World-Wide Crude Transportation Logistics :

A Decision Support System based on Simulation and Optimization

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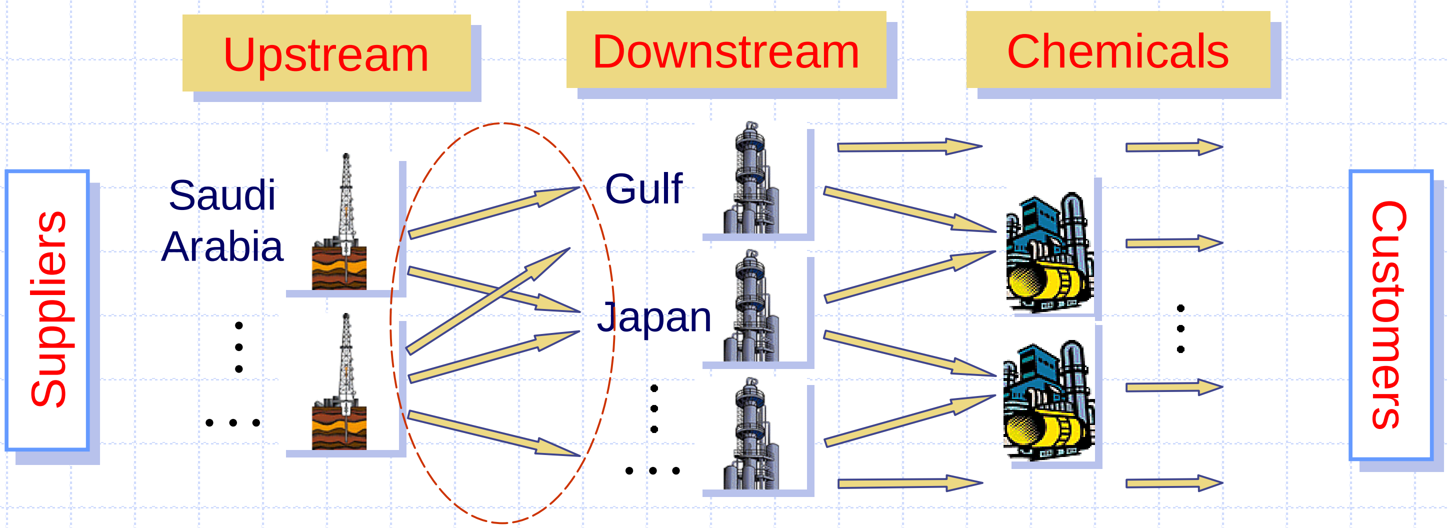
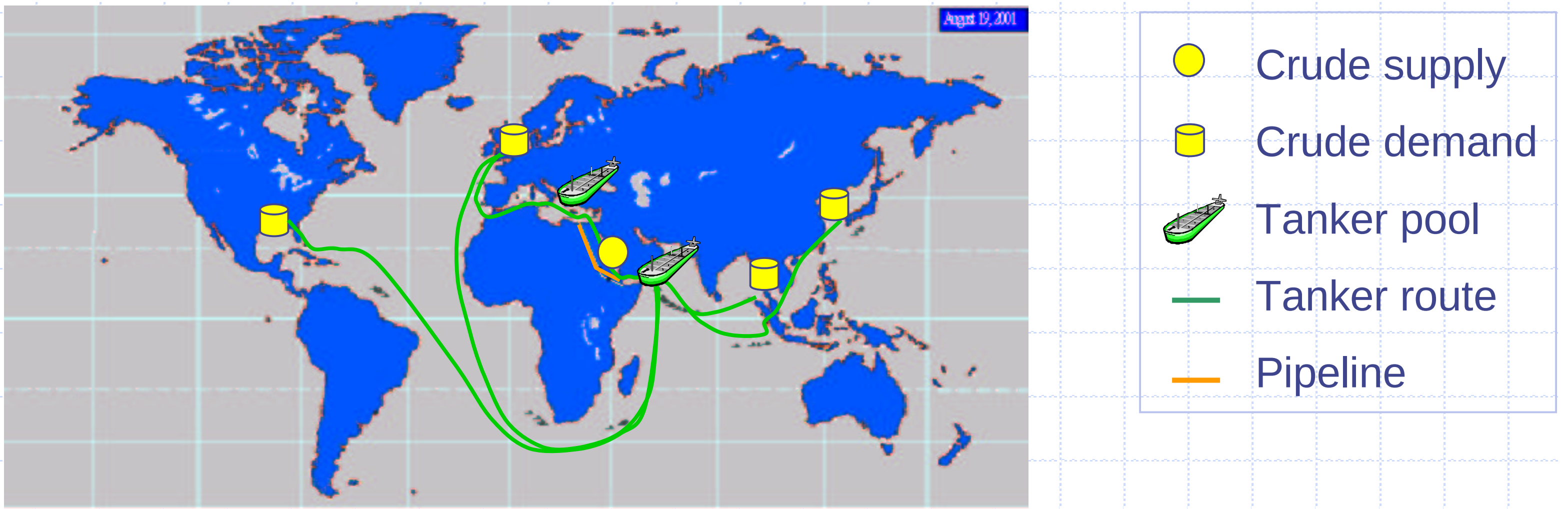
FOCAPO 2003, Coral Springs, Florida, January 12-15, 2003

Motivation and Objectives

- Transportation is the central operation between the "upstream" and "downstream" functions
- To investigate the behavior and improve the performance of the combined transportation and inventory system through simulation and optimization



World Wide Crude Logistics

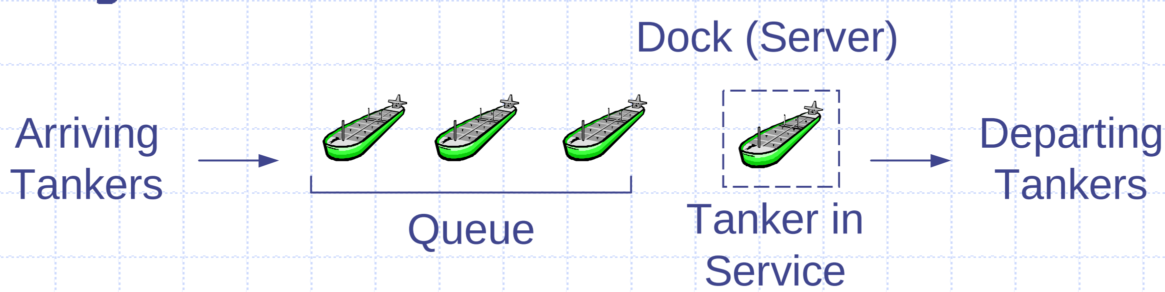


Assume:

