Measures of congestion in container terminals

Matteo Salani – TRANSP-OR EPFL
Ilaria Vacca – TRANSP-OR EPFL
Arnaud Vandaele – Univ. of Louvain

AIRO 2008 - Ischia
10 September 2008

TRANSP-OR

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Outline

- Introduction and motivation
- Literature
- Modeling
- Congestion measures
- Optimization
- Preliminary results
- Future work

TRANSP-OR

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Container Terminals (CT)

Zone in a port to import/export/transship containers

Container utilisation is the **easiest way** to transport goods

Different areas in a terminal : berths, yard, gates

Different types of vehicles to travel between the yard and the berth

Optimization in CT:

- Berth allocation
- Quay Cranes scheduling
- Yard operations

Motivation

Along the quay, several boats with **thousand** containers are loaded/unloaded

These containers movement lead to an high traffic in the yard zone, where the most of slowdowns occur.

(Tactical) Terminal planners often optimize the distance (time) traveled by container carriers because it impacts directly on the performance indicators, disregarding:

- Congestion issues (operations slowdowns because of bottlenecks)
- Alternative solutions (symmetries)

considering deterministic data

Aim of this study:

- Model the terminal and develop mesures of congestion
- Evaluate the impacts of the optimization of such measures on the terminal

Assumptions

In the berth/yard allocation plans, we define a **path** as an OD pair:

- An origin (berth or block)
- A destination (berth or block)
- number of containers

We consider flows of containers over a **working shift**.

Decisions could be taken on:

- The berth allocation plan (boats and berths)
- **The yard allocation plan (destination blocks)**
- Demand splitting (for berth to block flows only)

Given a set of *p* paths, determine the destination blocks

TRANSP-OR

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Literature

Layout:

Kim et al. **An optimal layout of container yards**, OR Spectrum, 2007.

Congestion:

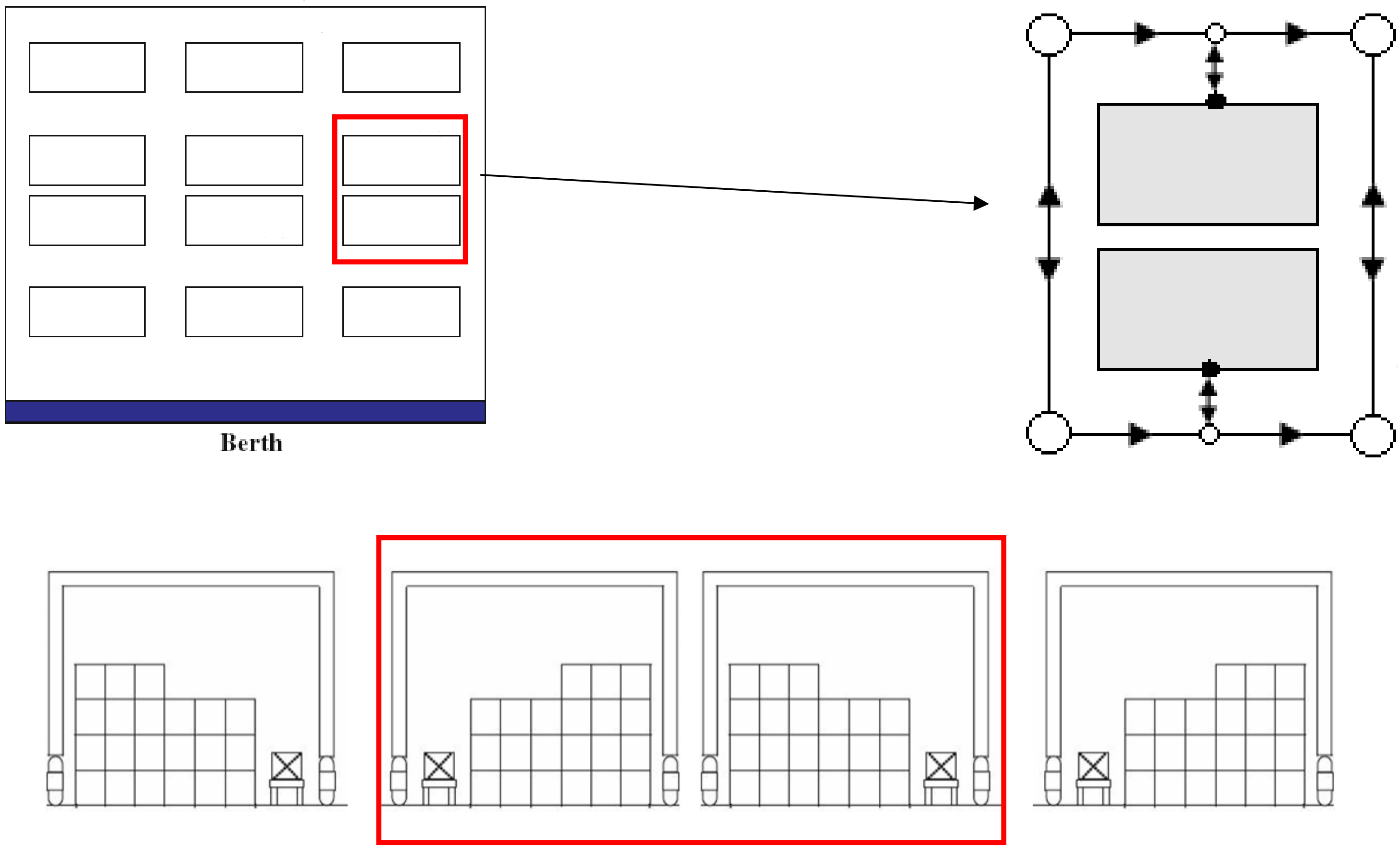
Lee et al. **An optimization model for storage yard management in transsshipment hubs**, OR Spectrum, 2006.

