Optimal Design of Reliable Integrated Chemical Production Site

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In collaboration with The Dow Chemical Company

Saudi Aramco & Dow: Huge grassroots Integrated Site (IS)

Petrochemical JV integrated with refinery complex (1)

60 production units (2)

28 commodities & specialty chemicals (2)

Will be one of the largest grassroots plastics and chemicals production facilities in the world. (1)

(1) http://news.dow.com/dow_news/corporate July 12, 2007

(2) http://www.icis.com/Articles February 2, 2010

Goal

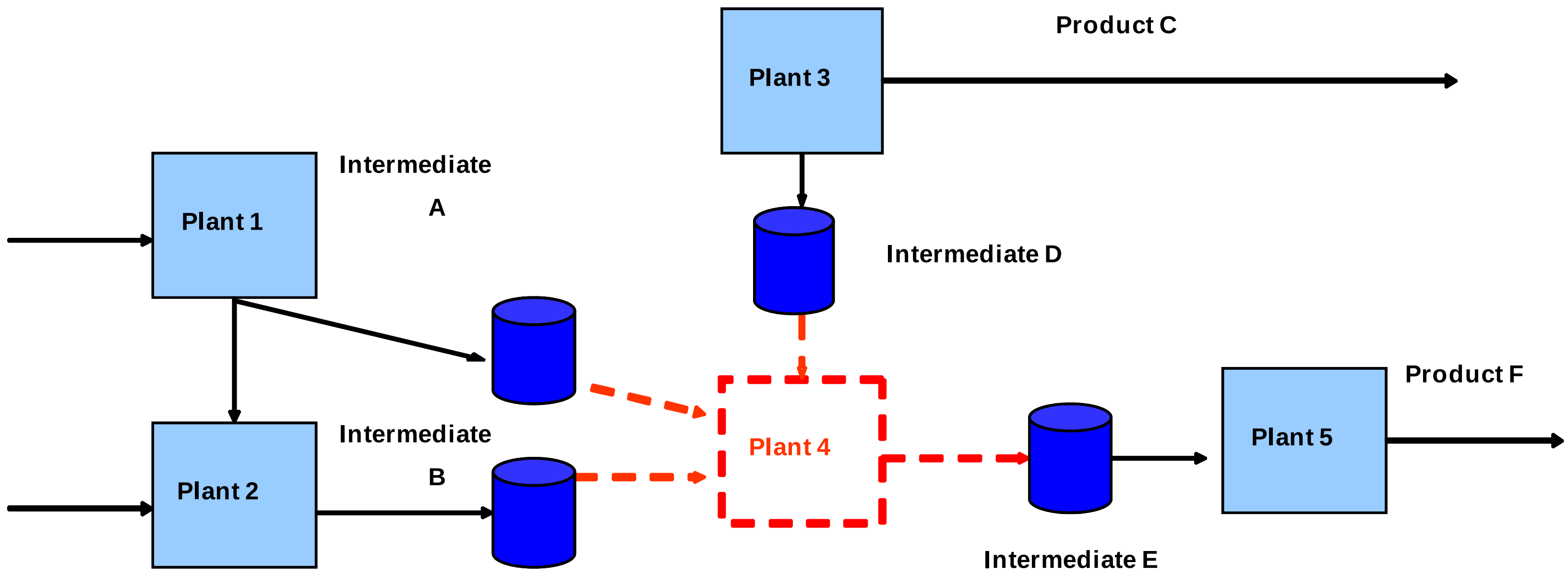
Provide a computational tool that:

Optimizes the use of available capital for the design of an Integrated Site considering random equipment failures

With the objective of maximizing Service level SL

i.e., maximizing probability of meeting entire demand
(while subject to discrete uncertainties).

