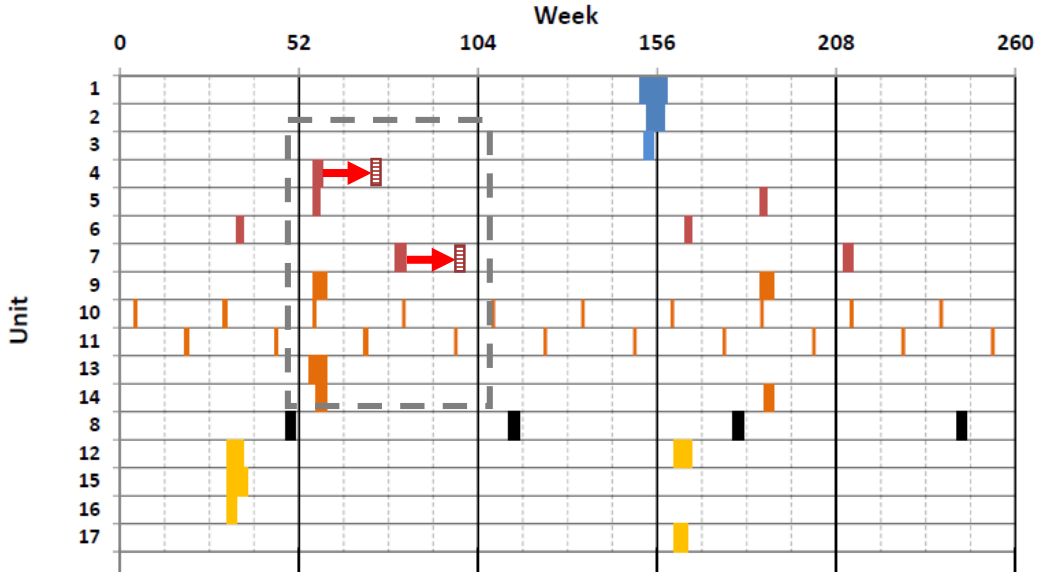
Flexible turnaround planning for integrated chemical sites



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Turnaround rescheduling

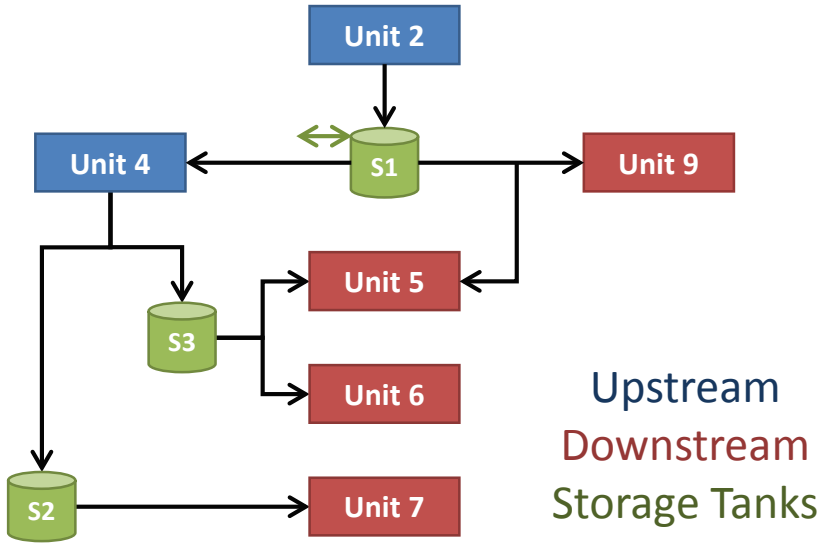
Motivation

- Respond to peak demands
  when demands are forecast to increase 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 (catalyst activity, HEX fouling), changes in turnaround frequency time period estimate

Problem statement

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

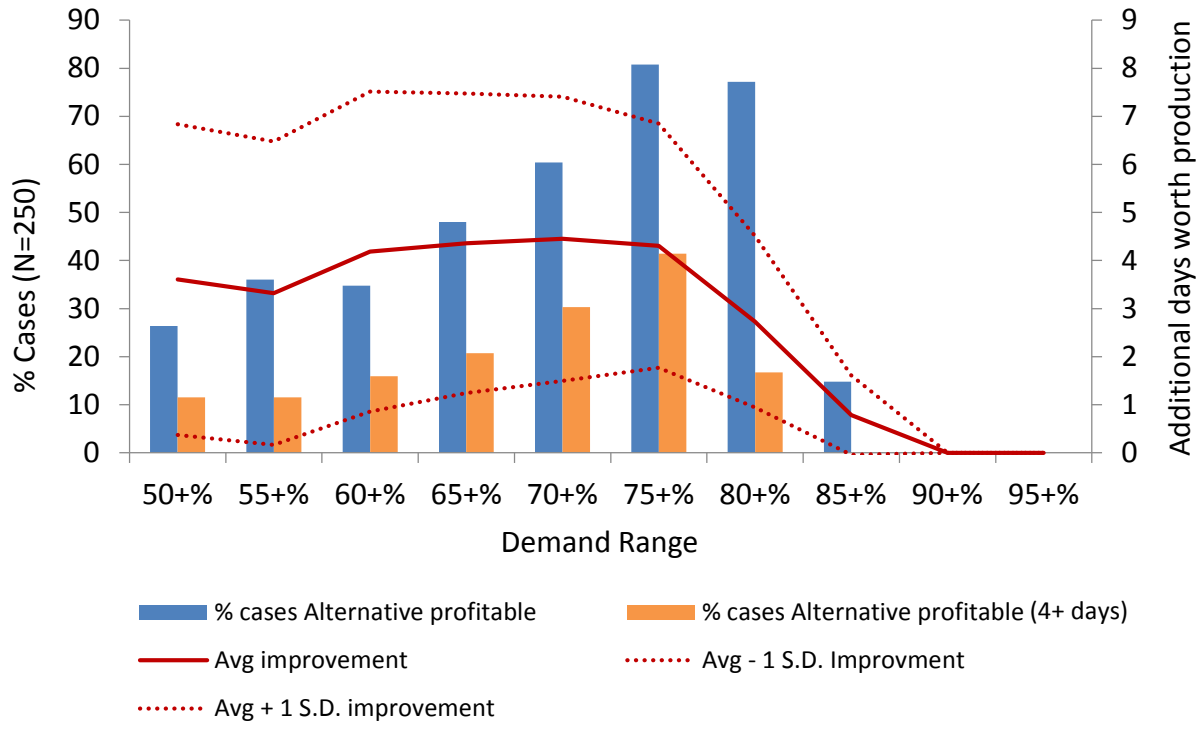
- Benefit of moving Unit 4 turnaround from March to July?
- Risk of loss in rescheduling?