Beamon. **System reliability and congestion in a material handling system**, Computers Industrial Engineering, 1999.

R. Möhring, **Routing in graphs**, Plenary session - AIRO 2008

Modeling

Basic element



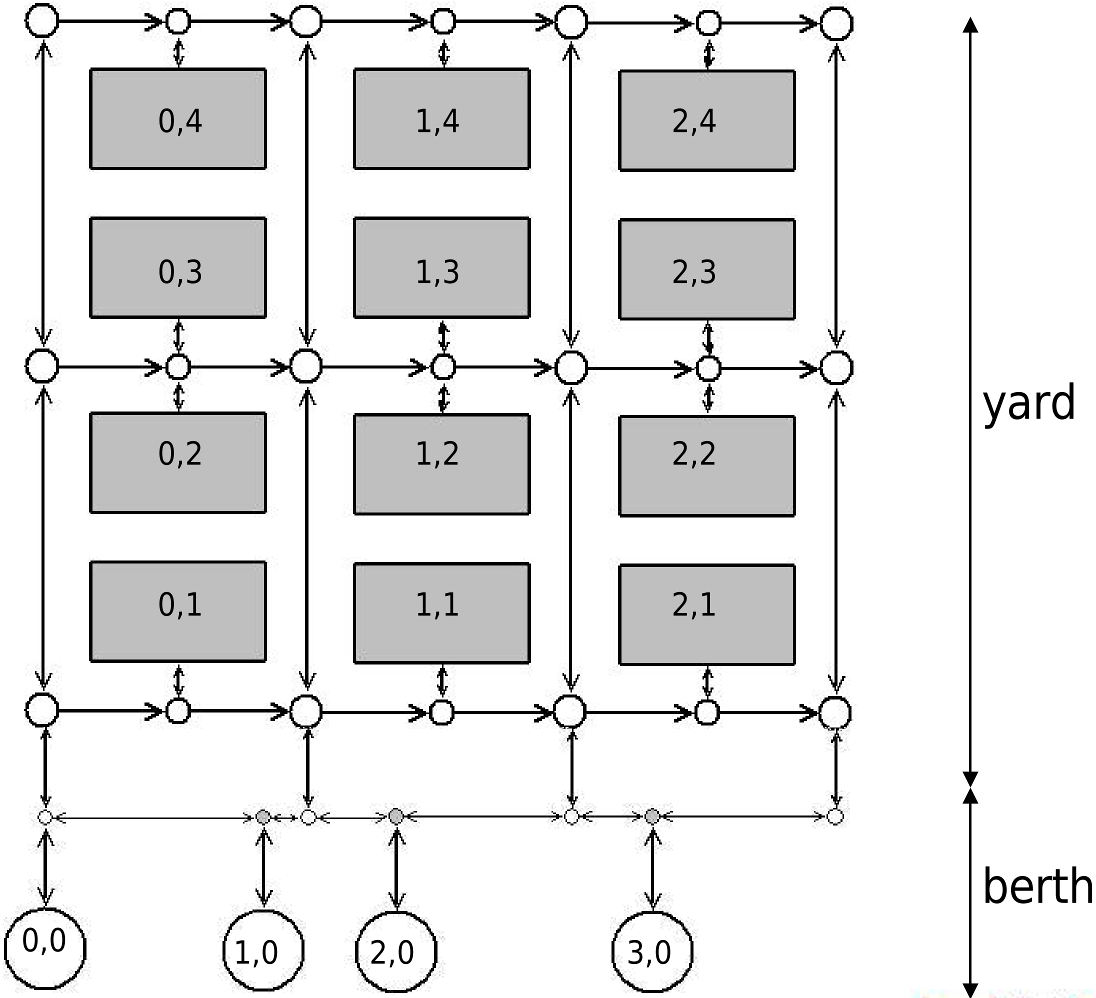
Modeling

(m x n) basic elements for a yard

Coordinates system to indicate origin and destination of containers

Only Berth-to-Yard and Yard-to-Berth paths :

$(x_o,y_o) – (x_d,y_d)$



Routing

Routing rules:

- Horizontal lanes are one way

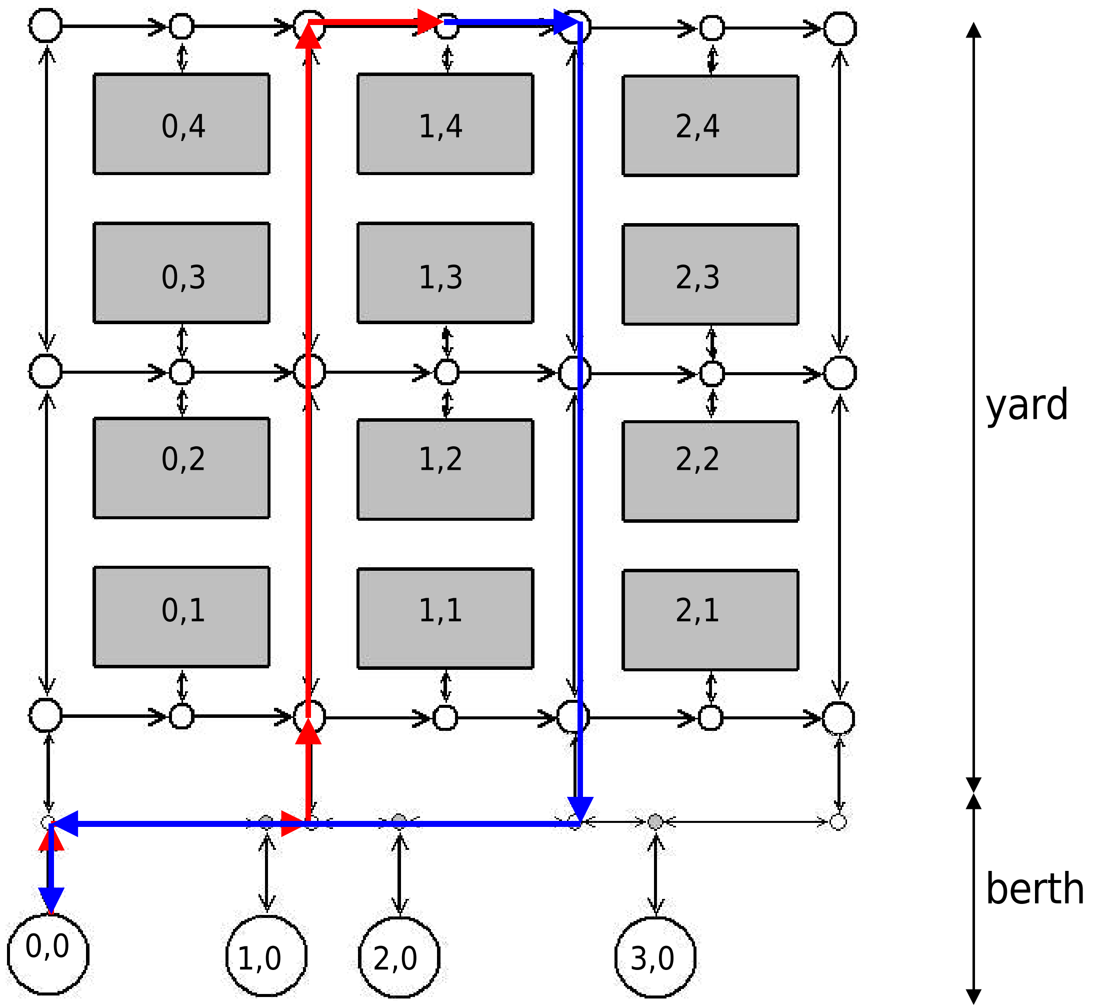
- Vertical lanes are two way

Toward the block, closest left vertical lane, turn right.

Toward the quay, turn right at the first vertical lane.

Back to origin berth position.

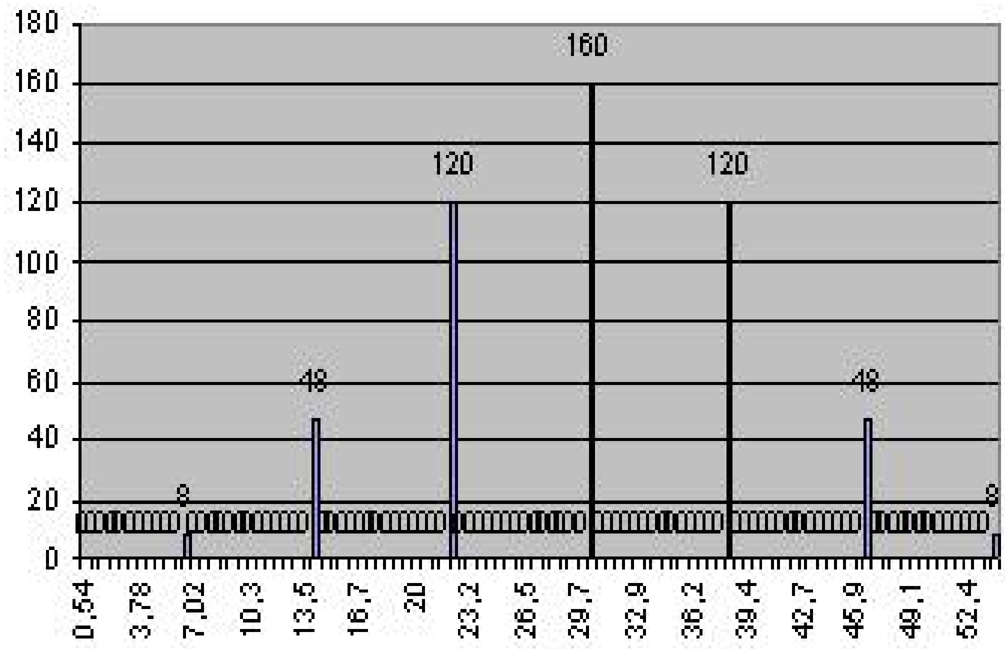
Distance travelled, closed formula (Manhattan)



Symmetries

Minimize distance:

In a 2x2 yard with 2 paths, no capacity on blocks



Number of solutions with equal distance

Measures

Aim: Estimate the state/congestion of a yard when implementing a plan (**using simple closed formulas**) in order to identify secondary objectives.

We considered:

- Interference among blocks sharing the same lane
- Lane congestion
- Path interference

Block congestion

$$b_{ij} = \begin{cases} 1 & \text{path } j \text{ arrive in area } i \\ 0 & \text{otherwise} \end{cases}$$