Intermediate storage increases the Service Level of an integrated site



<u>Effects of intermediate storage:</u>

Buffer of supply-demand mismatch

Material available if upstream plant fails

Upstream plant can keep running if downstream plant fails

Focus of this talk: Optimization of Service Level using intermediate storage

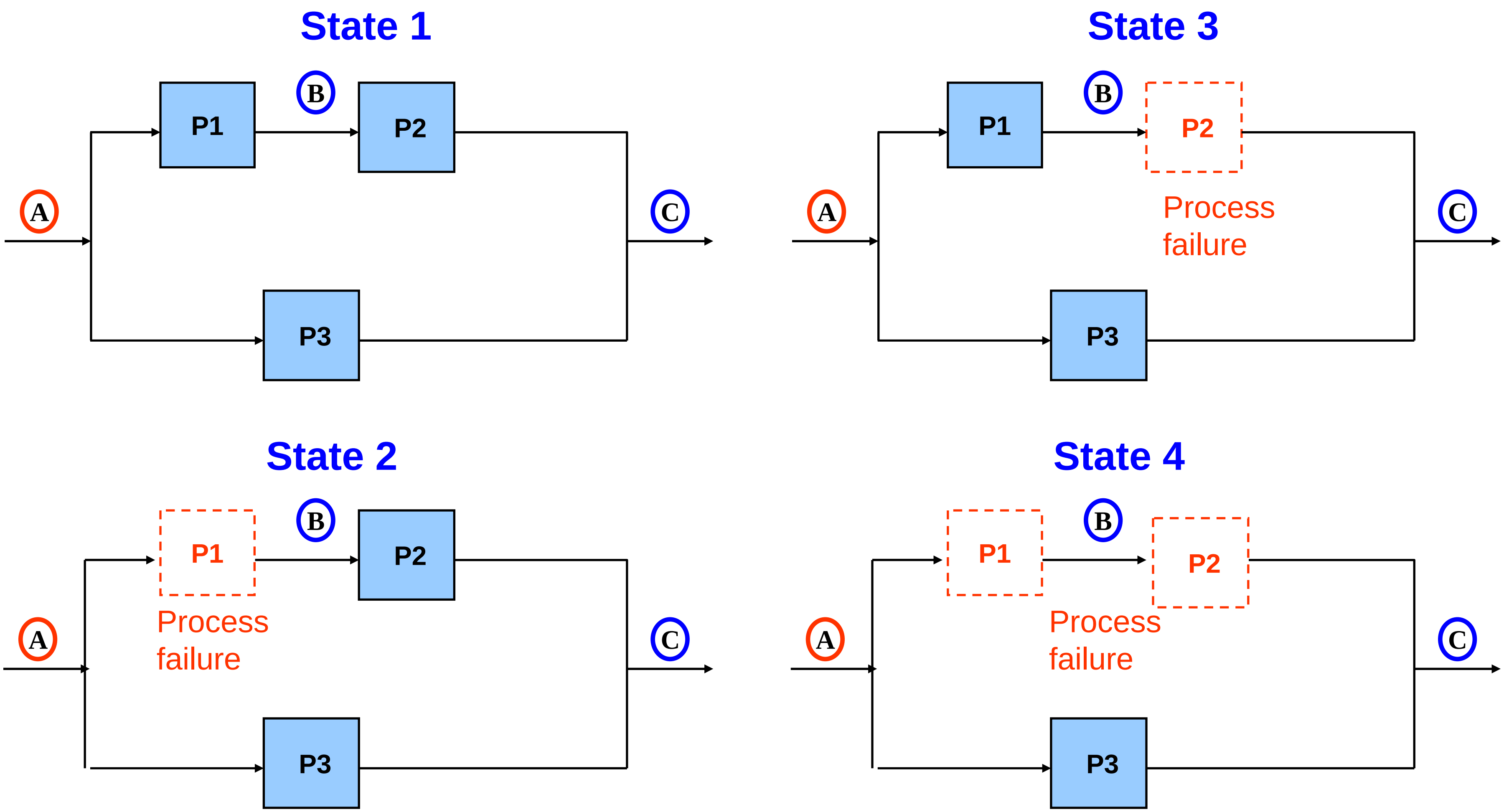
Given	Determine
• The flowsheet of an integrated site	• Size of intermediate storage
• A linear mass balance model	• Average inventory (set point)
• Probability distributions of discrete uncertainties (plant failure modes).	• Operation of intermediate storage during each failure mode scenario
• A cost function	

Objective

Maximize Service Level

Remark: This is a sub problem of the optimal design of reliable integrated chemical production sites

Our modeling approach uses a state space representation



The system continuously transitions among states

The following parameters are given for each state

- ***$prob_s$*** **probability associated with each state**
  How likely it is to find a combination of active and failed plants