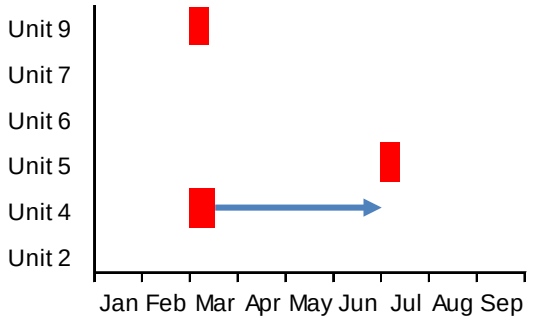
Potential benefits

Key factors

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

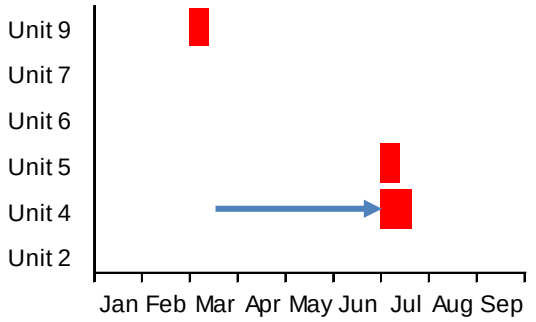


Base



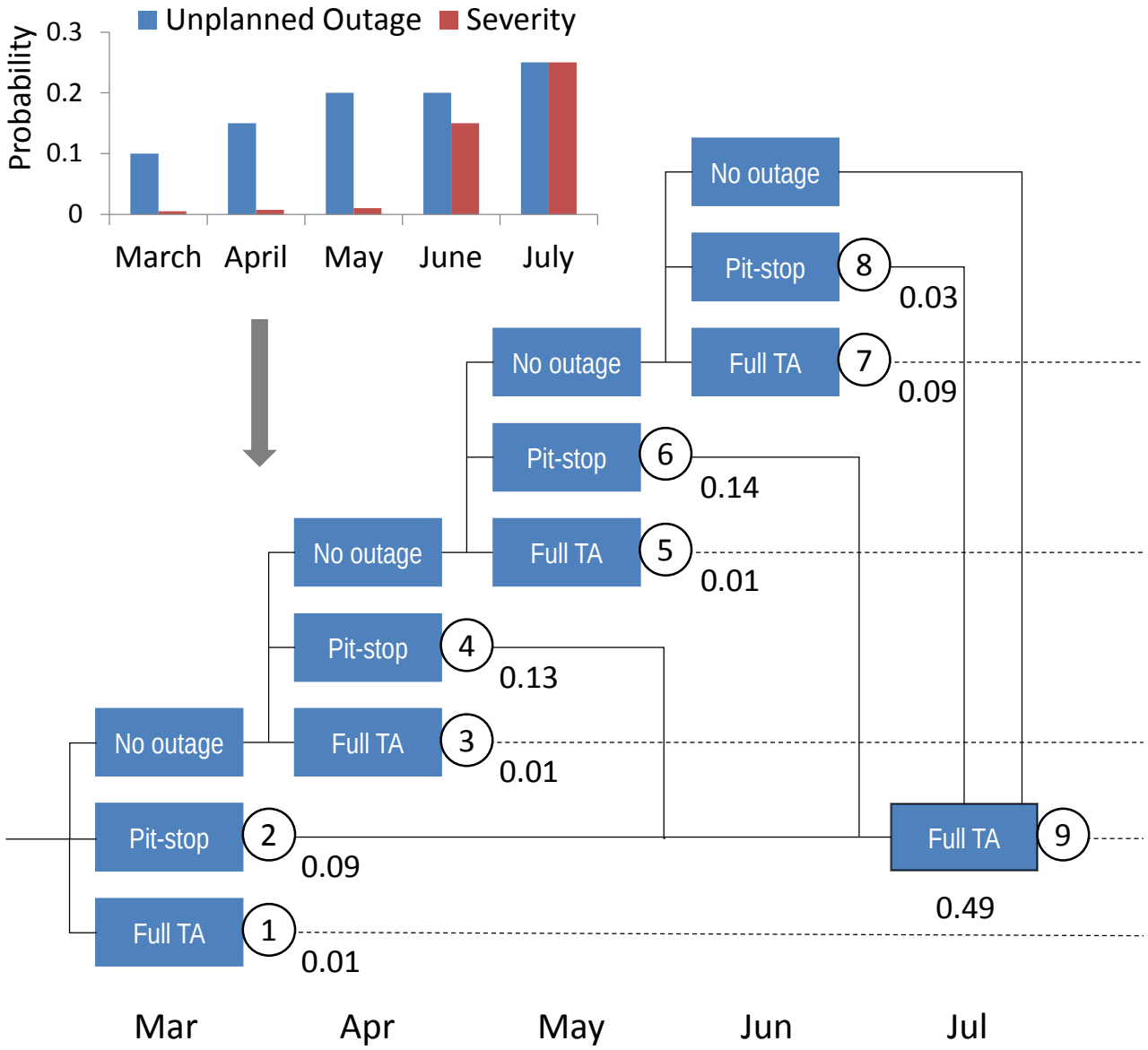
Unit 4 turnaround in March

Alternative

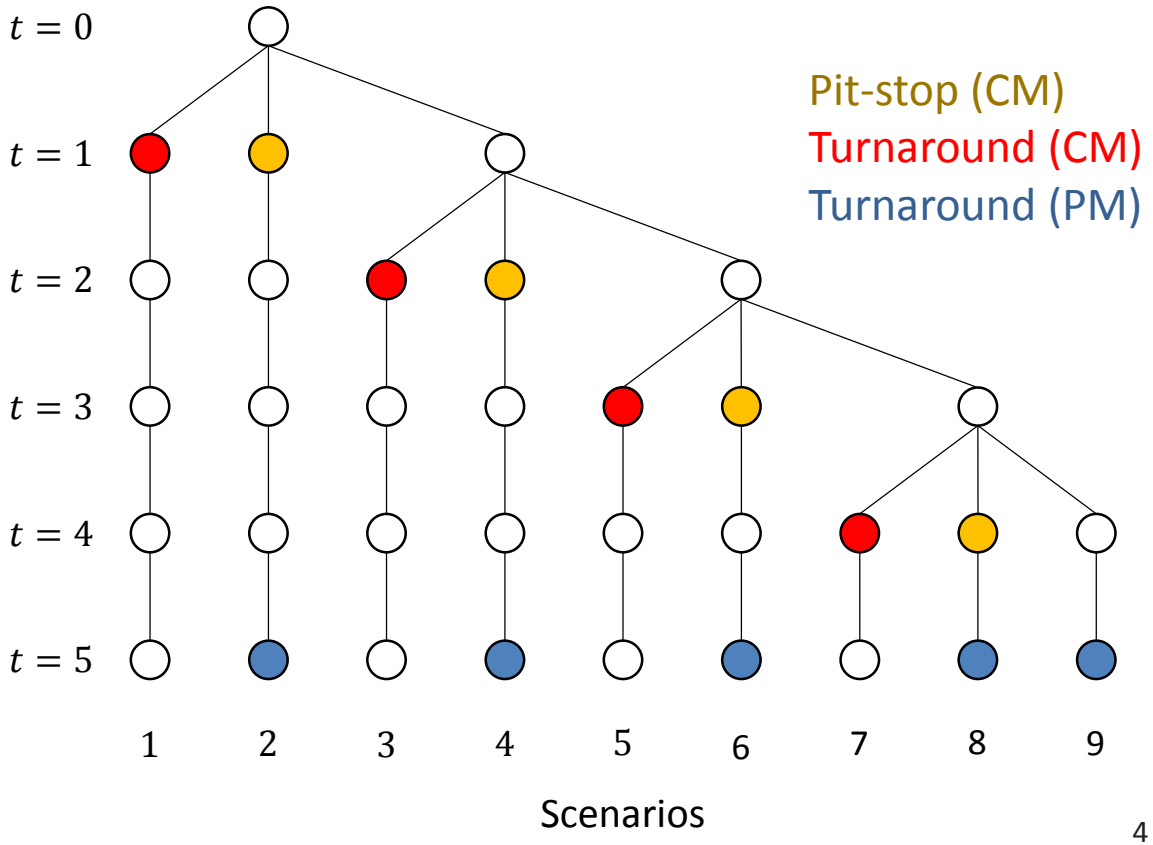


Unit 4 turnaround in July

Planning under uncertainty: unplanned outages



- Corrective maintenance decision policy: pit-stop (minor) and turnaround (major)
- Reactive planning (sequential LPs) vs. anticipative planning (stochastic programming) models



Stochastic programming model

Objective: 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, stages – weekly discretization, planning – semi-weekly