# of containers in each area and best case :

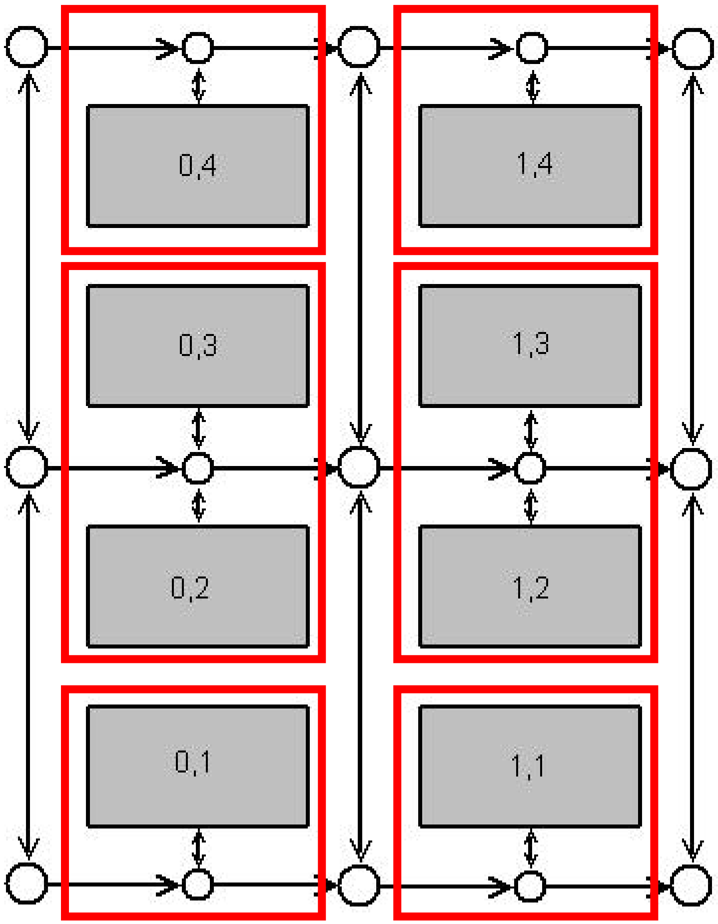
$$N_i = \sum_{j=1}^{p} b_{ij} c_j \qquad N^x = \frac{\sum_{j=1}^{p} c_j}{r}$$

Considered norm-1 and norm-2 with respect to the best over the worst case.

r = min(s, p)

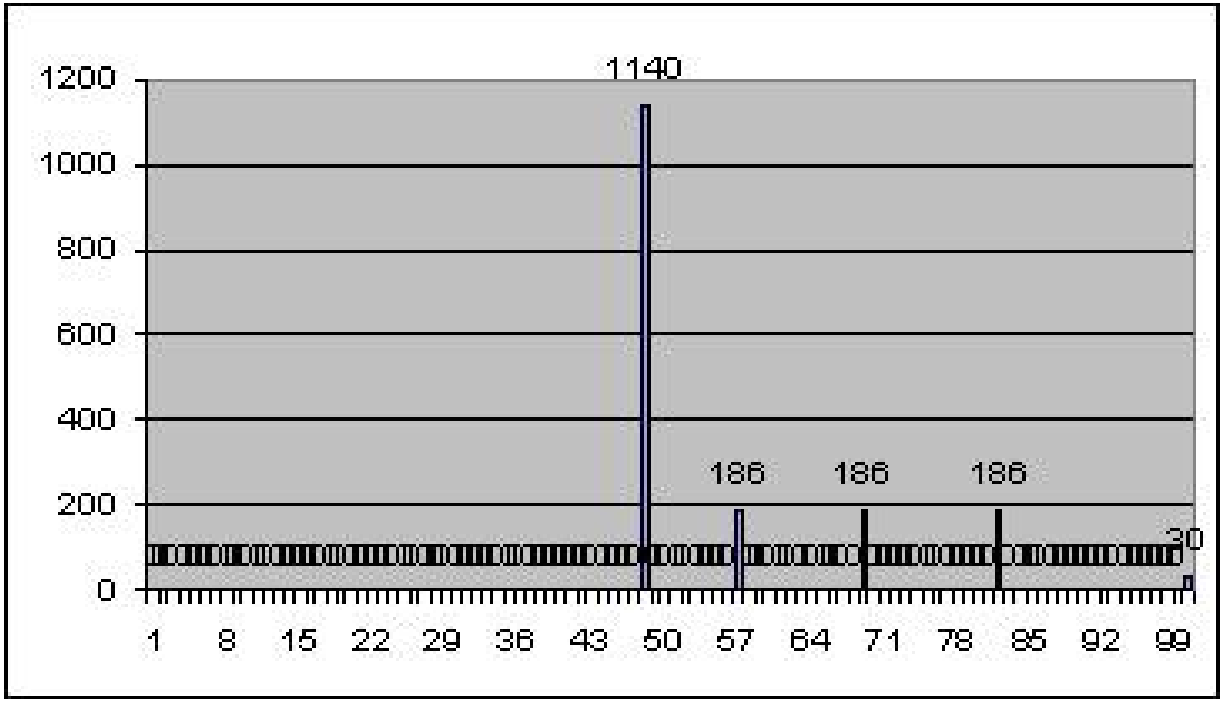
$$C_b = \frac{D}{D_{max}} = \frac{\sqrt{\sum_{j=1}^{p} (N_i - N^x)^2}}{\sqrt{\frac{(r-1)}{r}} \sum_{j=1}^{p} c_j}$$