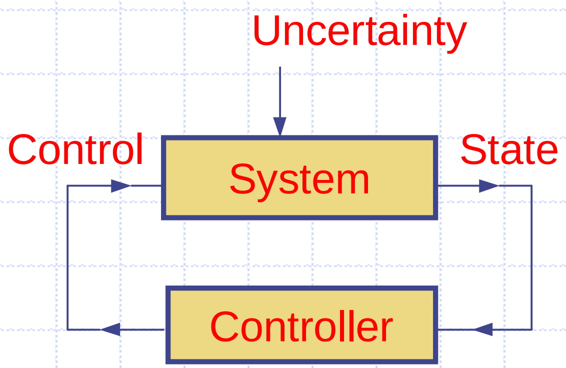
- Yearly world-wide crude transportation cost ~ 2 billion $
- Crude transportation through tanker fleet and pipeline
- Decisions: Sizing and composition of the tanker fleet; dispatch and routing of tankers

Methodologies

- Discrete event simulation
  - → Conduct experiments with the model of a real system to investigate the system behavior and evaluate operation strategies



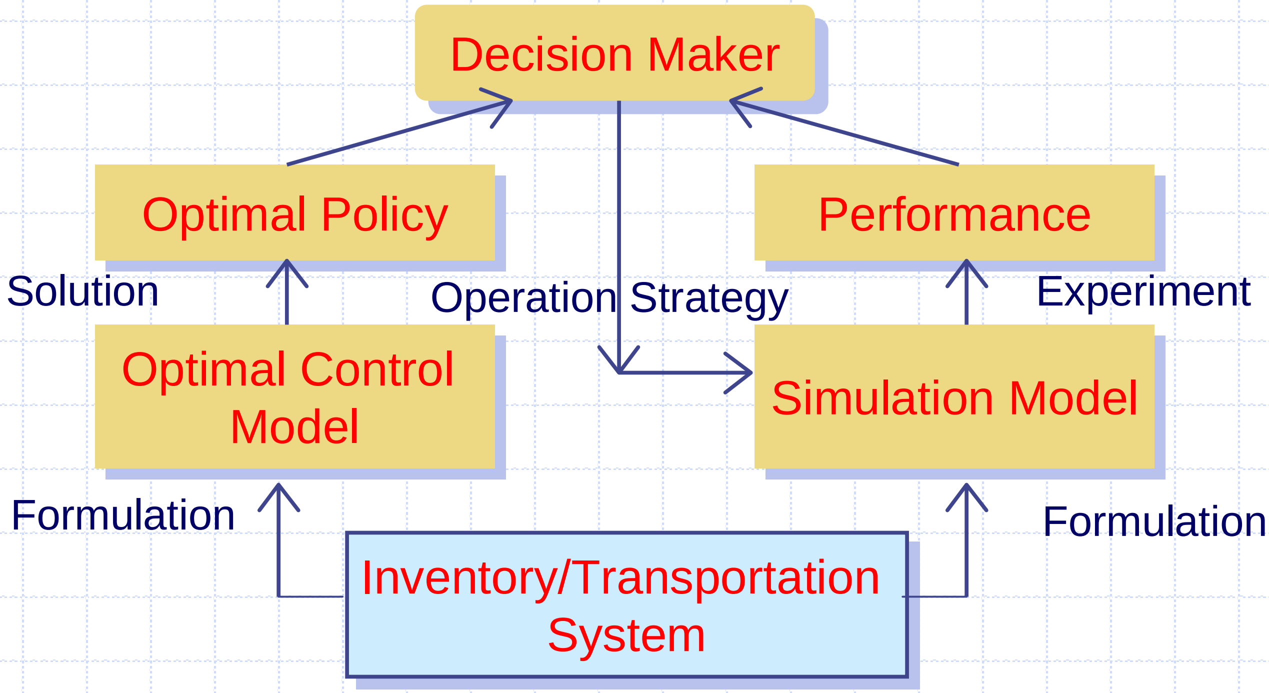
- Stochastic optimal control
  - → Decision makers periodically observe the state of the system and choose control actions according to certain policies



