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# Inter-Terminal Transportation

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**Worldwide containerization trends show a high growth in container turnover. Resulting from this increase all port authorities, but especially the ones of the world's leading ports face the challenge of transporting more and more containers from one ship to another or from ships to hinterland transportation systems. For instance this challenge is addressed at the ports of...**


Source: Data retrieved from Volk (2002), United Nations Conference on Trade and Development (UNCTAD) - Secretariat (RMT 2008, 2009, 2010, 2011, 2012, 2013), Clarkson Research Services Ltd. (2010), World Trade Organization (International Trade Statistics 2008, 2009, 2010, 2011, 2012)

## Exemplary means of transportation used in all three ports:

Automated Lifting Vehicles

...Hamburg...

MTS - Multi-Trailer System

...Shanghai...

Automated Guided Vehicles

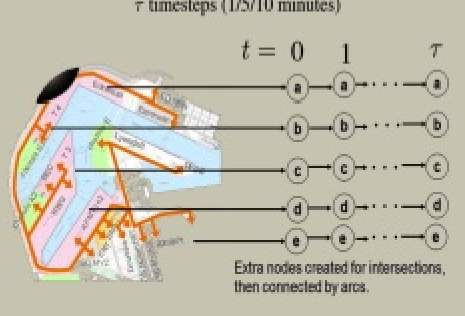
...and Rotterdam.

**We developed a Mathematical Model of Inter-Terminal Transportation**

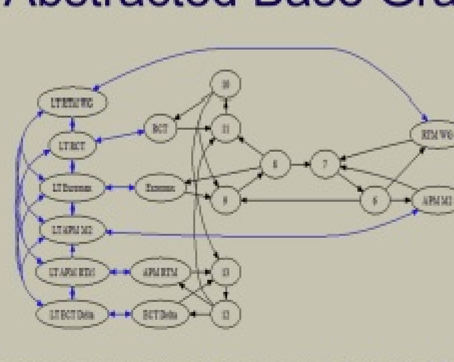
1. The first mathematical model of ITT, optimization based or otherwise.
2. A modified solution mechanism for solving ITT problems in which we solve the container flow problem without vehicle constraints first and use it in guiding the solution to the full problem.
3. Congestion modeling with vehicles servicing a multi-commodity flow.

### Map

### Time-Expanded Graph




### Abstracted Base Graph



Blue arcs are waterways and are removed along with LT nodes for non-barge instances.

### Exemplary Results and Description

500 Containers / 6 hours / 5 min. discretization

Probability of solving an instance with 25 - 125 vehicles

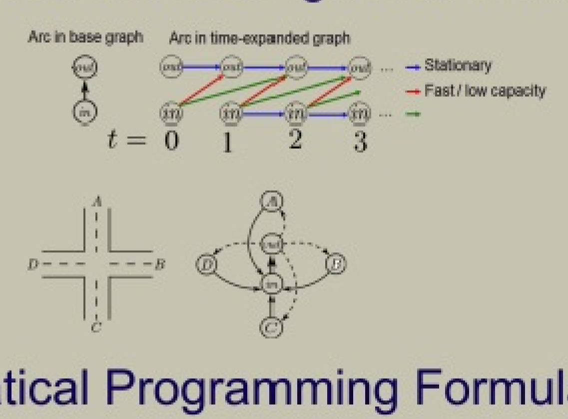
| | | 25 | 50 | 75 | 100 | 125 | |
|---|---|---|---|---|---|---|---|
| Multi-Trailer System | AGV | 0.15 | 0.55 | 0.80 | 0.65 | 0.75 | 5 containers |
| Automated guided vehicle | ALV | 0.00 | 0.40 | 0.90 | 0.95 | 0.95 | 1 container |
| Automated lifting vehicle | MTS | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 1 container |

Average CPU time (s) (excl. timeouts) and # of timeouts

| | 25 | | 50 | | 75 | | 100 | | 125 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | ∅ | TO | ∅ | TO | ∅ | TO | ∅ | TO | ∅ | TO |
| AGV | 379.51 | 14 | 819.10 | 6 | 380.61 | 1 | 237.78 | 4 | 317.48 | 2 |
| ALV | 1453.71 | 14 | 1563.72 | 11 | 356.19 | 1 | 196.45 | 8 | 107.47 | 0 |
| MTS | 66.64 | 8 | 56.58 | 8 | 85.68 | 0 | 52.59 | 8 | 55.28 | 0 |

Within 6 hours 500 containers are moved.
The 6 hours are divided into five-minute-instances.