we have $s = 2n + n(m-1)$ areas



Example with 2 norm

Possible solutions = 1728



Edge congestion

It simply measure the average traffic over an edge

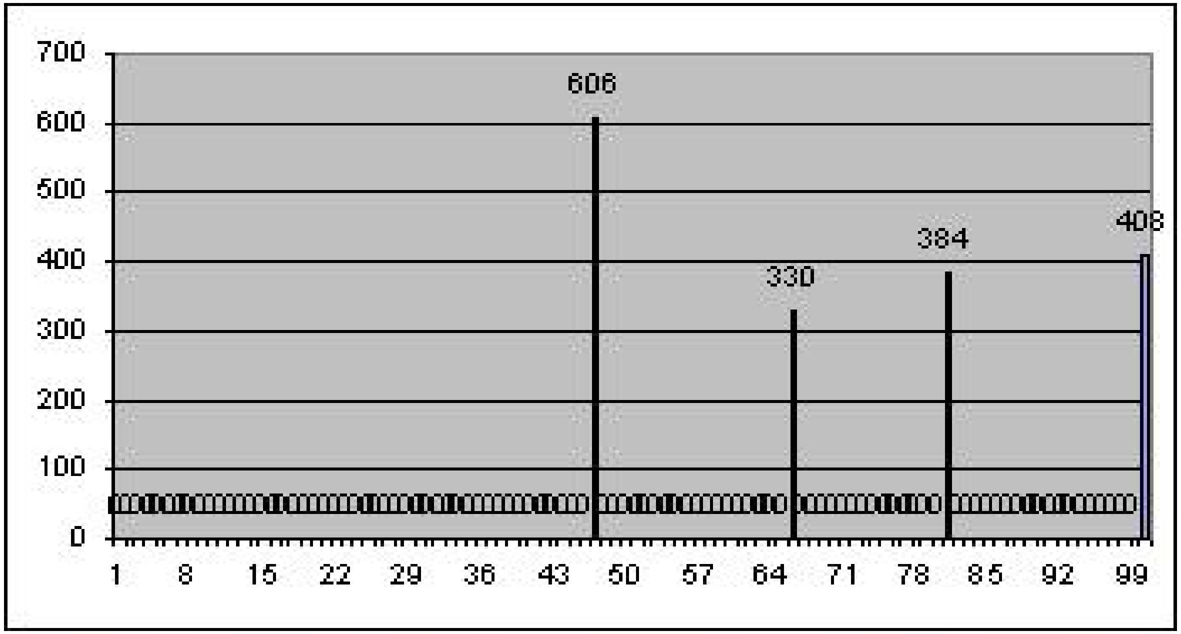
best traffic situation when flows are spread over the network

$\theta = \max_k f_k > 0 \qquad \mu = \min_k f_k > 0$

$$C_e = \frac{\theta - \mu}{\sum_{j=1}^{n} c_j}$$

improved:

$$C_e = \frac{n(\theta - \sum_{j=1}^{p} c_j)}{(n-1)\sum_{j=1}^{p} c_j}$$



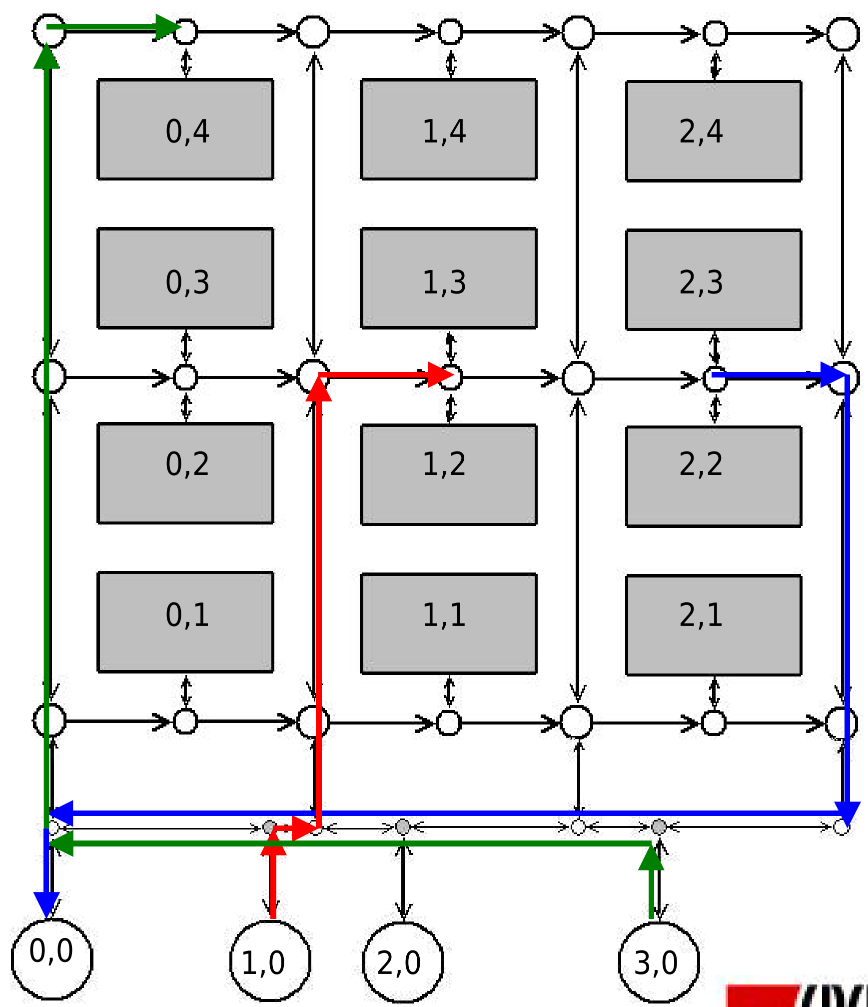
Path congestion

Measure disturbances among paths.

Proximity matrix P (2p X 2p), symmetric, 0 on the diagonal, influenced by routing rules.

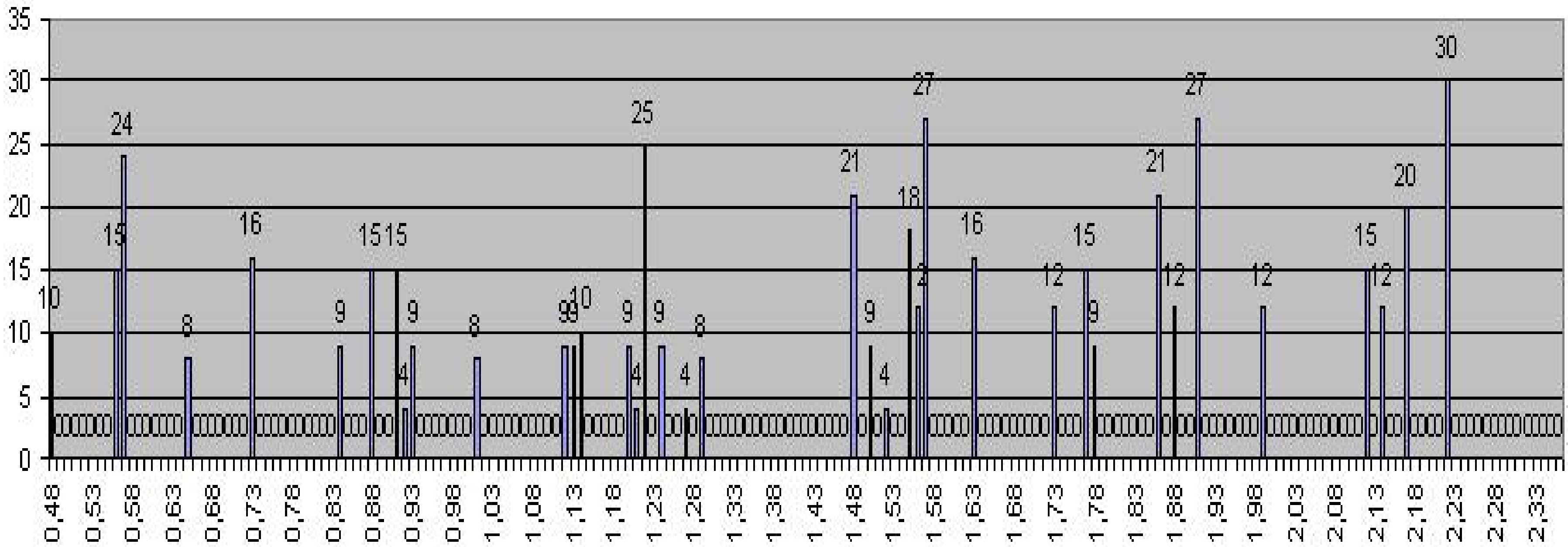
Worst case: all 1 matrix (except diagonal)