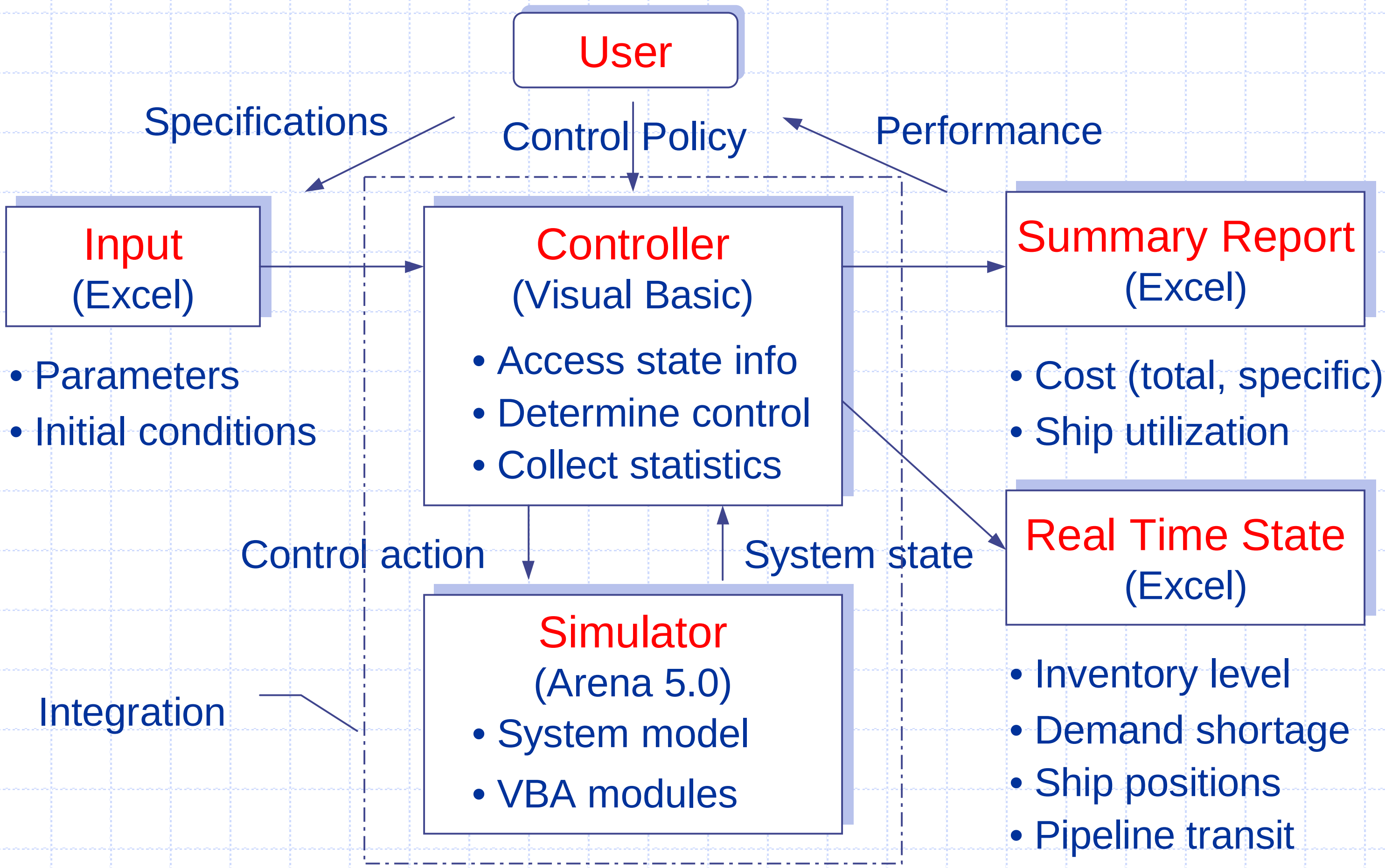
Discrete Event Simulation

Decision Support System

- An integrated decision support system
  - → Simulation: Investigate behavior and evaluate performance
  - → Optimization: Find the optimal or near optimal policies

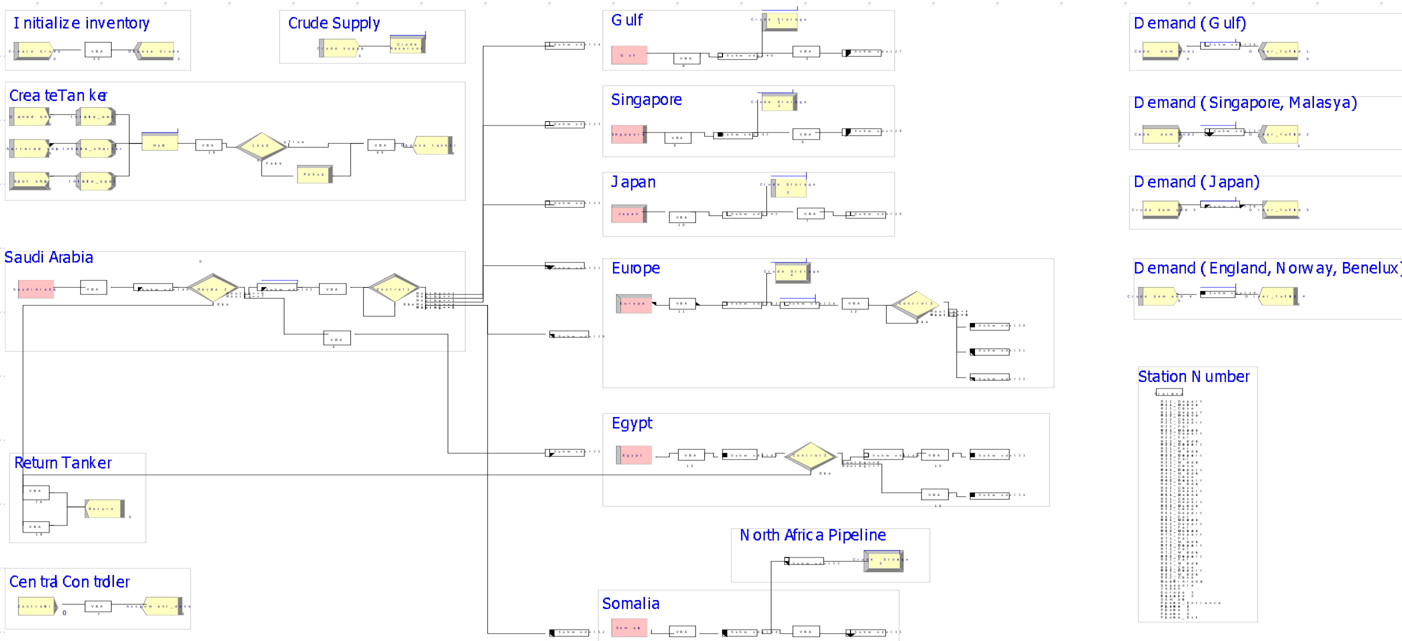


Simulation - Framework



Simulation - Model

- Discrete event simulation using Arena®
  - → Define the model using a process oriented approach
  - → Perform the simulation using an event driven approach



