Second Israeli-Dutch Queueing Workshop, Eindhoven, Sept. 2010

Design of Spare Parts Networks for High-Tech Equipment

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Where innovation starts

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Trends

- Capital goods and their maintenance become more and more complicated
- Users require higher availabilities (less downtime)
- Users look at TCO

- Maintenance is outsourced to a third party
- Manufacturers sell capital goods with full service contracts
- Or one even sells the “function + system availability”

Spare parts networks

Typical procedure for demand fulfillment

1. Normal delivery: 2 hrs.
2. Lateral transshipment: 14 hrs.
3. Emergency replenishment: 48 hrs.

Main research question (1)

Where to place your spare parts stocks in a service region?

At a central place in a service region, or at close distance of the capital goods?

Main research question (2)

<u>Close to capital goods:</u>

- Weak inventory pooling
- Short downtimes
- Low transportation costs for demand fulfillment

<u>At a central place:</u>

- Strong inventory pooling
- Long downtimes
- High transportation costs for demand fulfillment

<u>Close to capital goods plus lateral transsshipments:</u>

- Strong inventory pooling
- Short downtimes
- Transportation costs: ???

CONTENTS

Literature

- Design of spare parts networks:
  - Nothing available (to the best of our knowledge)
- Spare parts inventory models with lateral transshipments:
  - A lot available
  - In study II, we use an existing evaluation algorithm of Reijnen et al. (2009) (in line with Axsäter, 1990)
- Design of distribution systems:
  - A lot available
  - Some literature where inventory holding costs are incorporated
  - Nothing with the effect of lateral transshipments included

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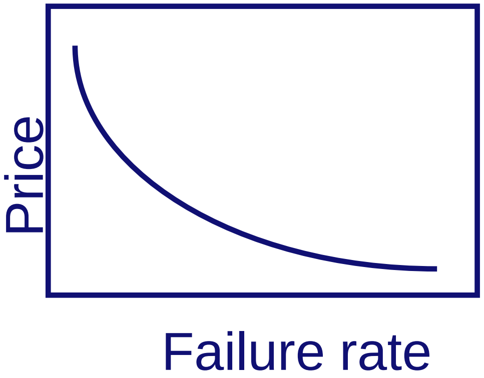
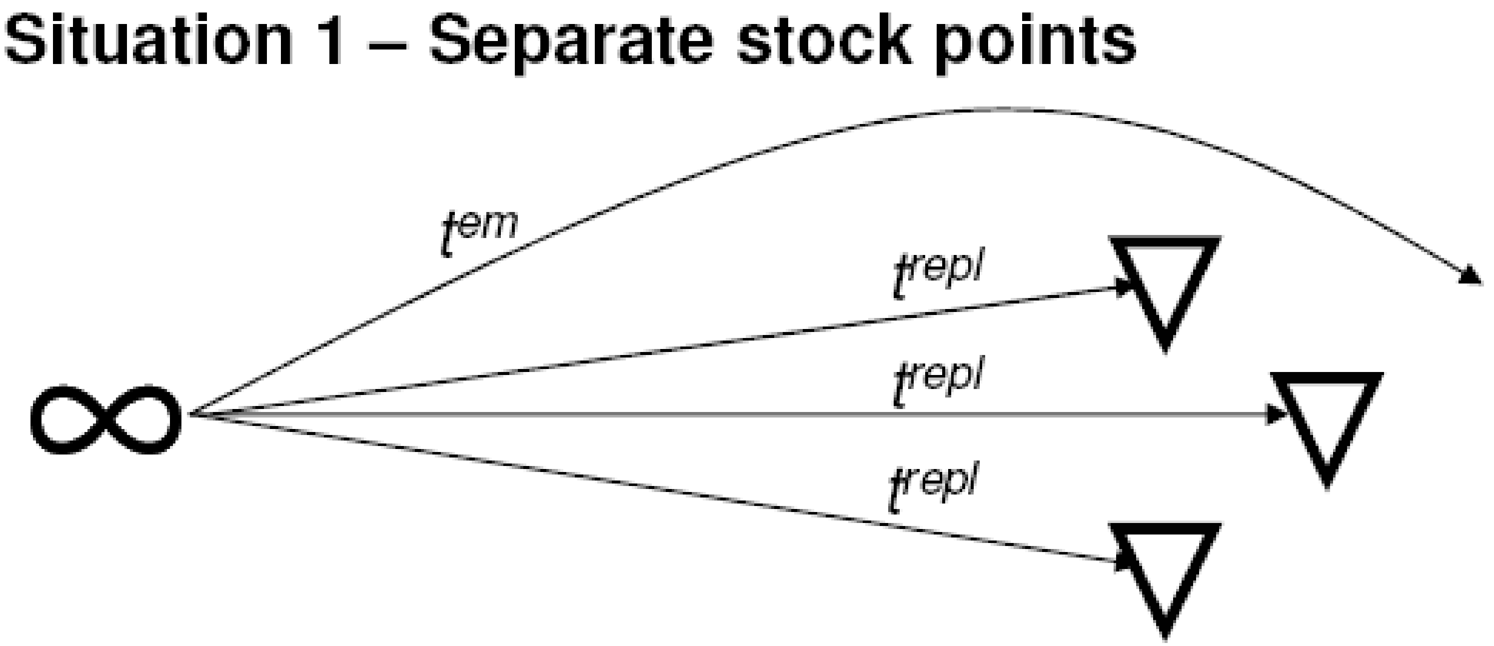
Model