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

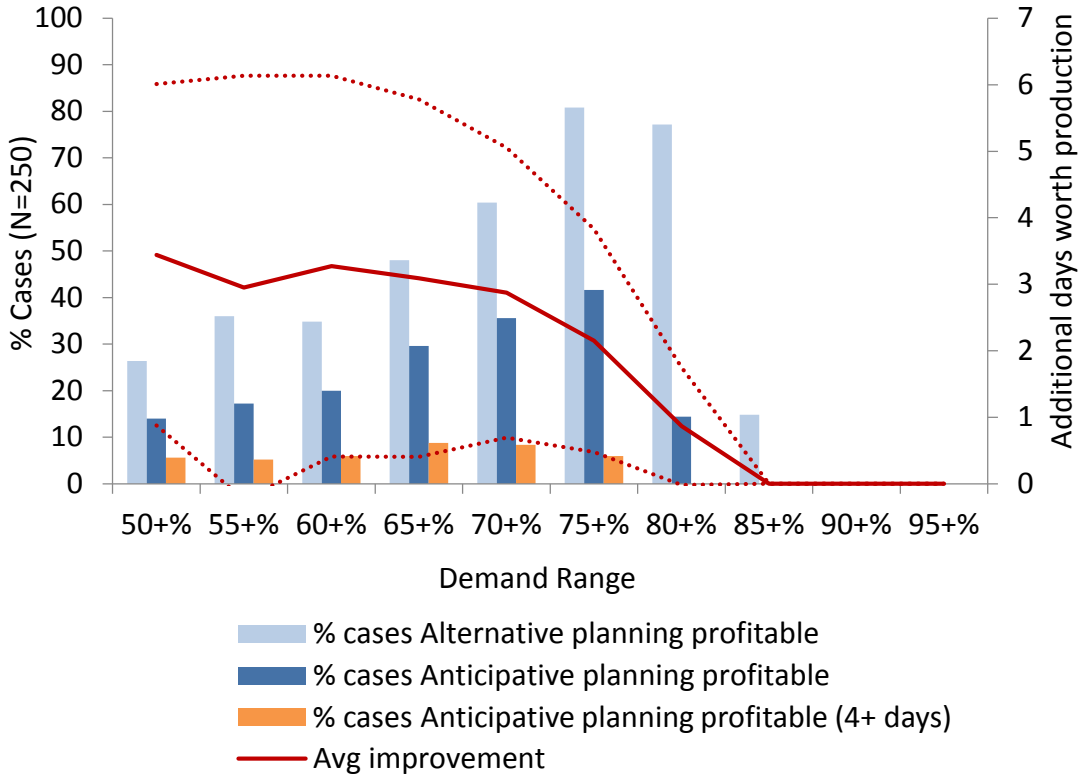
Model tractable to reliably reschedule single turnaround: stages ~ 2T

Solution time for deterministic equivalent of SP is < 2 sec

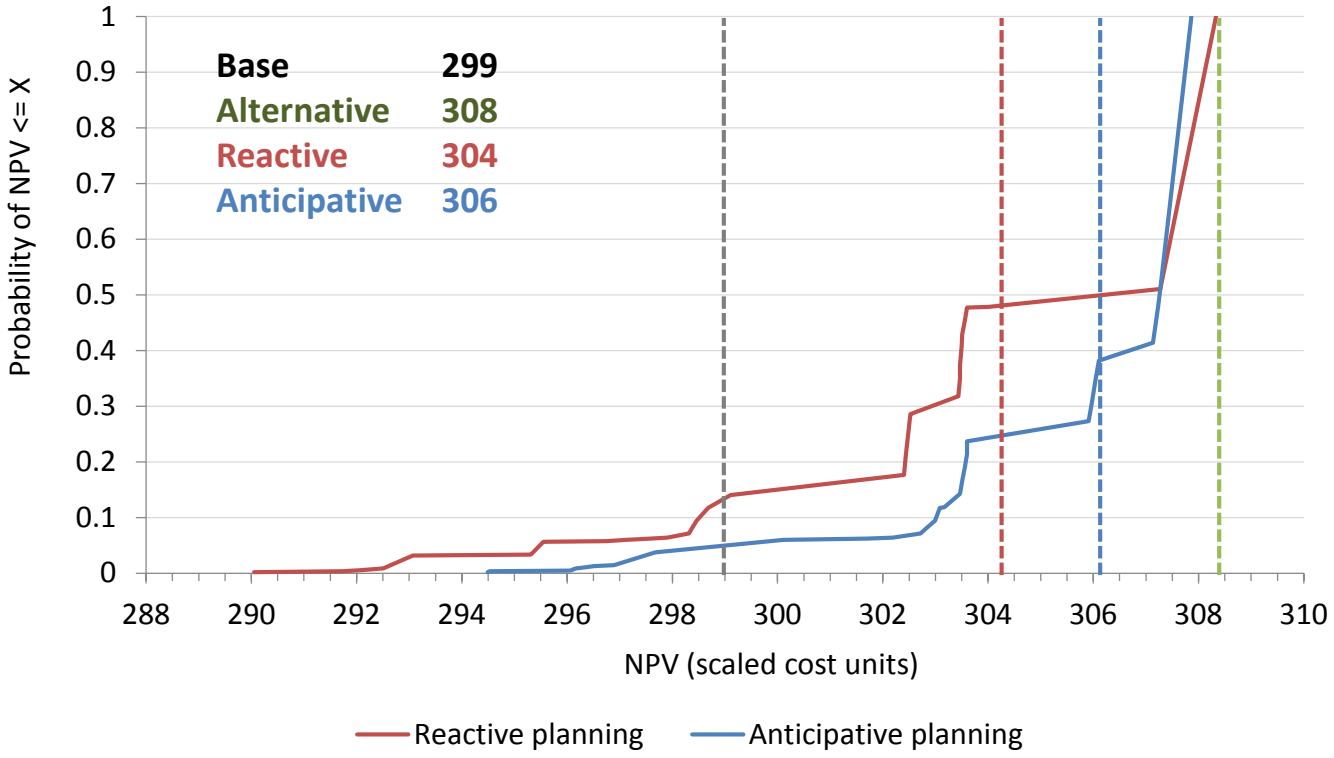
	Base	Alternative	Reactive	Anticipative
variables	**1,408**	**1408**	**27,648**	**54,736**
constraints	**1,987**	**1,987**	**38,435**	**434,035**
non-zeros	**5,441**	**5,441**	**105,281**	**916,513**