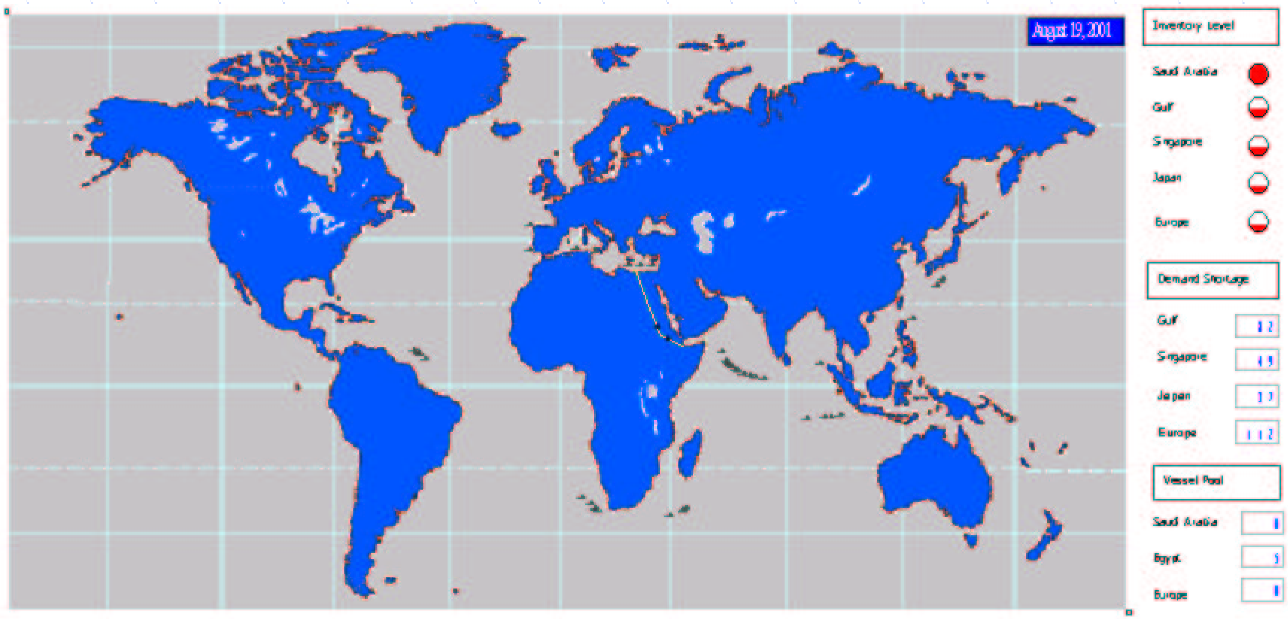
Controller Design

- Integration of simulation model and controller
  - → Access and monitor state information in simulation
  - → Manipulate variables or perform actions
- Active X automation through Visual Basic for Application
- Design and operate the tanker fleet

Physical actions	Arena actions
Rent/return tankers	Create/dispose entities
Dispatch tankers	Send release signals
Route tankers	Assign "route" attribute

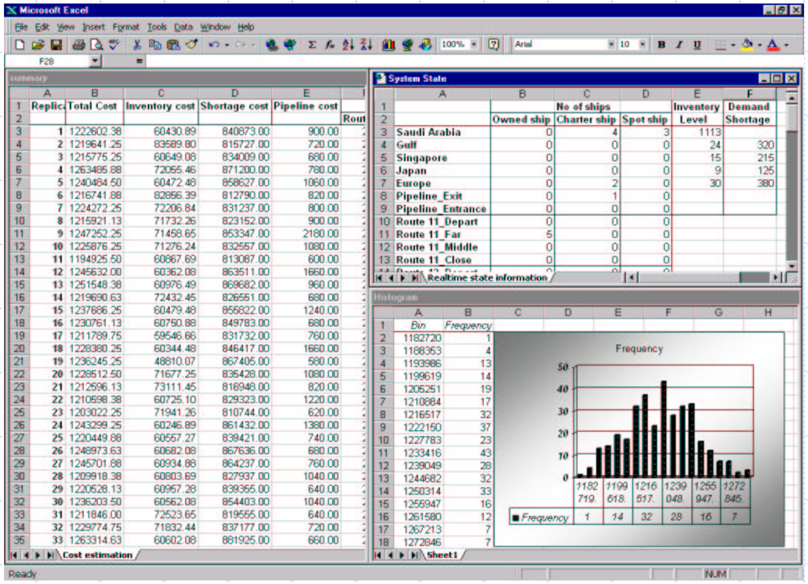
Simulation - Animation

- Visualize the entity flow through in the dynamic system
  - → Movement: traveling tankers, crude parcel, etc
  - → Queuing: crude inventory, waiting orders, etc



Simulation - Report

- Summary report
  - → Cost information - total cost, cost per route, cost per type of tanker, cost per barrel, etc.
  - → System statistics - tanker utilization, etc.
  - → Stochastic analysis
- Real-time state report
  - → Inventory levels
  - → Demand shortage
  - → Positions of tankers
  - → Status of pipeline



Statistical Analysis

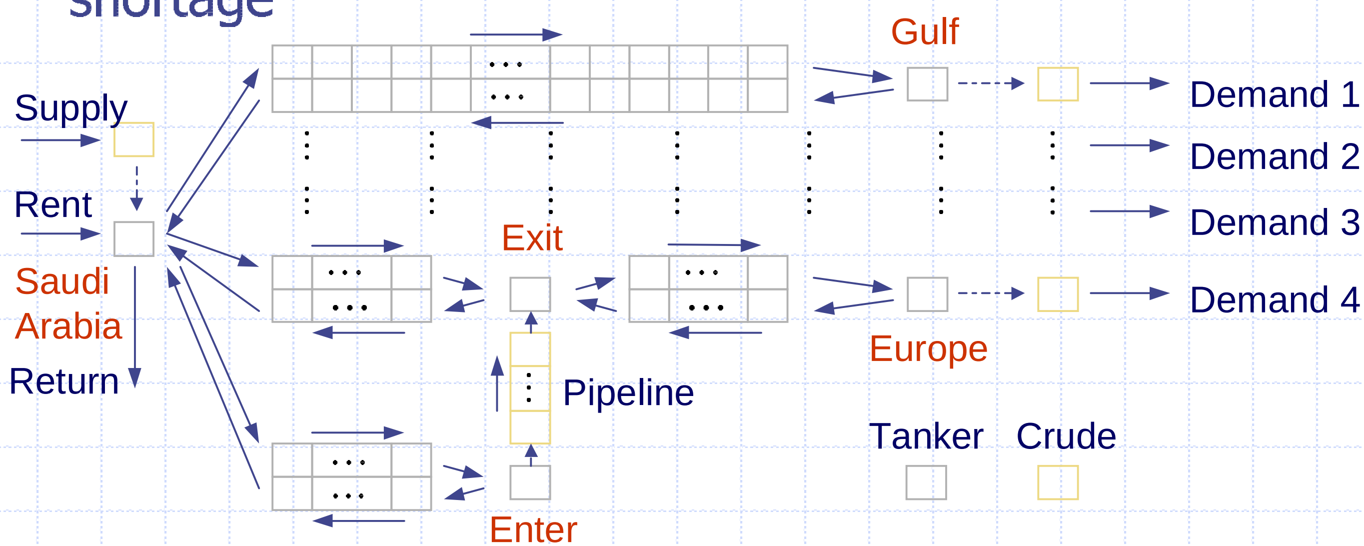
- Analyze and interpret simulation results
- Evaluate system performance under various design and operation strategies
- Example, "How many spot tanker shall we rent?"