- Single item
- Typical: low demand rate, expensive
- Assumptions (base model):
  - set of points where demand occurs: *J*
  - equal demand rates *m* (Poisson)
  - equal waiting time constraints
  - at most one item in stock in each local warehouse
  - randomized policies ("continuous base stock policies")

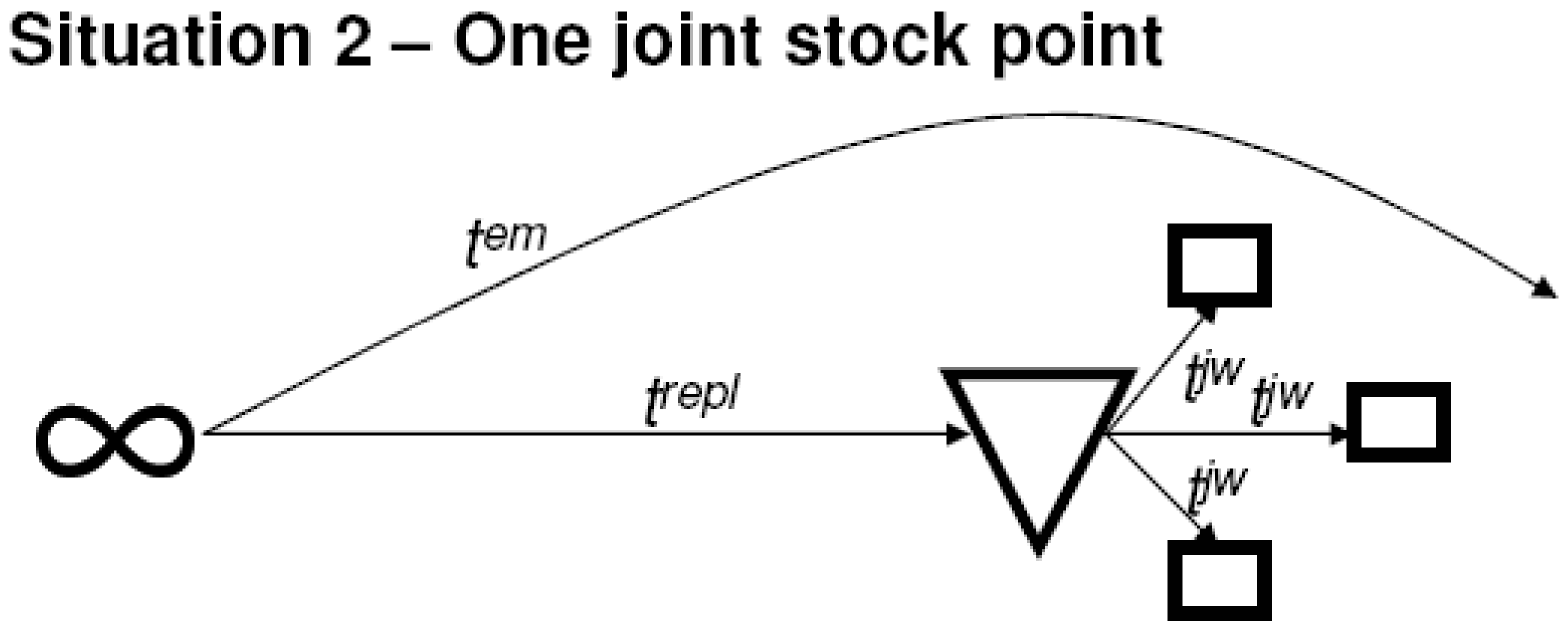


Problem: Minimize inv. holding and transportation cost subject to waiting time constraint(s)

