Flow Balancing-based Empty Container Repositioning

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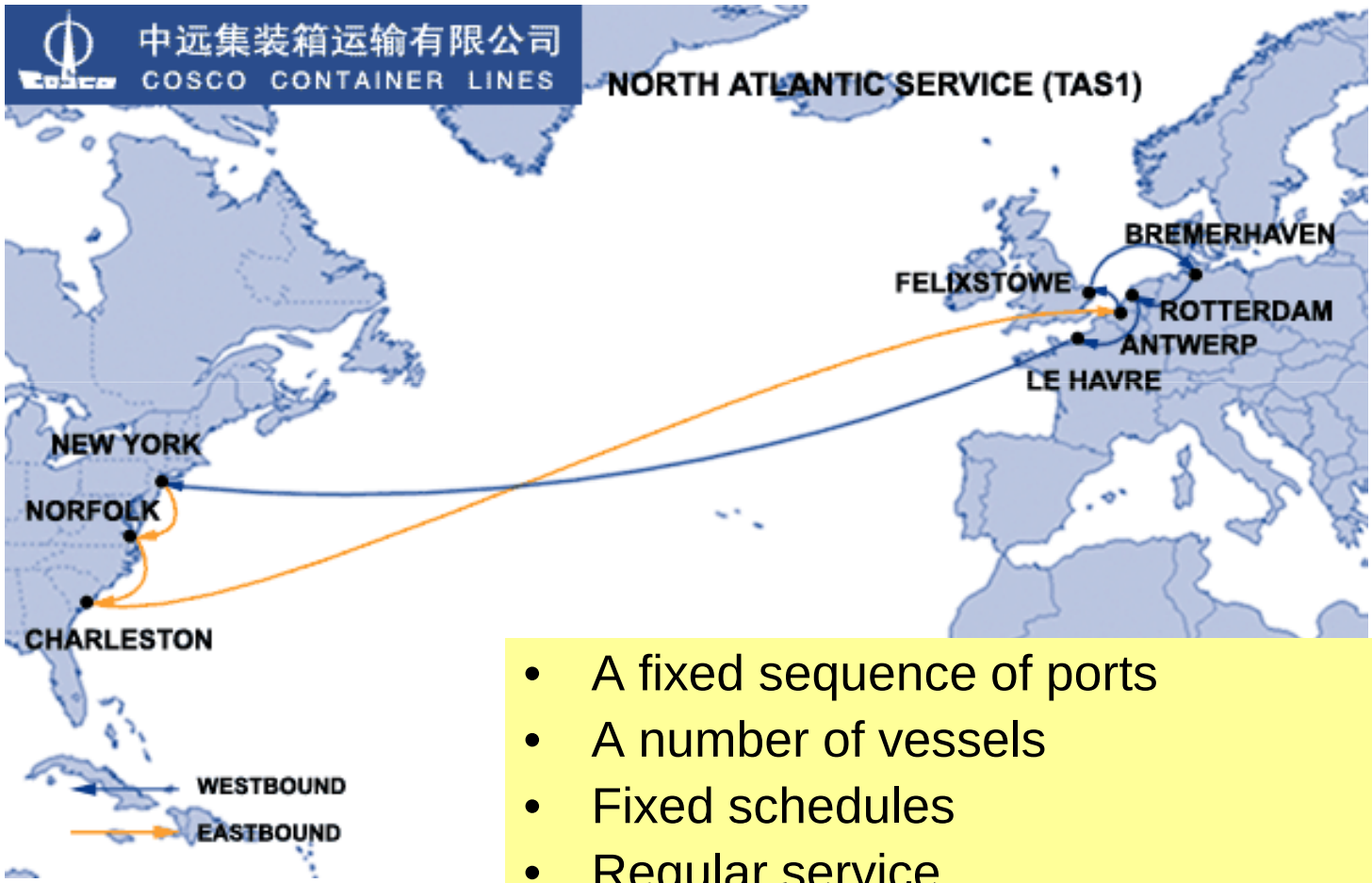
Outline

- Background & Literature
- Research purposes
- Flow-balancing repositioning policies
- Evaluation and Comparisons
- Conclusions