	Number of spot tanker	Total cost	Shortage penalty	Ship Utilization
1	0	784656.50	122665.95	59%
2	10	775240.81	8603.27	60%
3	20	841588.52	8578.35	52%

Stochastic Optimal Control

Transportation-Inventory System

- Inventory routing problem
  - → A central decision maker is responsible for replenishing inventory by managing a fleet
  - → Coordination between inventory control and vehicle routing
  - → Transportation system serves as a buffer against demand shortage



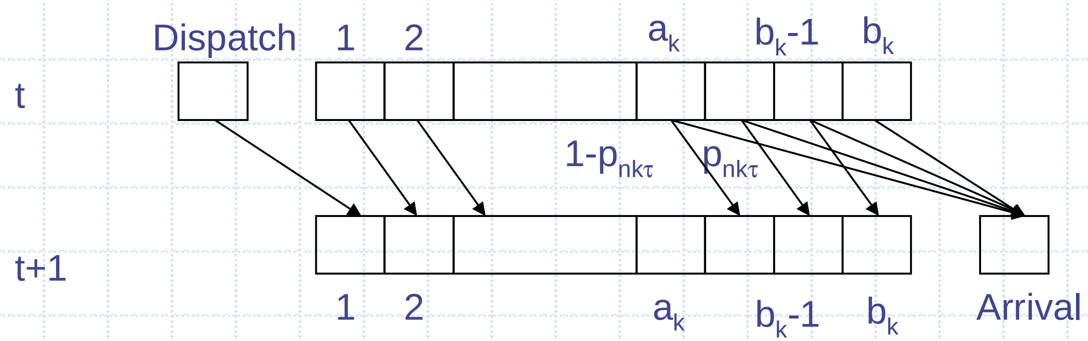
Uncertainty in Travel Time

- Incorporate uncertainty in tanker travel time into inventory/transportation system

$$\alpha_{nk\tau} = \begin{cases} 1 & \text{if tankers that have travled on route } (n,k) \text{ for } \tau \text{ days} \\ & \text{arrive today given that they have not arrived before} \\ 0 & \text{otherwise} \end{cases}$$

$$p_{nk\tau} = P\{\alpha_{nk\tau} = 1\} = \frac{F_{nk}(\tau+1) - F_{nk}(\tau)}{F_{nk}(\infty) - F_{nk}(\tau)}$$

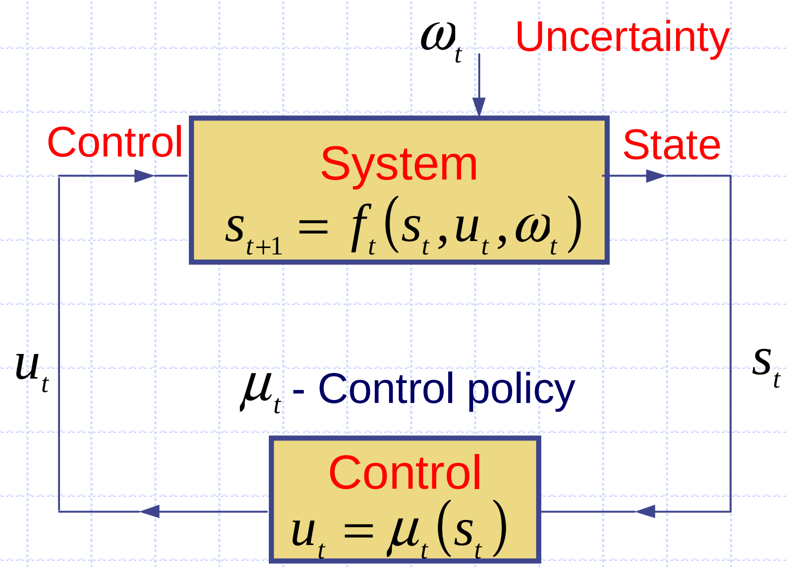
$F_{nk}(t)$ Probability distribution of travel time