Potential reschedulable instances

NPV improvement: Anticipative vs Base



Risk profiles: cumulative distribution of profits

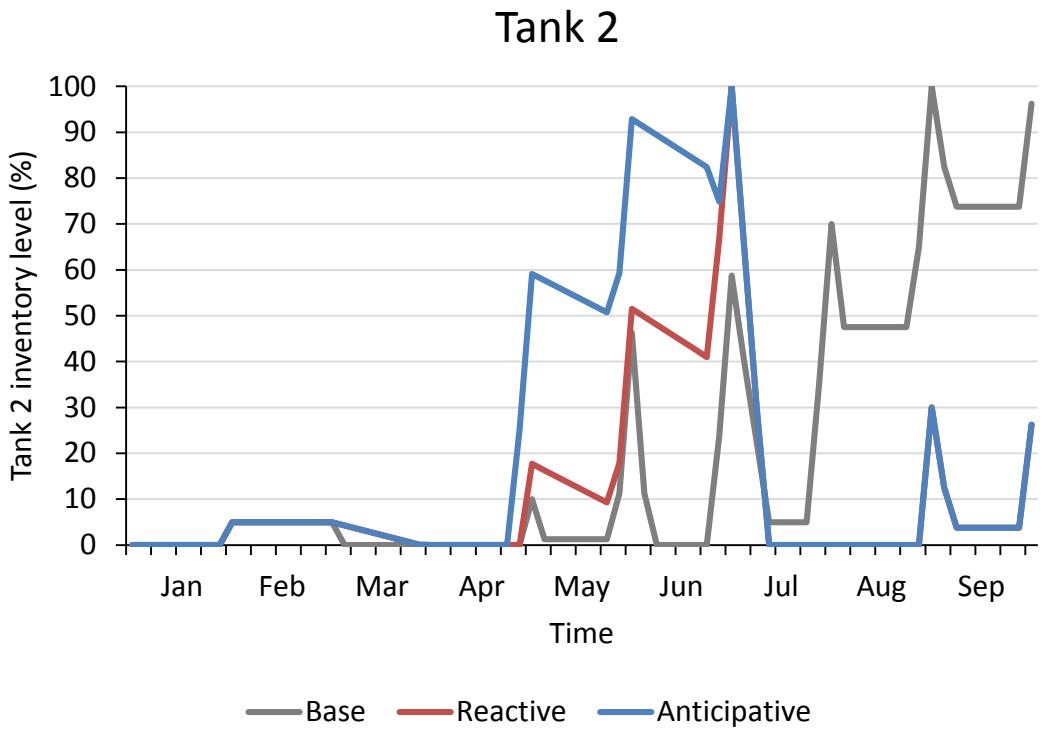


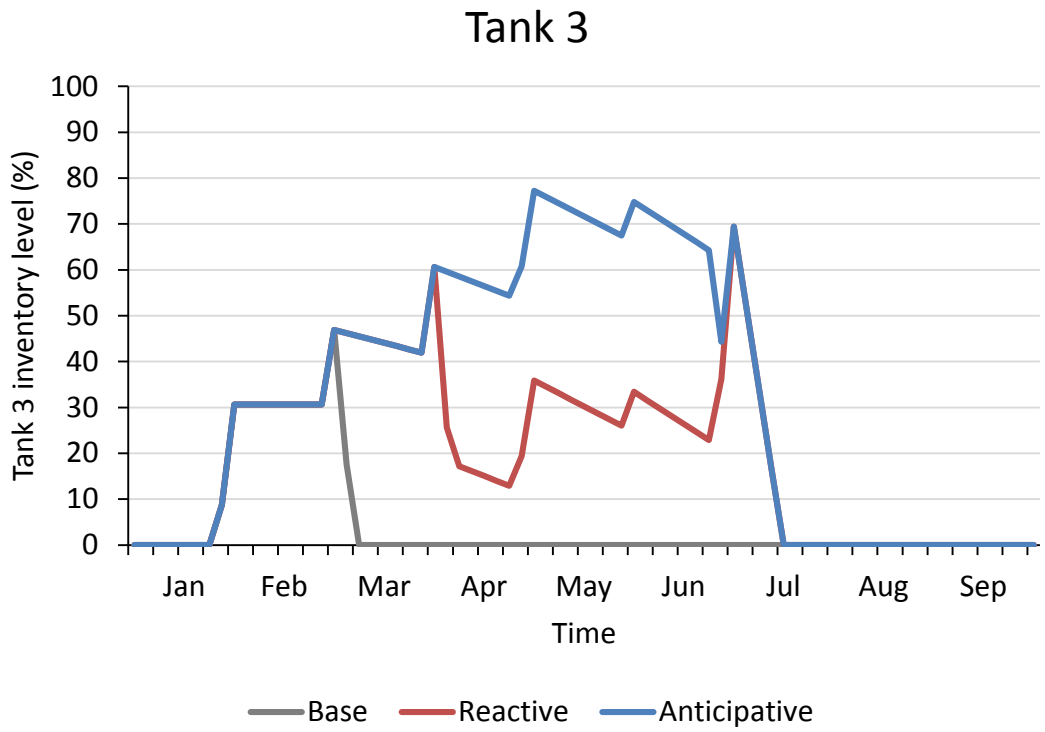
- 10-30% instances can be reliably rescheduled
- More than 4 days worth production recovery in about 5% cases