Background & Literature

- Empty containers have accounted for at least 20% of global port handling activity ever since 1998 (Drewry 2006).
- According to problem characteristics
  - Deterministic (e.g. Dejax & Crainic 1987)
  - Stochastic (e.g. Crainic et al. 1993)
- According to problem scope
  - Inland (e.g. Crainic et al 1993ab)
  - Seaports (e.g. Lai et al 1995, Cheung & Chen 1998, Cheang & Lim 2005, Li et al 2004,2007, Song 2007, Lam et al. 2007)
  - Intermodal (e.g. Erera et al. 2005, Kim et al 2008)

Liner Service

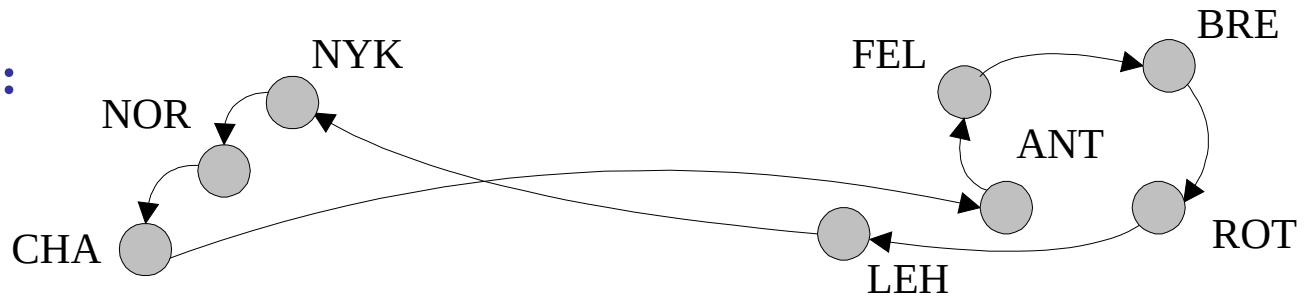


- A fixed sequence of ports
- A number of vessels
- Fixed schedules
- Regular service

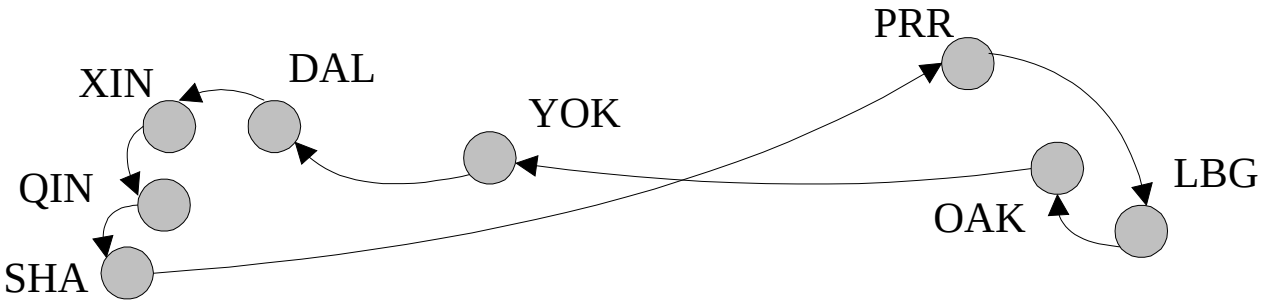
http://www.coscon.com/ourservice/TRANS_ATLANTIC/servicemapTAS1EN.jsp?group=ATLANTIC

Topological Structures (1)

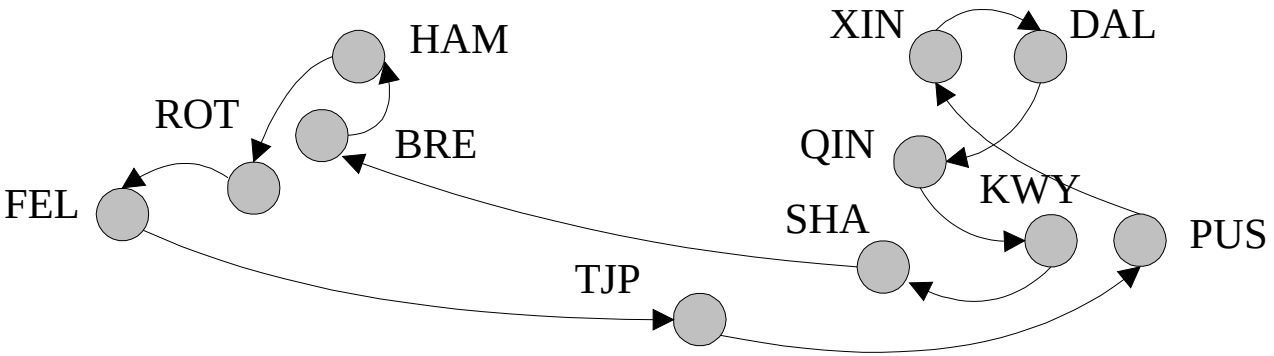
Trans-Atlantic:



Trans-Pacific:

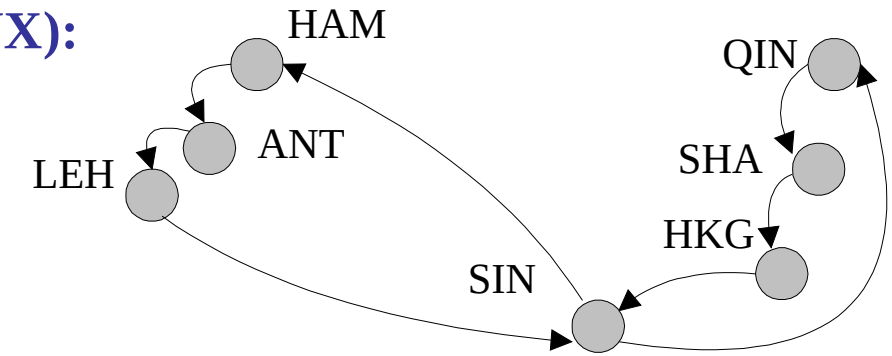


Asia-Europe:

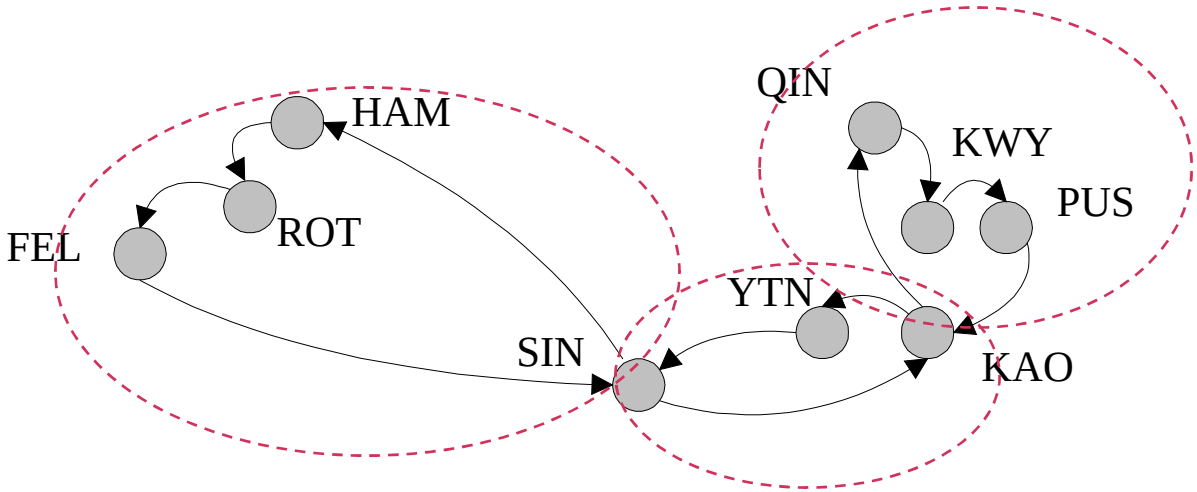


Topological Structures (2)

CN/North Eur Express (CNX):