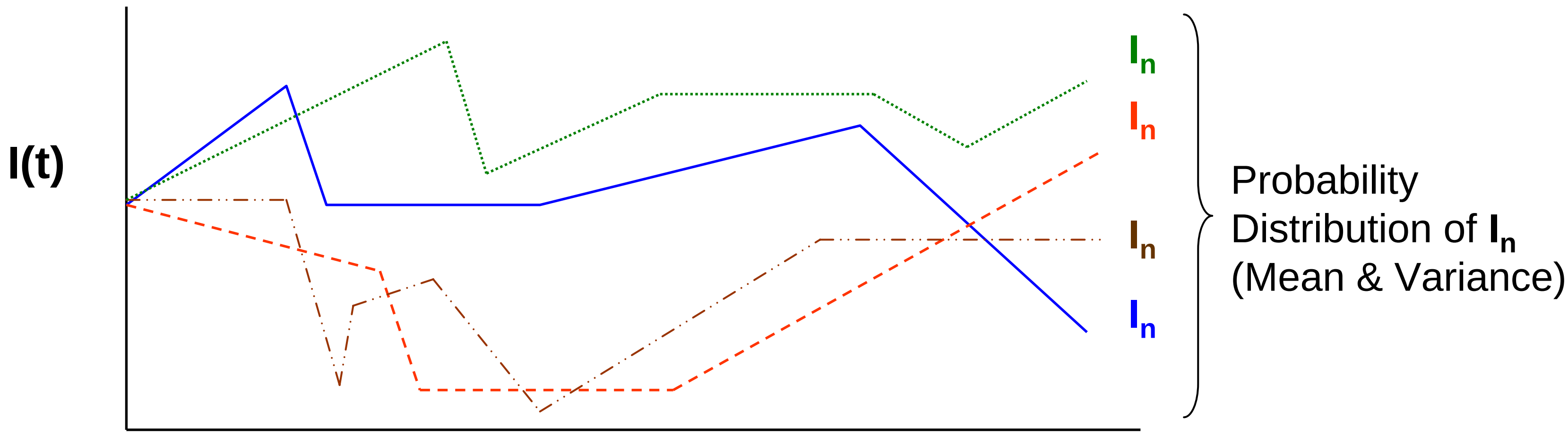
- ***fr_s*** **frequency for visiting each state**
  How often the system enters into a state (visits / unit time)

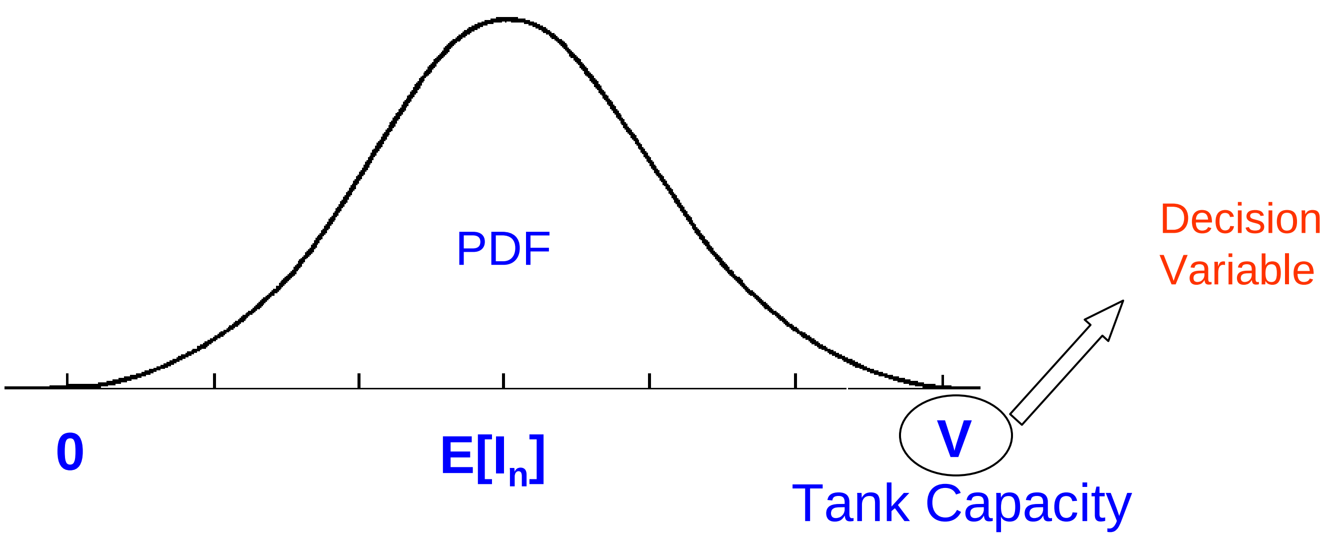
- ***mrt_s*** **mean residence time**
  Average time spent in each state