- 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



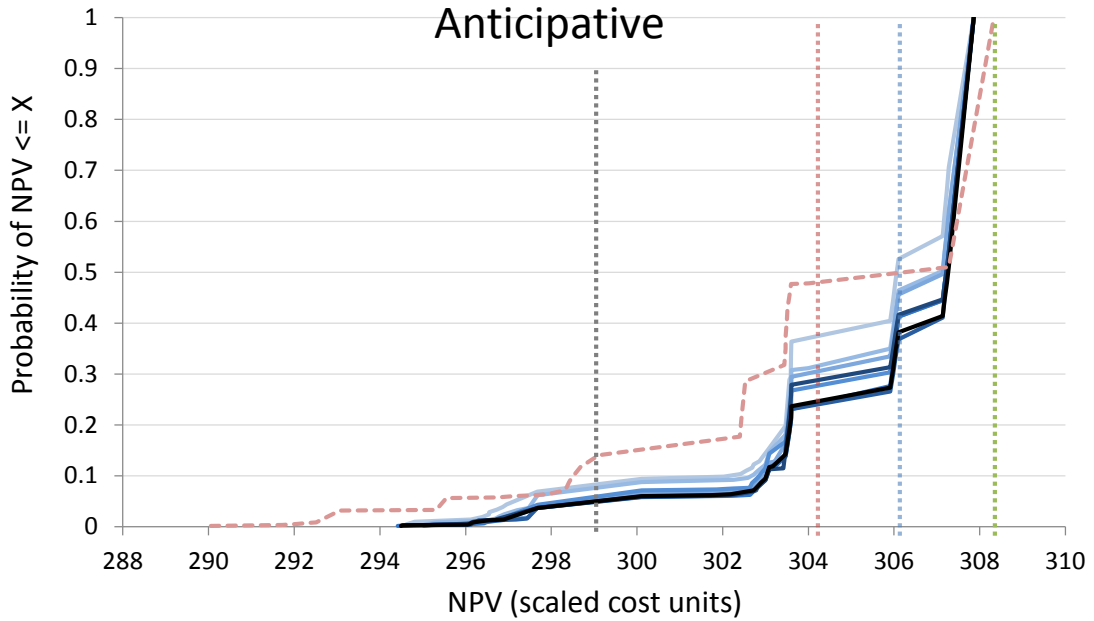


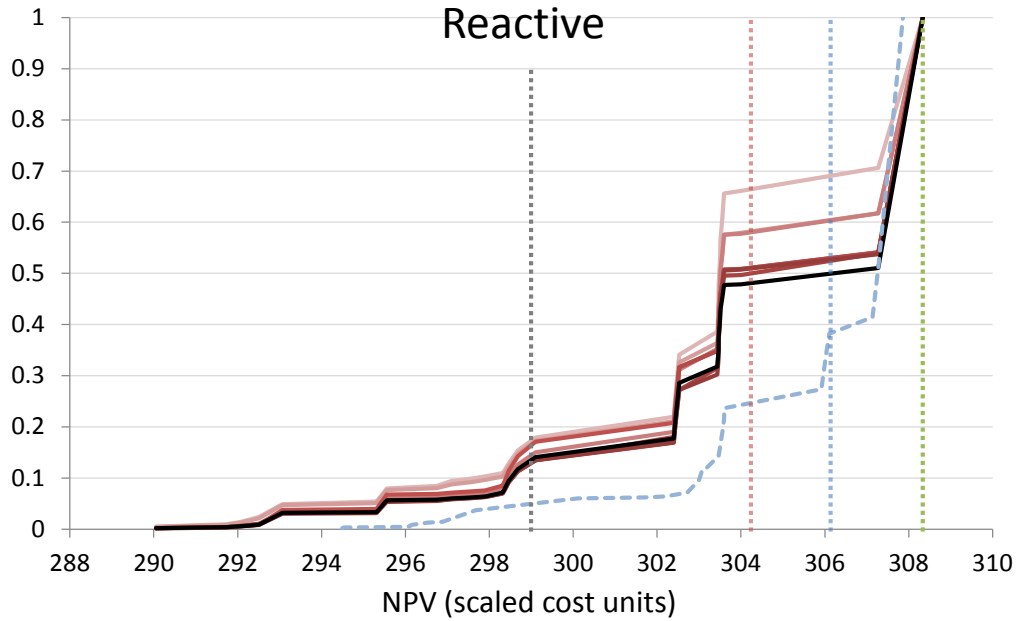
- Anticipative plan recommends more inventory to hedge against future uncertainties
- A small premium of 0.5 scaled cost units is incurred in the form of additional holding cost

Sensitivity to outage probabilities

What if outage probabilities data are underestimated?