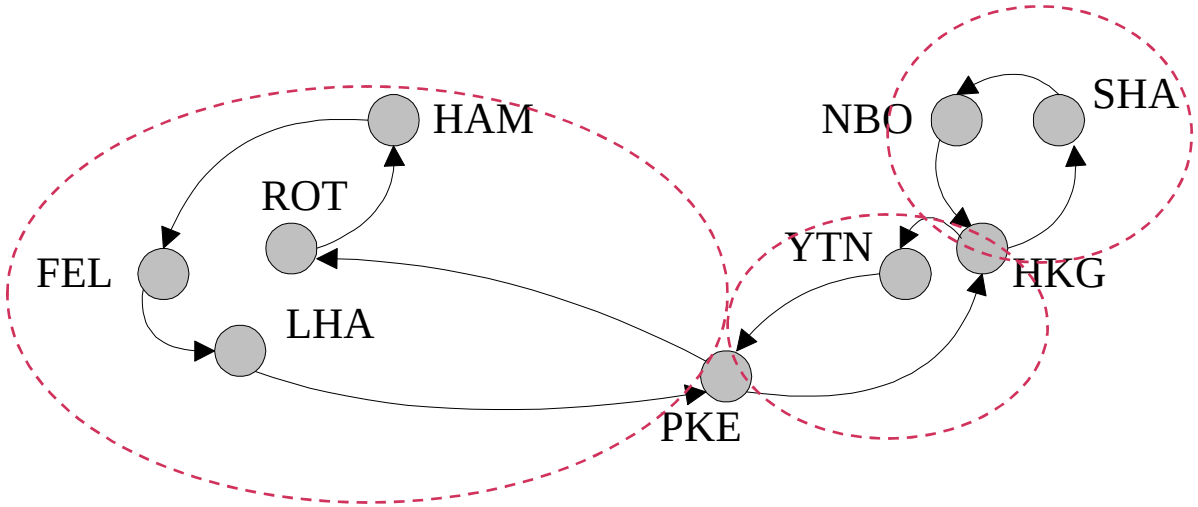


Asia/Eur Express (AE3):

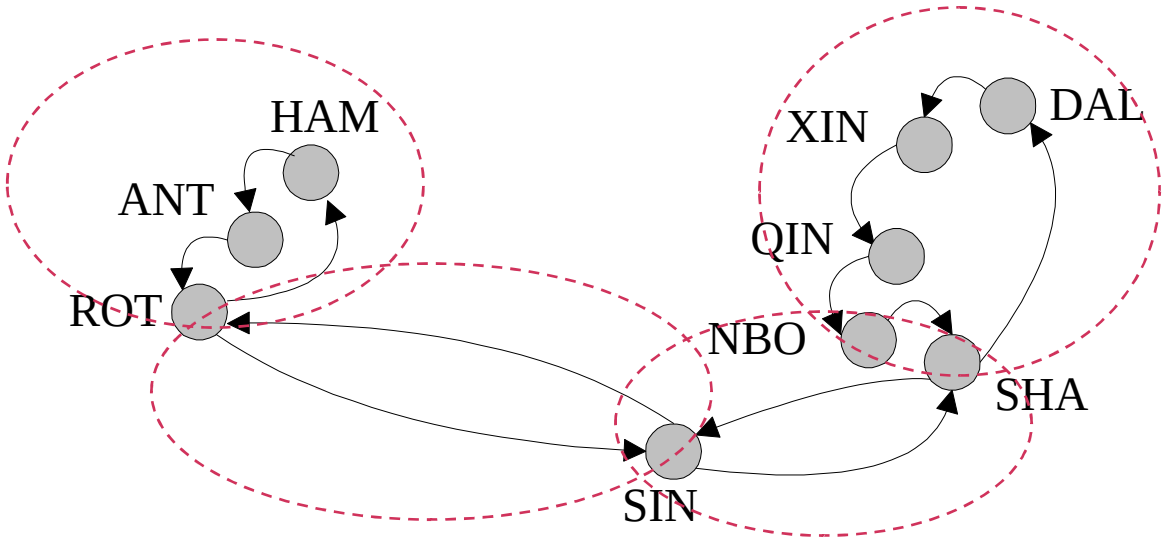


Topological Structures (3)

Asia / Eur (AES):



Asia / Eur (AEN):



Research Purposes

- Formulate empty repositioning policies based on two types of flow balancing mechanisms;
- Evaluate the policies in service routes with different topological structures,
  - contrast their performance in deterministic situation;
  - contrast their performance in stochastic situations.