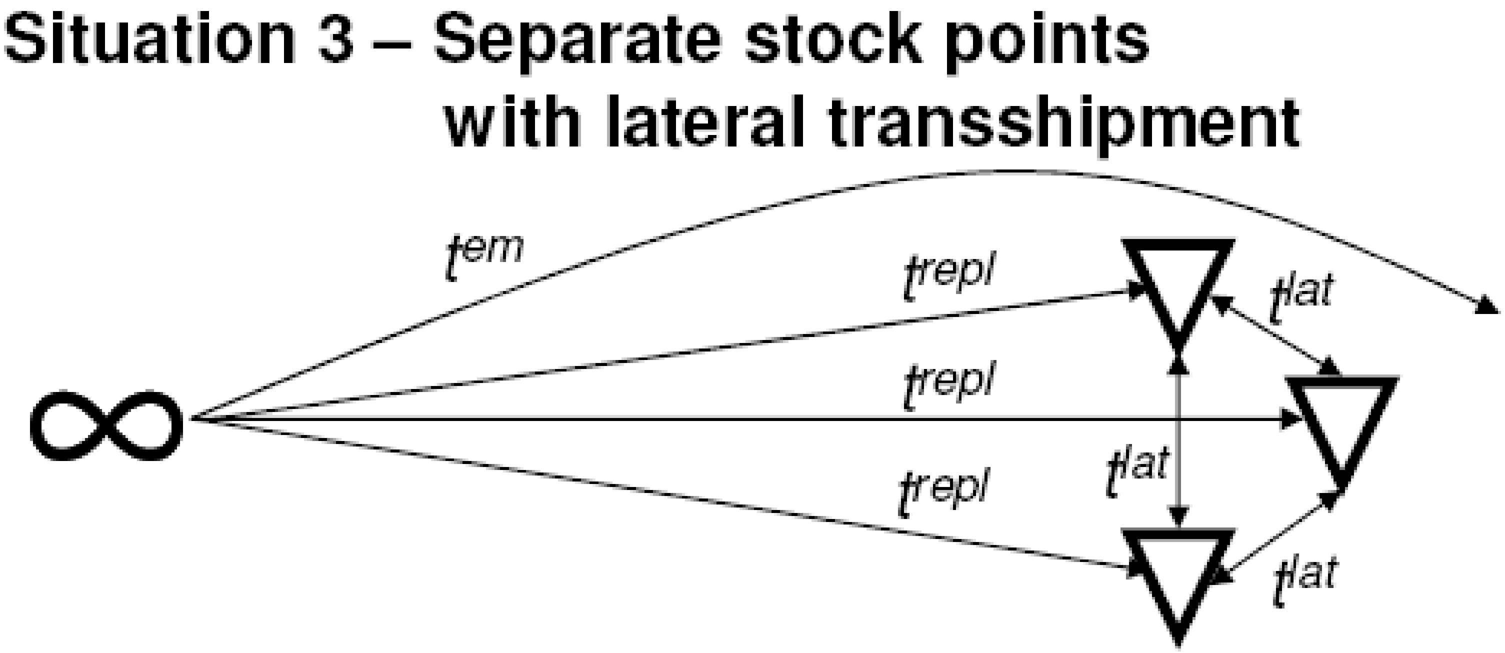
Model: Situation 1



Model: Situation 2

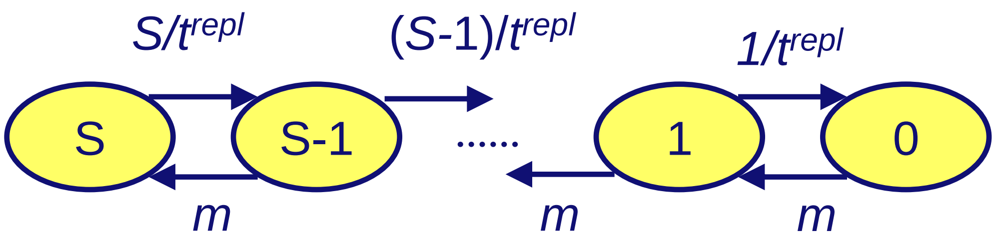


Model: Situation 3



Analysis: Sit. 1 (Separate stock points)