- ***vrt_s*** **variance of residence time**
  Dispersion for time spent in each state in different visits

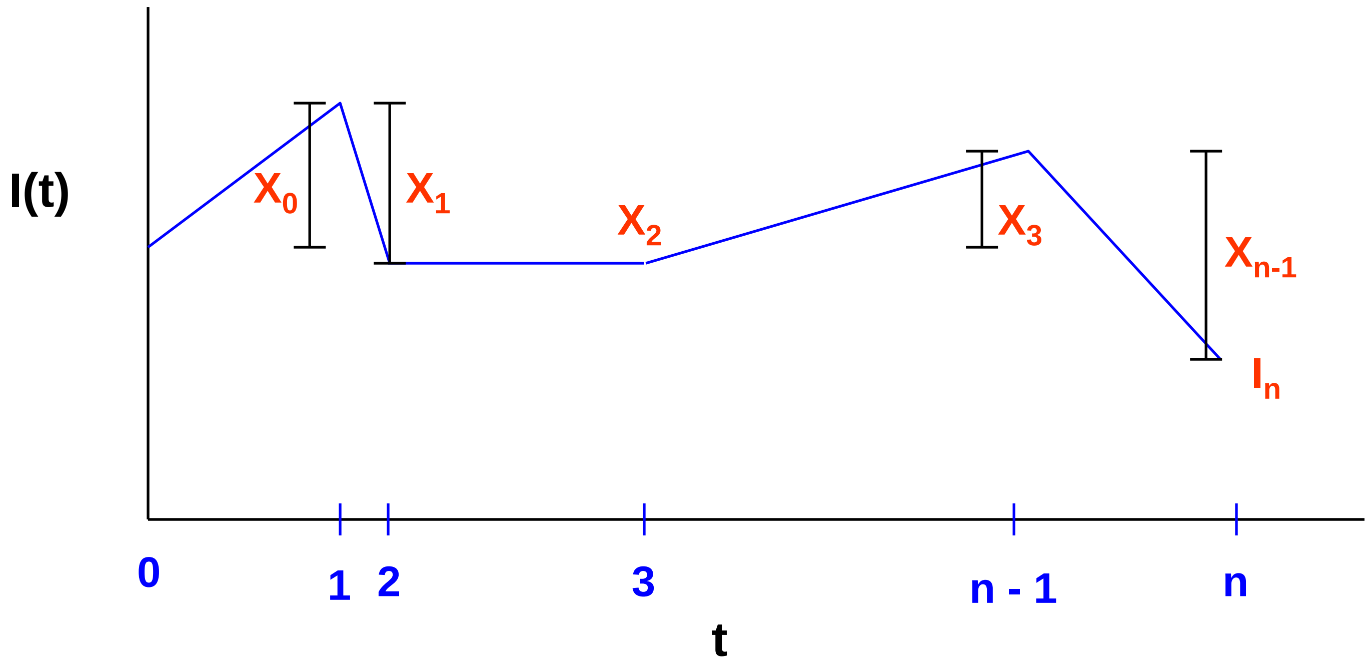
- ***tc_s*** **cycle time**
  Time interval between successive visits to a state

Each sequence of states results in a trajectory for inventory levels





Proposed approach: Describe inventory levels as a random variable



X_i : = material consumed/replenished from epoch *i* to epoch *i+1*

X_i is a random variable

$$I_n = I_0 + \sum_{i=0}^{n-1} X_i$$

Average and variance of inventory level are function of reliability parameters & decision variables

$$I_n = I_0 + \sum_{i=0}^{n-1} \delta_{s\text{ at }i} rt_{s\text{ at }i}$$

$$E[I_n] = I_0 + \sum_{i=0}^{n-1} \delta_{s\text{ at }i} E[rt_{s\text{ at }i}]$$

$$E[I_n] = I_0 + t \sum_{s \in S} \delta_s \, fr_s mrt_s$$

$$Var[I_n] = t \sum_{s \in S} \delta_s^2 \, fr_s vrt_s$$

S	**set of discrete states**
δ	**inventory rate**
rt	**residence time**
fr	**frequency for visiting each state**
mrt	**mean residence time**
vrt	**variance of residence time**