Stochastic Optimal Control

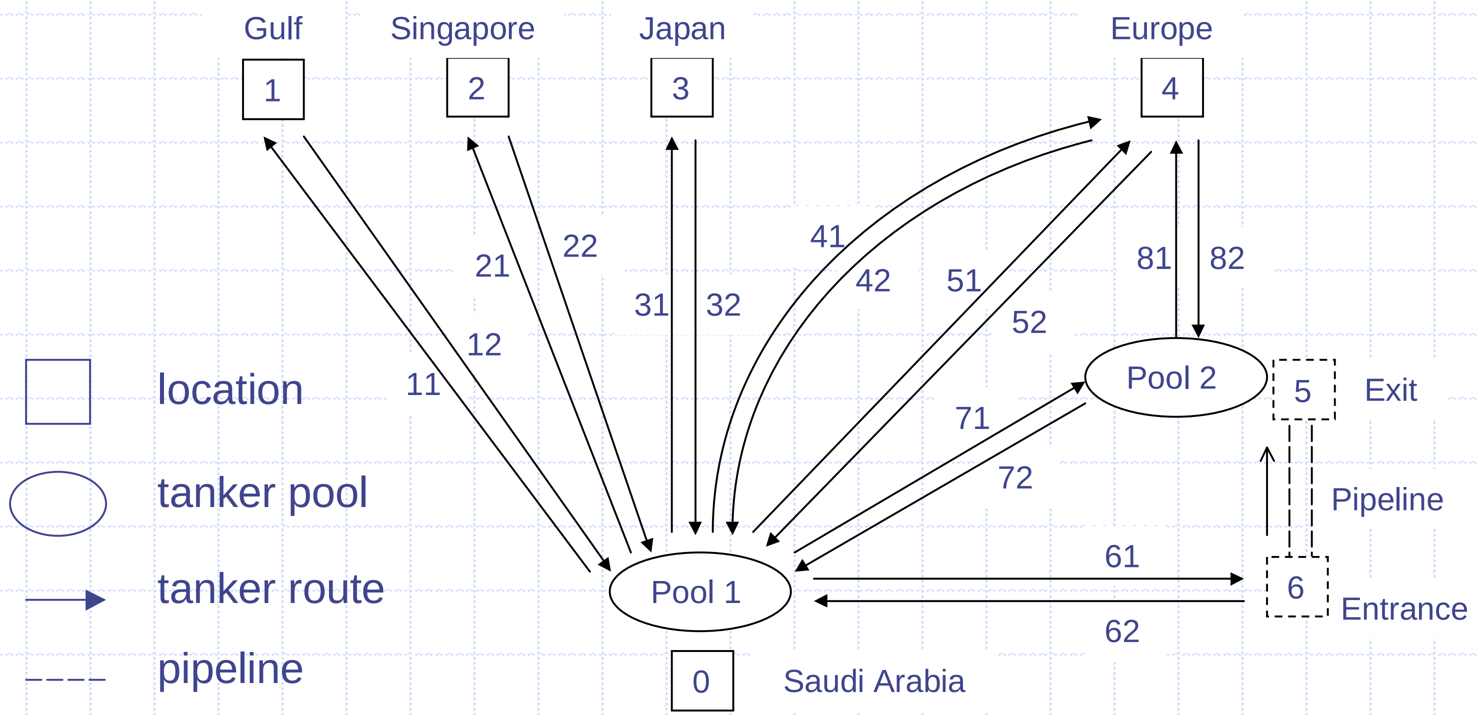
- State information
  - Inventory levels, Demand shortages, Tanker positions, Status of pipeline transportation
- Control decisions
  - Dispatch and routing of existing fleet
  - Creating (chartering or spotting) and returning of tankers
- Uncertainties
  - Crude demands, Tanker travel time, etc.

Minimize: E {Transportation cost + Inventory cost + Shortage penalty…}



Schematic Model

- A simplified representation of the combined inventory/transportation system



Mathematical Formulation

- System state s(t)

$w_{ij}(t)$ number of tankers j at location i

$x_{nkj\tau}(t)$ number of tankers j traveling on route (n,k) for τ days

$z_i(t)$ inventory level at location i

… … … … …

- Control action u(t)

$y_{nkj}(t)$ number of tankers j dispatched to route (n,k)

$r_{ij}(t)$ number of tankers j rented/returned at location i

- Random variable ω(t)

$d_i(t)$ number of tankers j rented/returned at location i

$\alpha_{nk\tau}(t)$ =1 if tankers j that have been traveled on route (n,k) for τ days arrive

Mathematical Formulation (cont.)

- State equations s(t+1) = f_t(s(t),u(t),ω(t))

$$w_{0j}(t+1) = w_{0j}(t) - \sum_{k=1}^{7} y_{1kj}(t) + \sum_{k=1}^{7}\sum_{\tau=a_k}^{b_k} \alpha_{2k\tau} x_{2kj\tau}(t) + r_{0j}(t)$$ tanker pool

$$z_0(t+1) = z_0(t) - \sum_{j=1}^{3}\sum_{k=1}^{6} y_{1kj}(t)\cdot c + v(t)$$ inventory change

… … … … …

- Cost equations g_t(s(t),u(t))

  tanker costs + operating costs + holding costs+ inventory costs + shortage penalty + canal toll + pipeline costs …

- Control Set u(t)∈U(s(t))

$$0 \le \sum_{k=1}^{7} y_{1kj}(t) \le w_{0j}(t) + r_{0j}(t)$$ tanker availability

$$\sum_{j=1}^{3} y_{21j}(t) \le (MC_1 - z_1(t))/c$$ storage availability

Dynamic Programming

- Optimal control is to find a strategy π, which is a sequence of control policies

$$\pi = (\mu_1, \ldots, \mu_N) \in \Pi \qquad u_t = \mu_t(s_t)$$

such that

$$J_{\pi^*}(s_0) = \min_{\pi \in \Pi} E\left\{ \sum_{t=1}^{N-1} g_t(s_t, \mu_t(s_t), \omega_t) + g_N(s_N) \right\}$$

- Bellmans' equations

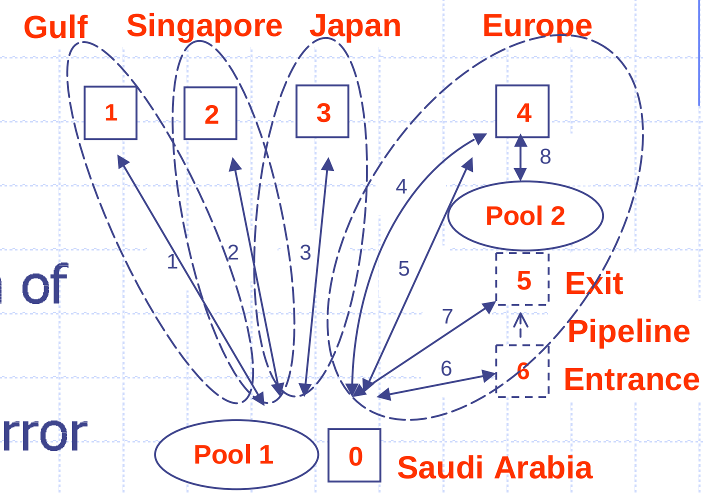
$$J_t(s_t) = \min_{u_t \in U(s_t)} \{ g_t(s_t, u_t) + E\{ J_{t+1}(s_{t+1}) \mid s_t, u_t \} \}$$

$$\mu_t(s_t) = \arg \min_{u_t \in U(s_t)} \{ g_t(s_t, u_t) + E\{ J_{t+1}(s_{t+1}) \mid s_t, u_t \} \}$$