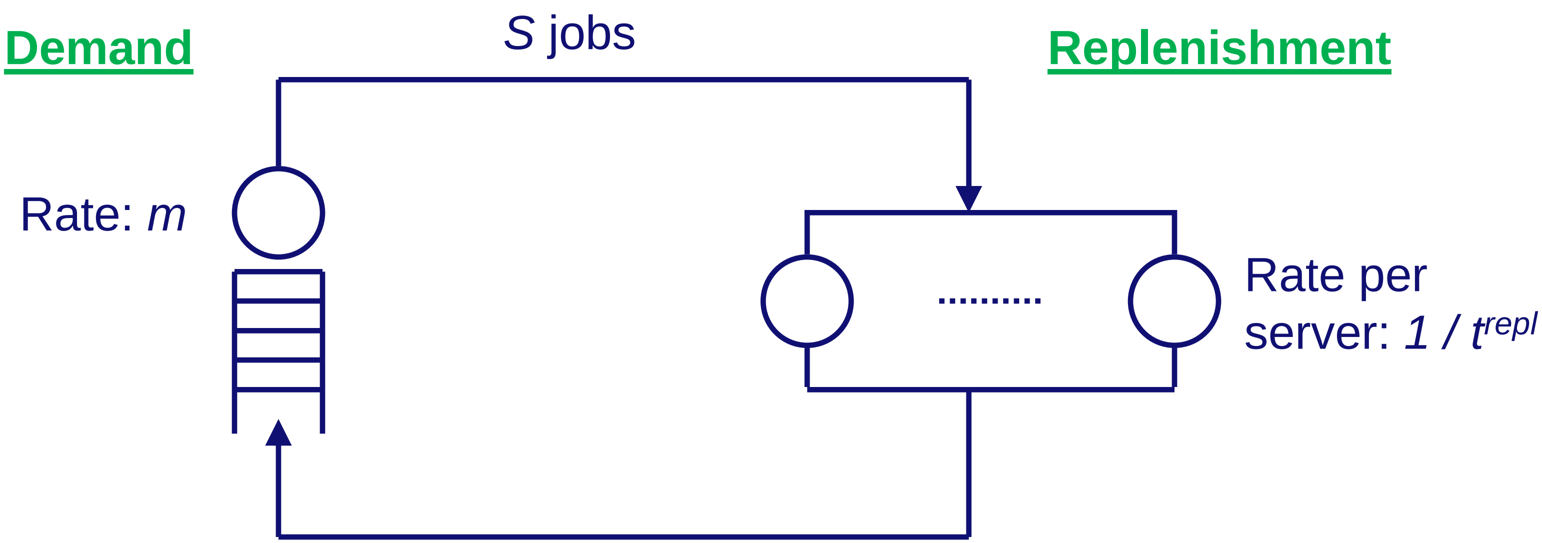
- Exponential leadtimes: Markov process per stock point (state = # items in replenishment):



- Generally distributed lead times: M/G/c/c model (service represents replenishment; c = *S*)

- Closed queueing network

Closed queueing network for situation 1



Analysis of Situation 2 (Joint Warehouse)

Similar to Sitation 1

BCMP (1975)

Closed-form expressions for queueing networks with stations of type:

(i) ample server

(ii) processor sharing

(iii) LCFS-PR

(iv) FCFS

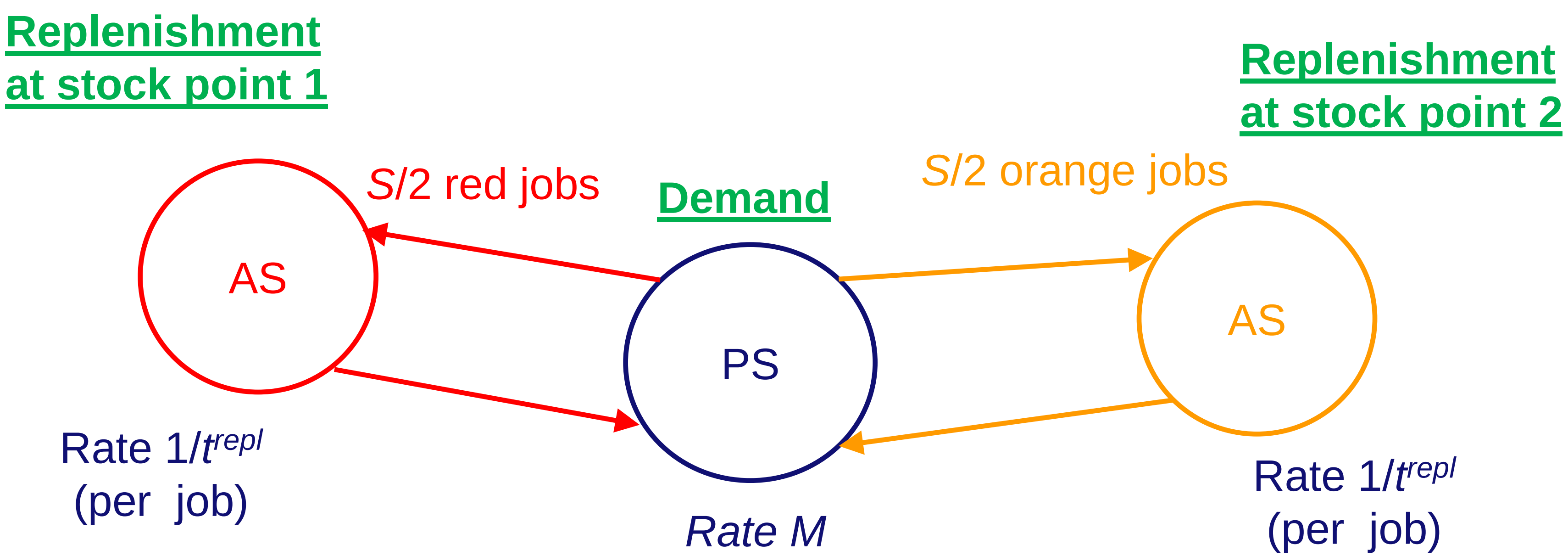
with PhaseType distr. in stations of type (i), (ii), (iii), and exponential distr. in stations of type (iv)

Barbour (1976)

Phase type → General

Analysis: Situation 3 (Separate stock points with lateral transshipments)

Closed queuing network with a *Processor Sharing (PS) server*



Analysis: Situation 3 (Separate stock points with lateral transshipments)

For general |J|:

- If $S/|J| \leq 1$ (at most one item on stock per stock point):
  - Standard processing sharing
  - Product-form solution
- If $S/|J| > 1$ (more than one item on stock per stock point):
  - Generalized PS, no closed-form solution known
- Asymmetric demand:
  - Discriminatory PS, no closed-form solution known

Waiting time comparison: Sit. 1 vs. Sit. 3

$$WT^1(|J|) - WT^3(|J|) = \underbrace{\left(t^{em} - \left(1 + mt^{repl}\right)t^{lat}\right)}_{\geq 0 \text{ in “convex case”}} \underbrace{\left(p^1(|J|) - p^3(|J|)\right)}_{\geq 0}$$

<u>In convex case:</u>

Under relatively weak additional conditions:

“Optimal cost situation 3” ≤ “Optimal cost situation 1”

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Waiting time comparison: Sit. 2 vs. Sit. 3

$$WT^2(S) - WT^3(S) =$$

$$\left(t^{jw} - \left(1 + mt^{repl}\right)t^{lat}\right)\left(1 - p^2(S)\right) + \frac{S}{|J|}t^{lat}$$

Observation:

Situation 2 is often infeasible

Numerical results (1)

Base case

Parameter	Value	Ratio	Value
m	0.001 demands per day		
C^{jw}	450 Euro	$C^{\mathrm{jw}}/C^{\mathrm{lat}}$	0.9
C^{lat}	500 Euro	$C^{\mathrm{lat}}/C^{\mathrm{em}}$	0.5
C^{em}	1000 Euro		
h	10 Euro	h/C^{em}	0.01
WT^{obj}	0.2 days	$WT^{\mathrm{obj}}/t^{\mathrm{em}}$	0.1
t^{jw}	0.45 days	$t^{\mathrm{jw}}/t^{\mathrm{lat}}$	0.9
t^{lat}	0.5 days	$t^{\mathrm{lat}}/t^{\mathrm{em}}$	0.25
t^{em}	2 days		
t^{reg}	10 days	$t^{\mathrm{reg}}/t^{\mathrm{em}}$	5
$\|J\|$	10		