fr, mrt, vrt **are problem parameters**

δ is a decision variable in the optimization formulation

Calculations of inventory set point and required tank size

$$E[I_n] = I_0 + t\sum_{s\in S}\delta_s\, fr_s mrt_s$$

$$Var[I_n] = t\sum_{s\in S}\delta_s^2\, fr_s vrt_s$$

$$\sqrt{Var[I_n]} \le \sum_{s\in S}\delta_s\sqrt{vrt_s\, fr_s t}$$

Overestimation of the variance

(A)

$$\sum_{s\in S}\delta_s\, fr_s mrt_s = 0$$

(B)

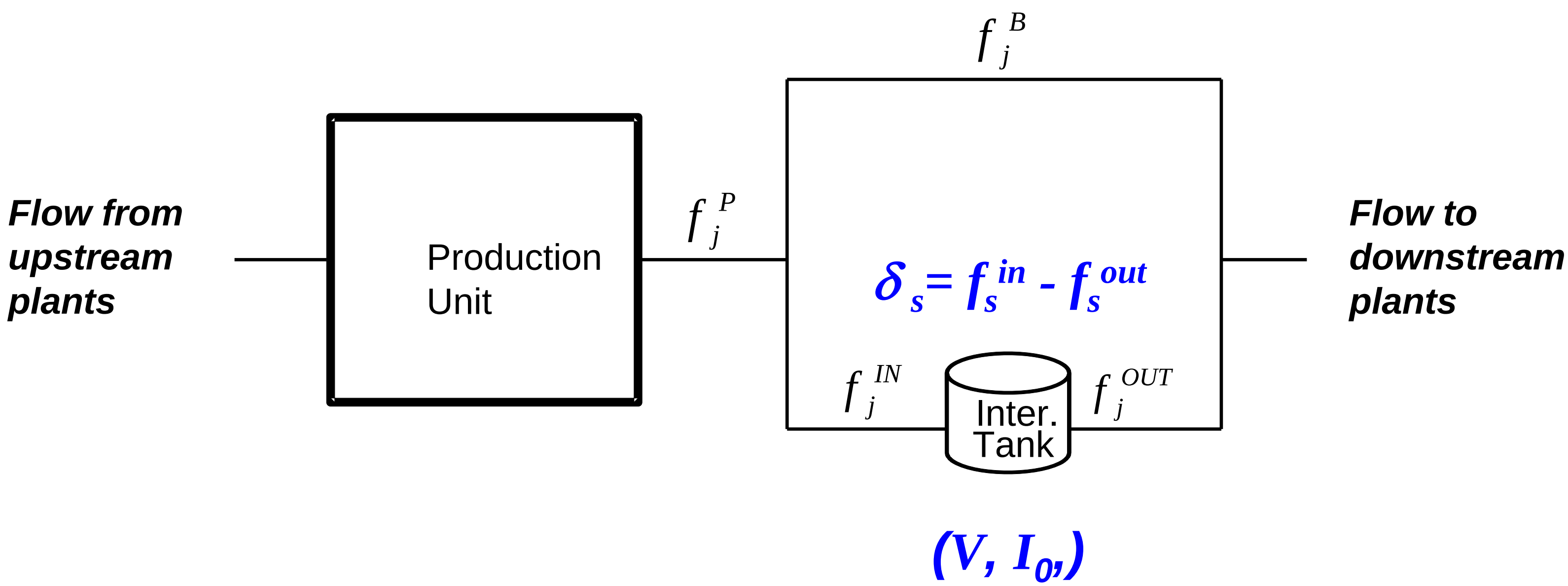
$$I_0 + \tau\sum_{s\in S}\delta_s\sqrt{vrt_s\, fr_s t} \le V$$