$\forall s_t \in S$ N(s) is prohibitively large – "curse of dimensionality"

Solution Strategies

- Decomposition of the system
  - → A controler for each subsystem
- Approximation of subproblems
  - → Parametric function approximation of individual cost function
  - → Find a parameter that minimizes error



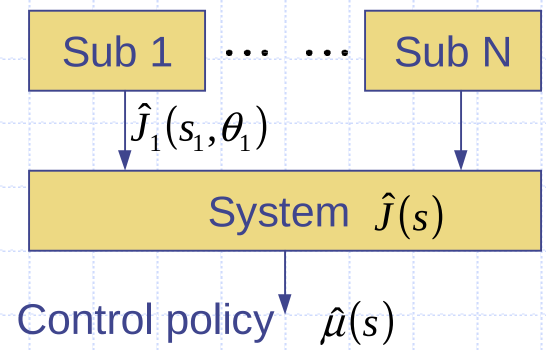
$$\tilde{J}_{mt}(s_{mt}, v_{mt}, \theta_t) = \theta_{1t}\phi_1(s_{mt}, v_{mt}) + \cdots + \theta_{Kt}\phi_K(s_{mt}, v_{mt})$$

v_{mt} tanker capacity assigned to subsystem m θ_t parameter vector

$$\min_{\theta_t} \sum_{(s_{mt}, v_{mt}) \in S} \gamma_{mt}(s_{mt}, v_{mt}) \left[J_{mt}(s_{mt}, v_{mt}) - \tilde{J}_{mt}(s_{mt}, v_{mt}, \theta_t) \right]^2$$

Solution Strategies (cont.)

- Computation of control policies
  - → Approximate the overal cost function by solving a knapsack problem
  - → Find near optimal policies based on the Bellman equations



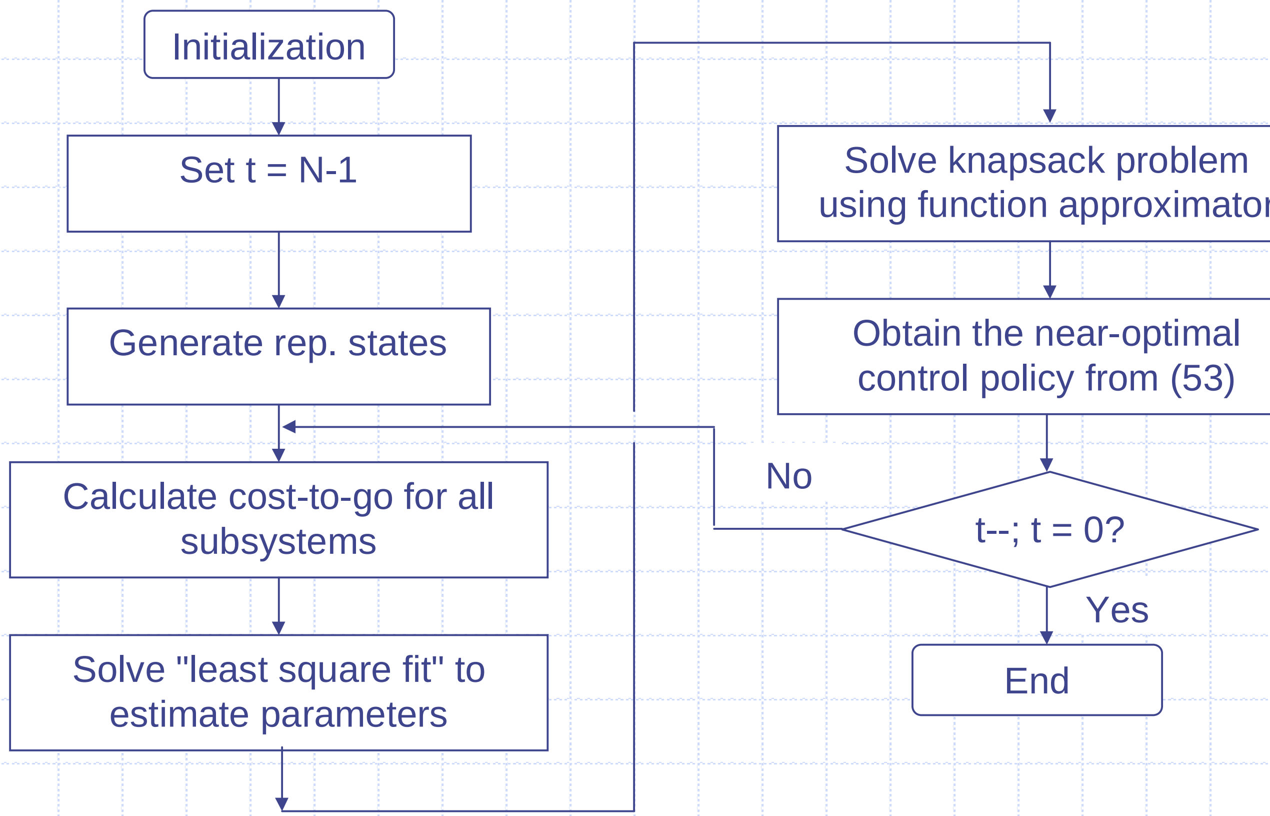
$$\hat{J}_t(s_t) = \min_{v_{mt}\in Z_+^1} \left\{ \sum_{m=1}^{4} J_{mt}(s_{mt}, v_{mt}) + r_{02}\cdot CC \right\}$$

s.t.