Objective Function

The objective is to minimize the total cost consisting of **laden** container transport costs, **empty** repositioning costs, and **penalty** costs for lost-sales.

$$J(x_{ij}^{v}, y_{ij}^{v}) = \sum_{v}\sum_{i}\sum_{j} [(C_{ij}^{v} + C^{o}_{p(i)} + C^{f}_{p(j)})\cdot(x_{ij}^{v} + y_{ij}^{v}) + C^{l}_{p(i)}\cdot(d_{ij} - y_{ij}^{v})]$$

Empty

Lost-sales

Laden

Subject to constraints:

1.Flow balancing;

2.Non-negative empty containers;

3.Non-negative laden containers;

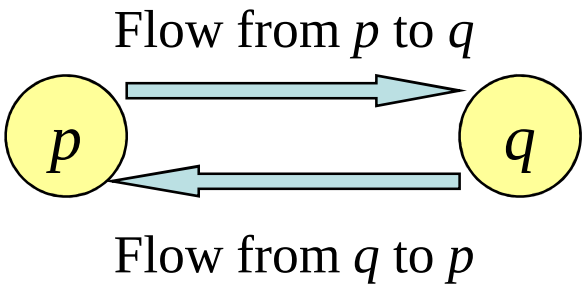
4.Laden containers are less than demands;

5.Vessel carrying capacity in each leg.

1. Point To Point (P2P) Repositioning Policy

For each port-pair (p, q), if $d_{pq} \geq d_{qp}$, then,

- $x_{lk}^{v} = d_{pq} - d_{qp}$, if $C_{lk}^{v} = C_{qp}^{v}$ with $p(l)=q$ and $p(k)=p$;
- $x_{lk}^{v} = 0$, for any (l, k) s.t. $C_{lk}^{v} \neq C_{qp}^{v}$ with $p(l)=q$ and $p(k)=p$;
- $x_{kl}^{v} = 0$, for any (l, k) s.t. $p(l)=q$ and $p(k)=p$.



2. Coordinated Repositioning Policy (CRP)

Define **net demand** for each port (flow-in – flow-out),

- $\Delta D_p := \sum_q d_{qp} - \sum_q d_{pq}$

Define the sets of **surplus** ports and **deficit** ports,

- $P_S := \{p \in P \mid \Delta D_p > 0\}$;
- $P_D := \{p \in P \mid \Delta D_p \leq 0\}$.

A **heuristic procedure** to reposition empty containers:

Step 1: Initialisation and set $x_{ij}^v = 0$ for any i and j;

Step 2: Select the cheapest port-pair (p, q), $p \in P_S$ and $q \in P_D$;

Step 3: Find the cheapest index-pair (i, j);

Step 4: Determine x_{ij}^v according to net-demands;

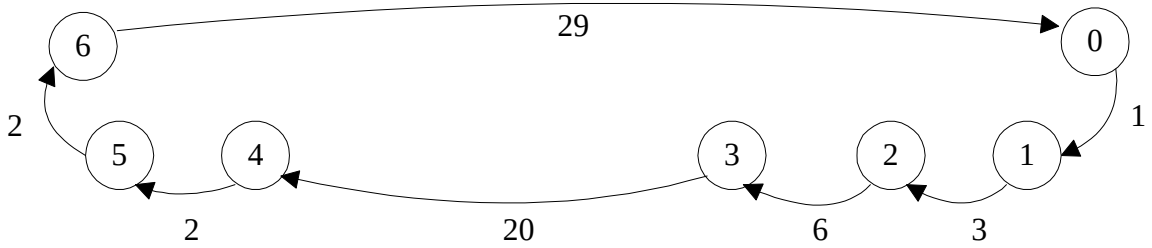
Step 5: Update net-demands, P_S and P_D;

Step 6: If P_S is not empty, go to Step 2.