$$I_0 - \tau\sum_{s\in S}\delta_s\sqrt{vrt_s\, fr_s t} \ge 0$$

(A) and (B) are constraints in the optimization model

Formulation for optimizing intermediate storage

Each plant in the integrated is represented by a module



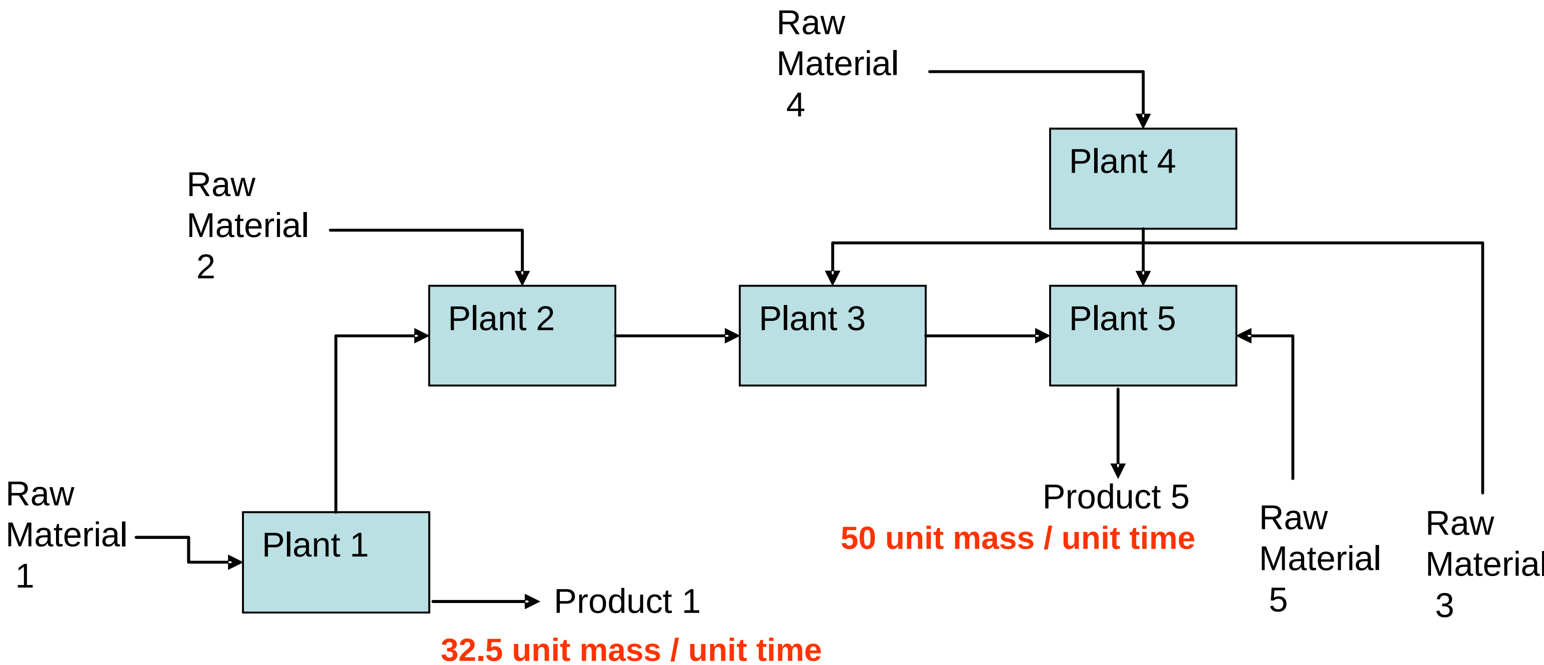
$$\max \quad Service\ Level(V, I_0, \delta_s)$$