$$\sum_{m=1}^{4} v_{mt} \le \begin{pmatrix} w_{01t} \\ w_{02t} + r_{02} \\ w_{03t} \end{pmatrix}$$

$$\hat{\mu}_t(s_t) = \arg\min_{u_t\in U(s_t)} \left\{ g_t(s_t, u_t) + E\left\{ \hat{J}_{t+1}(s_{t+1}) \mid s_t, u_t \right\}\right\}$$

Approximate Algorithm



Suboptimal Control Schemes

Refinery Operation

Assume: A typical large refinery

~ 3-10 Crude tanks

~ 10-30 Intermediate tanks

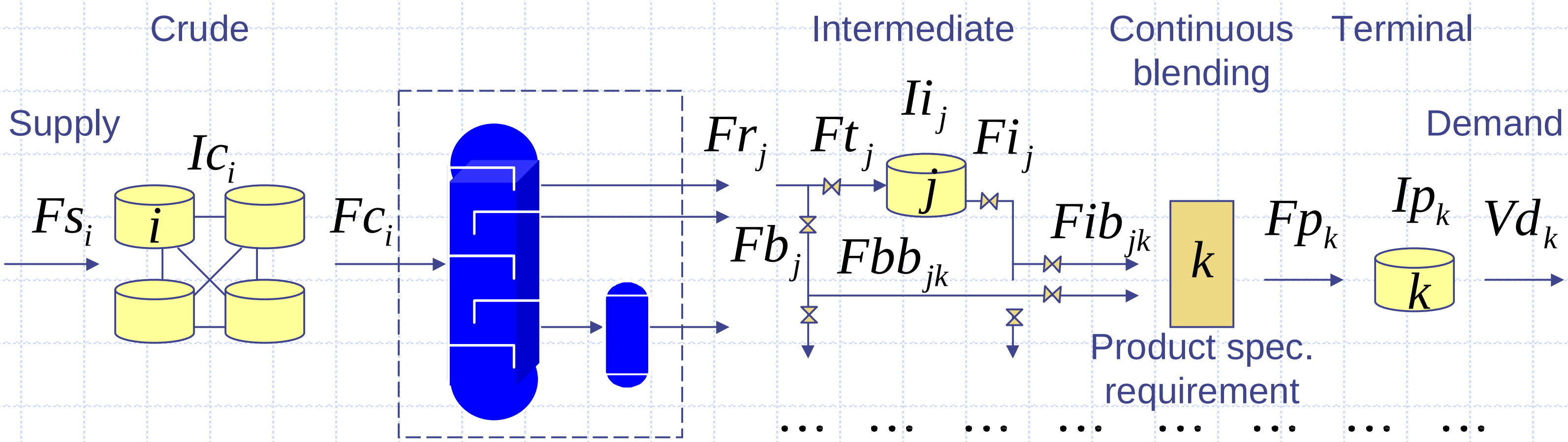
~ 30-50 Product tanks

~ 2 week demand amount of inventory

Assume:

- Tank investment ~ 3 million $/each; Tank yearly operating cost ~ 150 thousand $/each
- Continuous blending technology makes it possible to produce finished products only when they are needed
- Decisions: ordering/delivery, real-time plant operation

Model Formulation

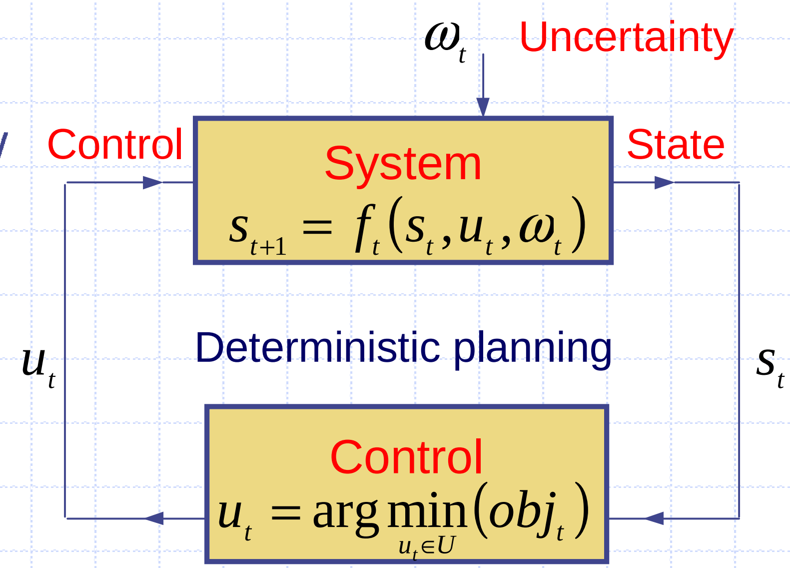


- Inventory $I(t)$: Ic_i - crude; Ii_j- intermediate; Ip_k- product
- Flowrates $F(t)$: Fc_i - feed; Ft_j, Fb_j- tank/blender splits;
  Fbb_{jk}, Fib_{jk}- blend recipes $\cdots\cdots$
- Equations: e.g. $Ip(k,t) = Ip(k,t-1) - Vd(k,t-1) + Fp(k,t-Lt-1)\cdots$
  Lt- transportation lead time
- Objective: Cost $= \alpha\sum_t I(t)\overline{P}(t) + \sum_t S(t)\overline{C}(t)\cdots$ α - interest rate

Moving Horizon Control (sub-optimal)

- State information
  - → Inventory levels (crude, intermediate, finished)
  - → Crude supply/Product demand
  - → Production yields
- Control decisions
  - → Purchase/Delivery
  - → Plant operation (feed, tank/ blend splits, blend recipes)
- Uncertainties
  - → Crude supply availability
  - → Production yields
  - → Product stream prices

Minimize: Inventory/Tankage cost + Shortage penalty



Conclusions

- Systematic decision makings in the supply chain management through simulation and optimization

Crude logistics system

- Coordination between transportation and inventory control
- Simulation based investigation and evaluation
- Optimal control of the transportation/inventory system
- Approximation architecture for computing policies

- Currently working on model verification, validation and efficiency improvement
- Could be implemented in a world wide crude logistics system