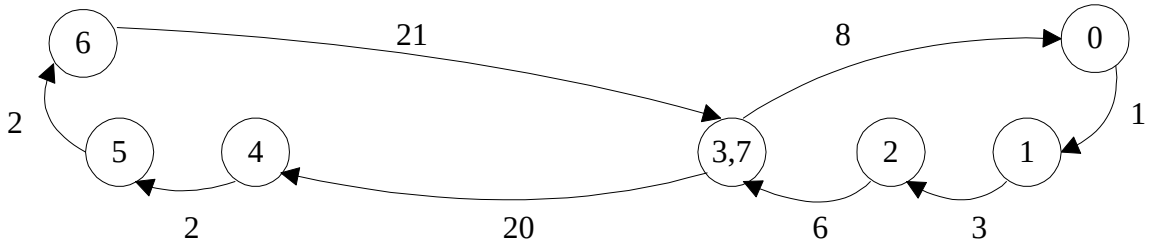
Policy Evaluation in Deterministic Situations

- Three topological structures
  - A single circle
  - Two circles
  - Three circles
- Three levels of demand patterns
  - Low imbalance
  - Medium imbalance
  - High imbalance

Three Topological Structures



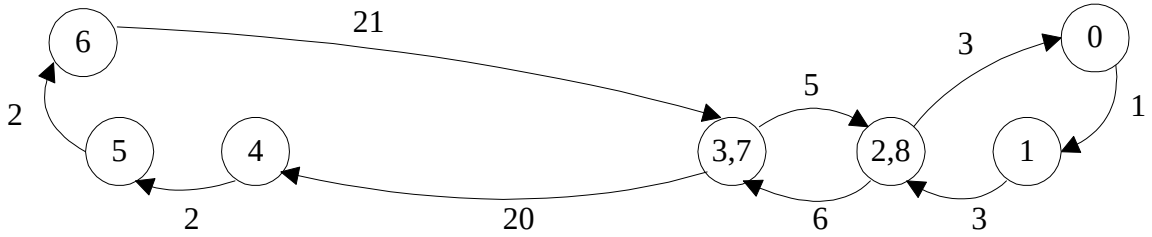
(a) A cyclic route



Europe

Asia

(b) Two-circle route



(c) Three-circle route

Three Demand Patterns

- Low imbalance:
  - AsiaToEur / EurToAsia = 1.27
- Medium imbalance:
  - AsiaToEur / EurToAsia = 1.77;
- High imbalance:
  - AsiaToEur / EurToAsia = 2.96.

- Other parameters: 9 vessels with 10,000 TEU each.

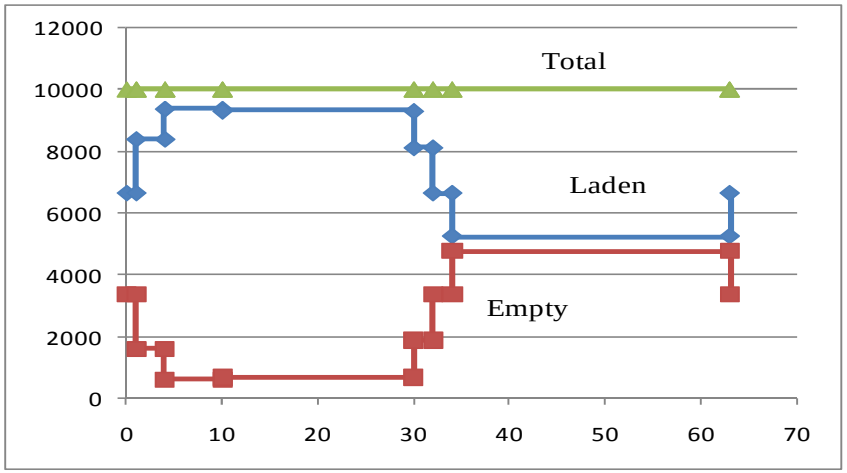
Relative Performance in Deterministic Situations

Case	Demand pattern	Route Structure	Relative empty cost (P2P – CRP) / CRP
1	low	(a)	18.78%
2	low	(b)	29.84%
3	low	(c)	18.18%
4	medium	(a)	22.65%
5	medium	(b)	14.30%
6	medium	(c)	7.60%
7	high	(a)	16.74%
8	high	(b)	10.18%
9	high	(c)	5.70%