$$s.t \quad Capital\ Investment \leq \varepsilon$$

$$+\ rest\ of\ model\ constraints$$

s/S: index/set of discrete states

Example: Subset of industrial integrated process



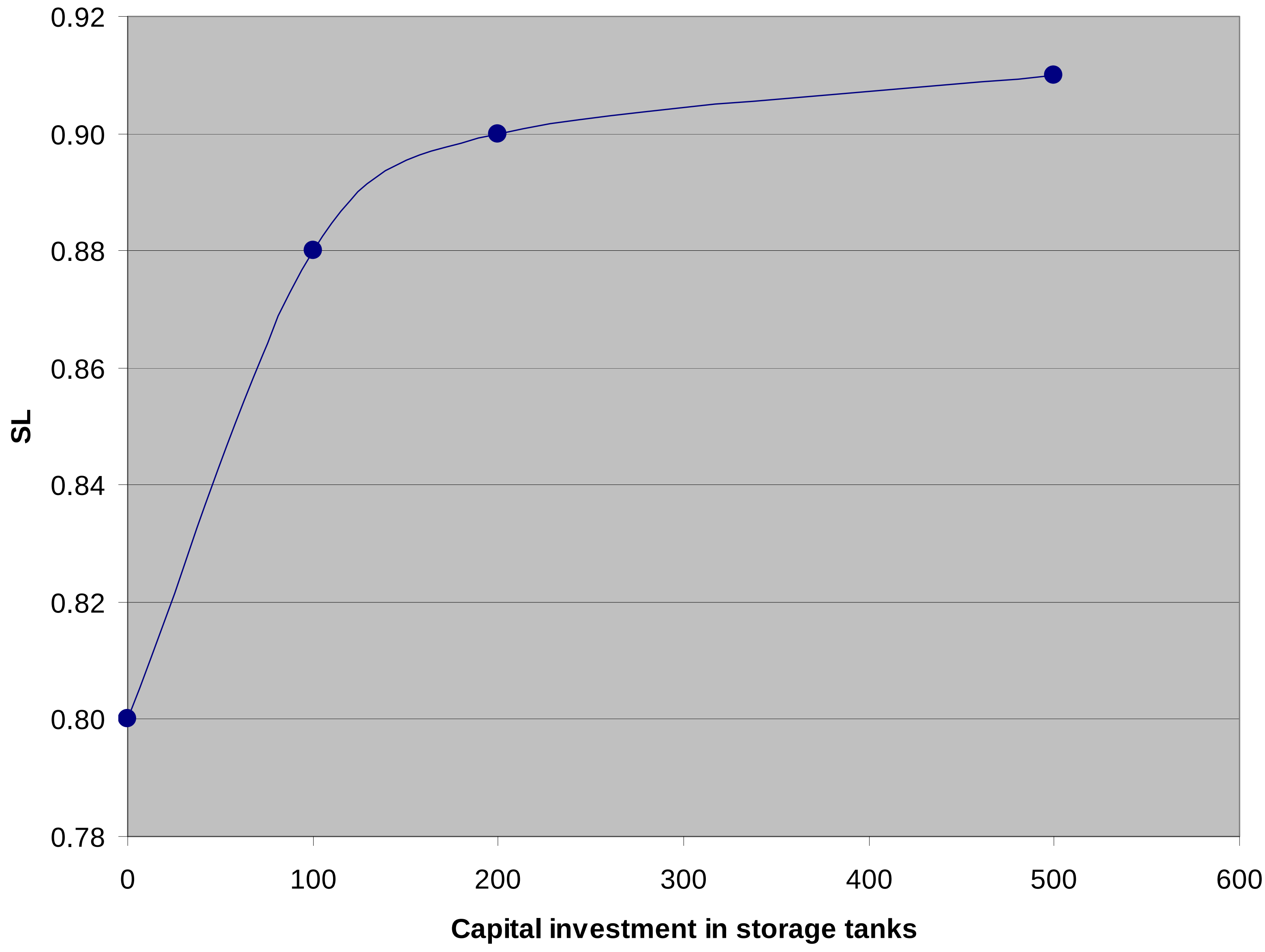
Multiple failure modes in each plant

Aprox. 160 discrete states (combinations of failure modes)

5-plant example is a subset of 9-plant real industrial case study

Size of MILP: 0.5 M constraints; 0.2 M variables; 160 discrete variables

Example: Effect of intermediate storage



Example: Effect of intermediate storage

Available Capital for storage tanks *	Tank 1 [mass units]		Tank 2 [mass units]	
	Volume	Average Level	Volume	Average Level
0 k	-	-	-	-
100 k	-	-	2465	1232
200 k	4760	2380	7500	3750
500 k	15000	7500	7500	3750

Tank 3 [mass units]		Tank 4 [mass units]		Service Level
Volume	Average Level	Volume	Average Level	
-	-	-	-	0.80
7500	3750	-	-	0.88
7500	3750	56	28	0.90
7500	3750	5000	316	0.91

Total CPU time : 240 s

* 1 unit of volume = 10 monetary units

Concluding Remarks

- **The full problem of optimal design of integrated sites also includes process superstructure and variable production capacities.**

  Paper submitted to Computers & ChemE

- **We are developing an algorithm for large-scale problems.**

  Based on Benders Decomposition

  10^6 total variables & constraints; 10^3 discrete variables

- **We have verified our results using state of the art discrete event simulation tools.**

  ExtendSim from *Imagine That! Inc.*