Dark to light: by 5% months 1, 2, 3, 4, by 5% for all months, + severity by 10%, outage + severity by 10%
[7 profiles + nominal (black) + alternative planning(dashed)]

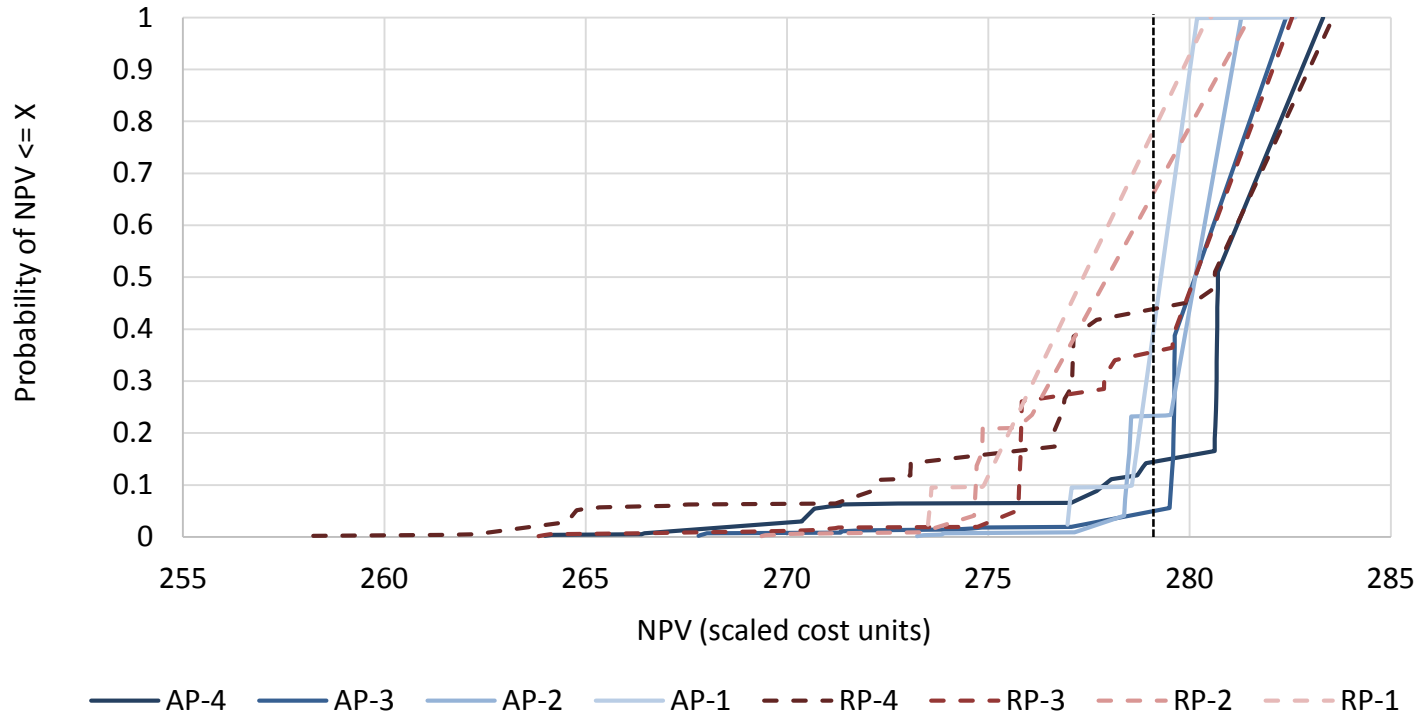




- For small target profit values (near base NPV of 299), the change in probability of loss is within 5%
- Even for 5%-10% underestimation in outage probabilities, CDFs of profits from anticipative planning model values reschedule more than reactive plan