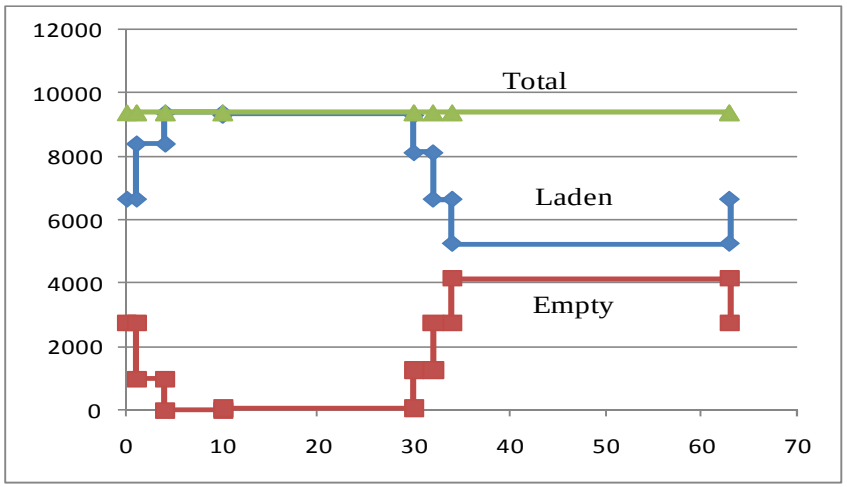
- Cost = Empty cost + Lost-sale penalty (0)
- Without vessel capacity constraints