Numerical results (2)

- For a base case with data matching real-life characteristics:
  - Sit. 2 (joint warehouse) is infeasible
  - Sit. 3 is 33% cheaper than Sit. 1

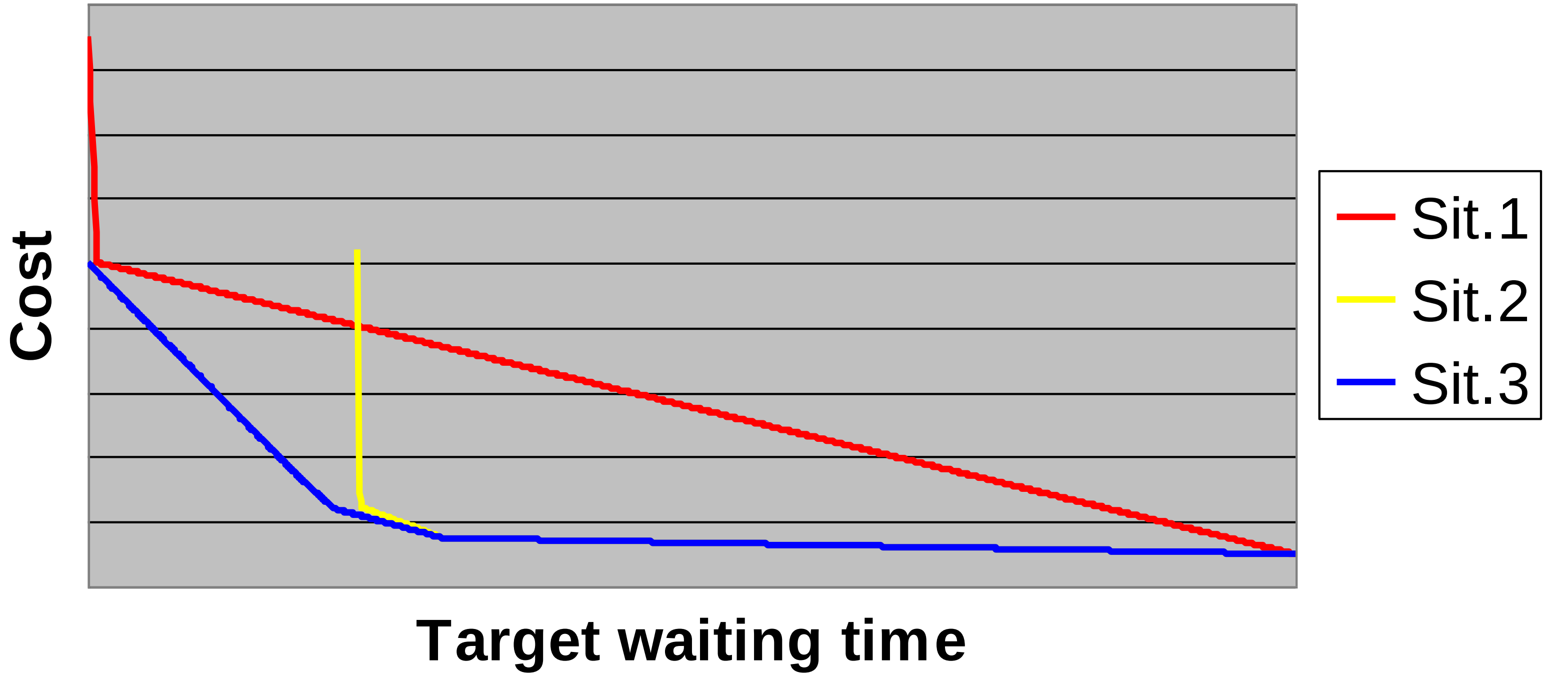
=> Lateral transshipment is good

Numerical results (3)

- For an adjusted base case (less strict waiting time constraint):
  - Sit. 2 saves 73% compared to Sit. 1
  - Sit. 3 saves 75% compared to Sit. 1

=> Situations 2 and 3 are comparable

Numerical results (4)



Conclusion

Where to place your spare parts stocks in a service region?

- At a sufficiently close distance of the demand points

- Use lateral transshipments in the “convex case”, and otherwise not