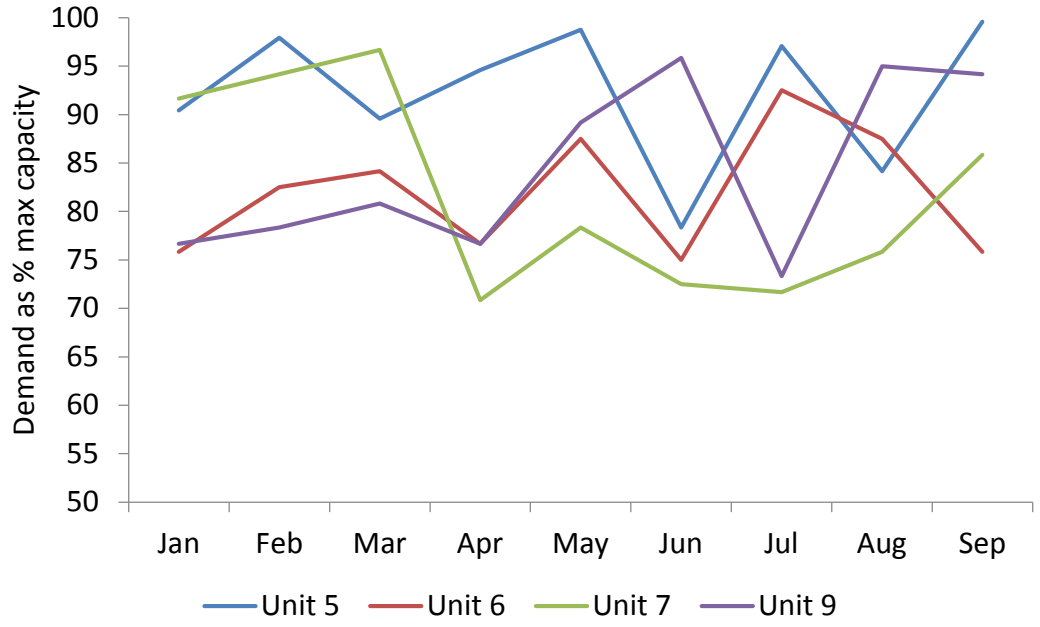
Sensitivity to reschedule time window

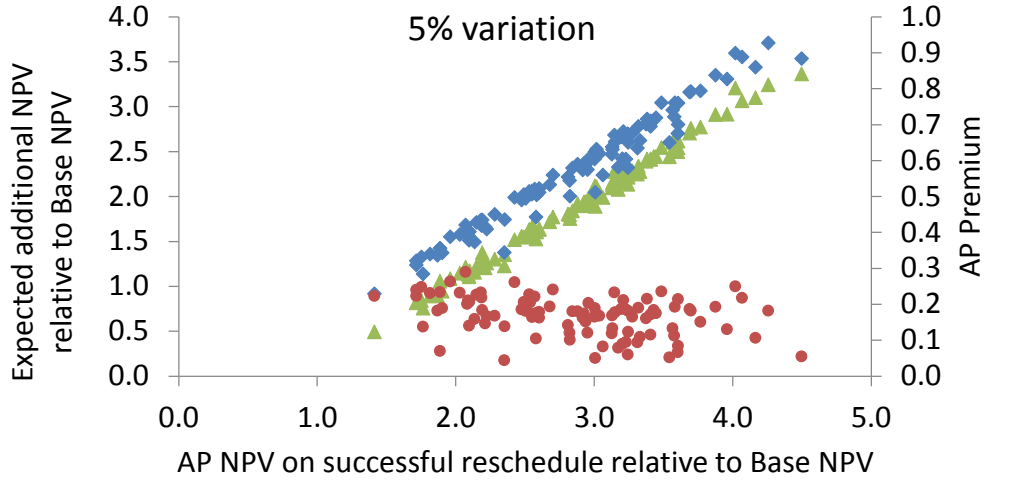
Effect of reschedule time (1 to 4 months) for decreasing demands

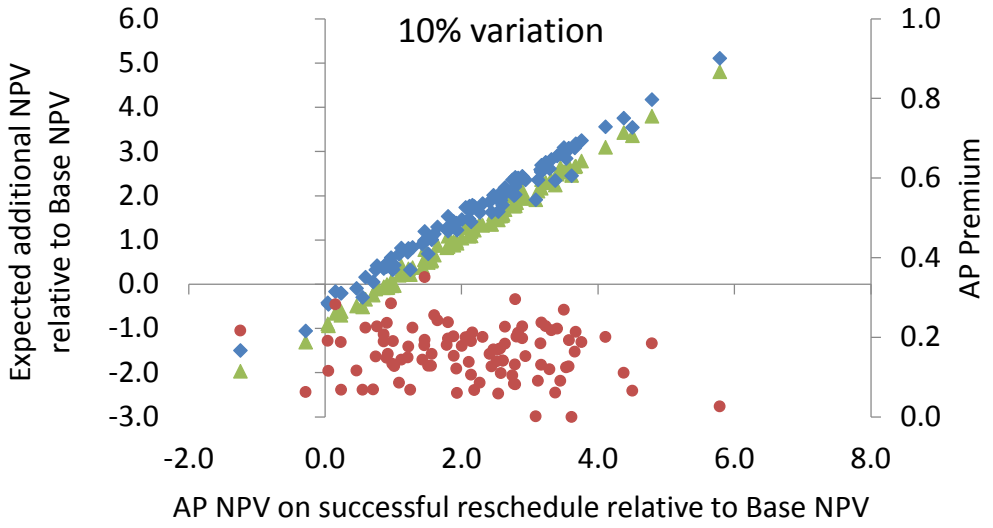


- Rescheduling by a short window (1-2 months) is risky since demands are not sufficiently low to save on loss from sales revenue
- Longer window (4 month) is also risky here due to corrective maintenance costs from potential outages

Sensitivity to demands







- Variation within 5% is still profitable
- Anticipative better than reactive planning
- Premium is roughly the same – doesn't cost more

Conclusions

- Planning turnaround reschedules as multistage stochastic programming model hedges against uncertainties due to outages at a small premium
- Rescheduling turnarounds offer production recovery as high as 11-12 days depending on demands and integration effect
- 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

Data for case studies

- Reactive TA's are ~35% longer and ~20% more expensive
- PS's are ~25% of TA costs
- Costs were time value adjusted for some test cases
- Production rate degradation assumed 2-6% every month
- Time value of money: 10% per annum