Load Factor in Cyclic Route

TEU



Transit time



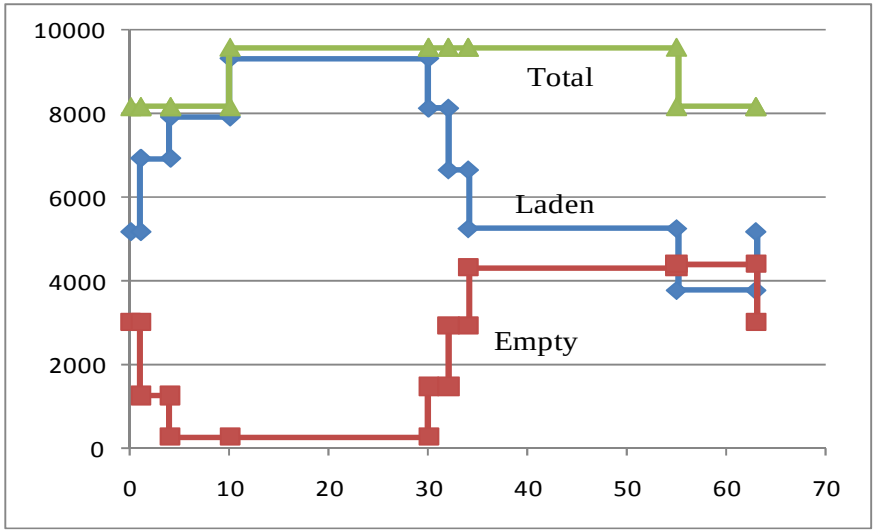
Medium-imbalance under P2P

- Total = 10010 TEU
- LF = 1.001

Medium-imbalance under CRP

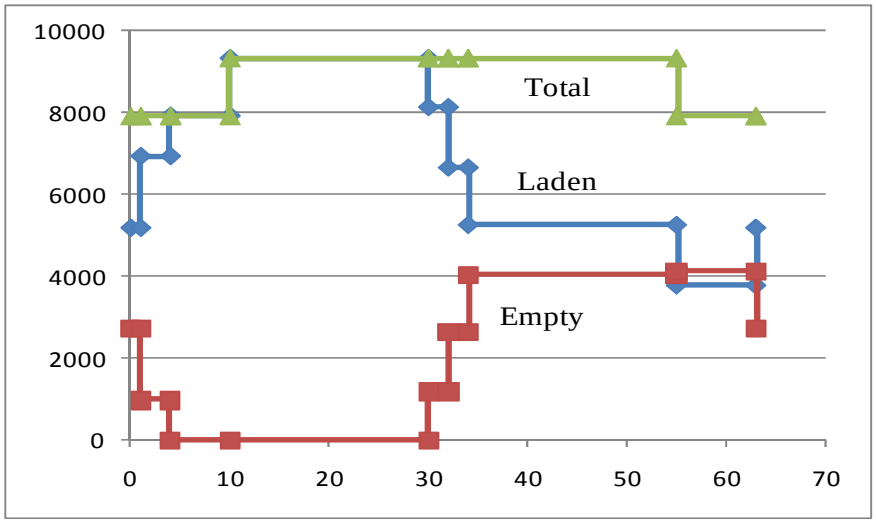
- Total = 9380 TEU
- LF = 0.938

Load Factor in 2-circle Route



Medium-imbalance under P2P

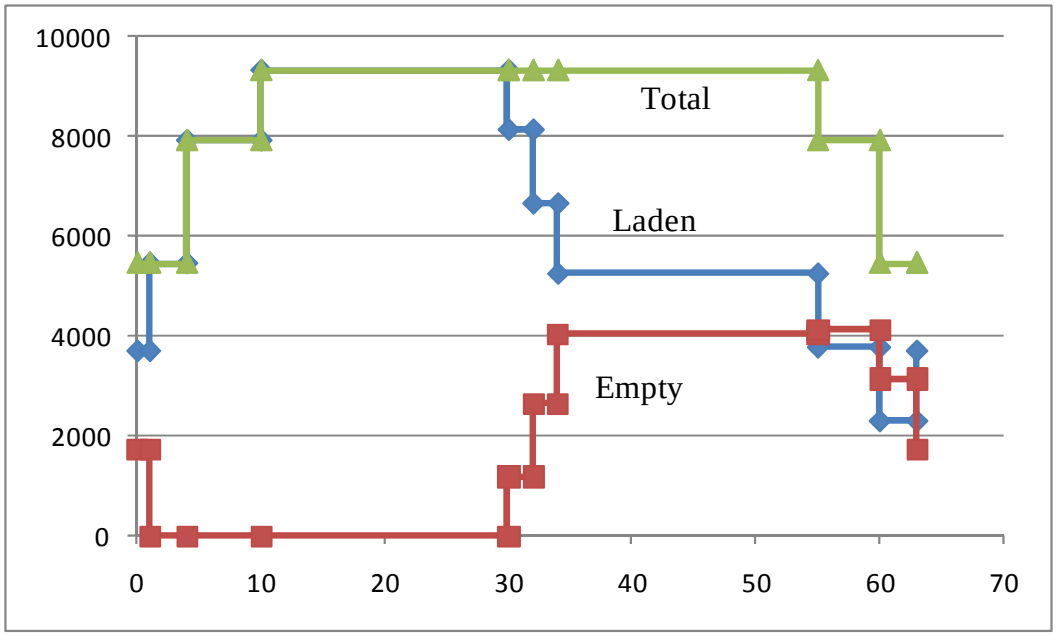
- $0.819 < LF < 0.959$



Medium-imbalance under CRP

- $0.791 < LF < 0.931$

Load Factor in 3-circle Route



Medium imbalance

- Load factors are the same for P2P and CRP.
- $0.546 < LF < 0.931$
- Empty container movements are not the same.

Policy Evaluation in Stochastic Situations

- Three topological structures
- One level of demand patterns (medium imbalance)
- Two types of daily demand distributions
  - Normal distribution $N(\mu, \sigma^2)$ with $\sigma = 0.2\mu$.
  - Uniform distribution $U(0, 2\mu)$.

- An event-driven **simulation** is used (Dong & Song, TRE2009).
- Vessels' voyages include a period from 01/10/2007 to 17/08/2009.

Relative Performance in Stochastic Situations

Cost reduction (%) from P2P to CRP

Demand pattern	Route Structure	Normal distribution	Uniform distribution
medium	(a)	35.70%	20.22%
medium	(b)	14.05%	5.78%
medium	(c)	7.30%	4.67%

- Cost = Empty cost + Lost-sale penalty
- Impose vessel capacity constraints

Conclusions

- CRP performs significantly better than P2P in most cases;
- The topological structure affects the relative performance;
- The demand pattern also affects the relative performance;
- Under P2P, it may violate the vessel capacity constraints;
- Under CRP, the maximum load factor is determined by the laden container movements in the dominant leg;
- The degree of uncertainty in demands affects repositioning policies' relative performance.

Any questions?