$$C_p = \frac{1^T P \vec{c}}{(2p-1)\sum_{j=1}^{2p} c_j}$$



Example

Objective function : $z = C_b + C_e + C_p$



Example

Objective function : $z = C_b + C_e + C_p$

	Nb solutions	Nb different values	MIN	Nb MIN	CPU (s)
(2x2) – 3 paths	512	46	0,4764	10	0,2
(2x2) – 4 paths	4096	282	0,3473	30	1,4
(2x2) – 5 paths	32768	1831	0,5068	21	12,23
(2x2) – 6 paths	262144	7354	0,461	12	112,85
(2x3) – 3 paths	1728	52	0,4764	116	0,67
(2x3) – 4 paths	20736	470	0,3473	350	7,29
(2x3) – 5 paths	248832	4271	0,13	108	121,65

Algorithm: GRASP

Greedy randomized adaptive search procedure

	MIN	CPU (s) (enumeration)	CPU (s) (algorithm)	Nb iteration to reach optimum
(2x2) – 3 paths	0,4764	0,2	0,1	5
(2x2) – 4 paths	0,3473	1,4	0,2	10
(2x2) – 5 paths	0,5068	12,23	0,5	30
(2x2) – 6 paths	0,461	112,85	3	150
(2x3) – 3 paths	0,4764	0,67	0,1	5
(2x3) – 4 paths	0,3473	7,29	0,1	5
(2x3) – 5 paths	0,13	121,65	0,5	25
(2x3) – 6 paths	0,1953	??	15	1000

more Tests

More realistic instances

	in 0,1s	in 1s	in 5s	in 10s	in 20s	in 60s
(3x10) – 3	0,4764	0,4764	0,4764	0,4764	0,4764	
(3x10) – 4	0,3473	0,3473	0,3473	0,3473	0,3473	
(3x10) – 5	0,13	0,13	0,13	0,13	0,13	
(3x10) – 6	0,389	0,195	0,195	0,195	0,195	
(3x10) – 7	0,343	0,267	0,267	0,267	0,267	
(3x10) – 8	0,26	0,1692	0,1646	0,1646	0,1646	
(3x10) – 9	0,304	0,2763	0,2763	0,2763	0,2763	
(3x10) – 15	0,2446	0,1931	0,1705	0,1582	0,1817	0,1602
(3x10) – 20	0,3275	0,2276	0,1663	0,1624	0,1609	0,1389

more Tests

Other ongoing tests (3x10), 3 to 5 ships, up to 20 paths:

- Balanced/unbalanced repartition of loads among paths
- Balanced/unbalanced repartition of loads among ships
- Number of paths per ship (2 to 5)

Optimizing measures does not degrade too much the main objectives while helping in differentiate symmetric solutions

Conclusions and Outlook

Simple closed formulas to evaluate **congestion** in container terminals

Useful to differentiate symmetric solutions with equal distance (or expected completion time)

TODO:

- Additional tests

- Multi-objective optimization problem, explore other than weighted sum

- Evaluate the effects with a CT simulator (queuing model)

- Improve the algorithm: study an exact approach, relax the assumptions, i.e. extend the set of possible decisions (berth allocation, demand splitting, working shifts)