### Intersections and Congestion Modeling




### Mathematical Programming Formulation

Variables:

- $x_{ij} \in \mathbb{Z}^{\geq 0}$ - Number of vehicles on arc (i,j)
- $y_{ij\theta} \in \mathbb{Z}^{\geq 0}$ - Amount of demand theta on arc (i,j)
- $z_{ij} \in \{0,1\}$ - Fan arc (i,j) is being used?

Important constants:

- $V^T$ - Nodes in time expanded graph
- $A^T$ - Arcs in time expanded graph
- $H$ - Number of vehicle types
- $\Theta$ - Number of demands

$$\min \sum_{1\leq\theta\leq\Theta}\sum_{u<t\leq\tau}\sum_{i\in In(d_\theta)} p_\theta(t-u_\theta)y_{id_\theta\theta}$$

(Minimize late delivery penalty)

(Vehicle flow)

(Cargo flow)

(Maximum container load/unload moves at terminal)

(Only use 1 congestion arc)

(Long-term node moves)

### Conclusion

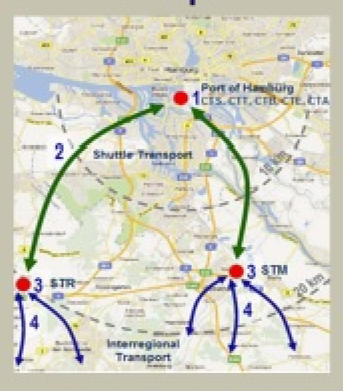
Preliminary study
Slow speed of ALV hurts performance with few vehicles
Fast load time of ALV outperforms MTS with many vehicles
High capacity of MTS gives stable performance almost regardless of number of vehicles
In our model, if solutions are feasible there rarely any delays experienced

### Comparison to Terms of Reference Document

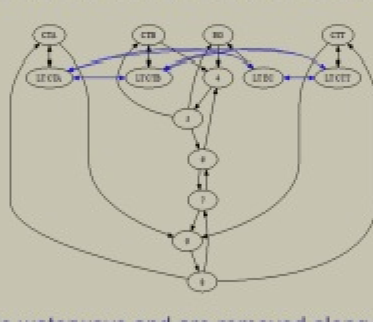
**What we model:**
AGV/ALV/MTS for ITT
Barges for ITT
Vehicle interactions with any type of terminal (rail, sea, barge)
Vehicle/Terminal interface through number of moves restrictions
Congestion interactions between ITT vehicles
With the capability to model outside interactions, too

**What we do not currently model, but the model supports:**
Crossings with external road/rail
3 TEU trucks (our MTS currently has 5 containers)
Dedicated lanes
ITT/Terminal interfacing details
What our model does not support yet, but we can add:
Combinations of manned and unmanned vehicles
What our model can't support/analyze:
Preventing "monopolists" from dominating the system / game theoretical analysis

### Map




### Abstracted Base Graph



Blue arcs are waterways and are removed along with LT nodes for non-barge instances.

### Exemplary Results and Description

500 Containers / 6 hours / 5 min. discretization

Probability of solving an instance with 25 - 125 vehicles, 1 barge

| | | 25 + 1 | 50 + 1 | 75 + 1 | 100 + 1 | 125 + 1 | |
|---|---|---|---|---|---|---|---|
| Multi-Trailer System | AGV | 0.00 | 0.25 | 0.55 | 0.80 | 0.75 | 5 containers |
| Automated guided vehicle | ALV | 0.00 | 0.45 | 0.70 | 0.80 | 0.90 | 1 container |
| Automated lifting vehicle | MTS | 0.80 | 0.80 | 0.80 | 0.80 | 0.80 | 1 container |

Average CPU time (s) (excl. timeouts) and # of timeouts

| | 25 | | 50 | | 75 | | 100 | | 125 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | ∅ | TO | ∅ | TO | ∅ | TO | ∅ | TO | ∅ | TO |
| AGV | 1380.75 | 0 | 1336.82 | 0 | 911.77 | 0 | 337.17 | 0 | 511.86 | 0 |
| ALV | 841.49 | 1 | 1187.61 | 0 | 645.64 | 0 | 288.38 | 0 | 103.22 | 0 |
| MTS | 105.67 | 0 | 56.48 | 0 | 56.08 | 0 | 57.19 | 0 | 46.83 | 0 |

Within 6 hours 500 containers are moved.
The 6 hours are divided into five-minute-instances.

Electric Cargo Conveyor (ECCO) (model)
Source: http://aiq.ga.com/EM/transportation/images/main1.jpg

SAFE Freight Shuttle (model)
Sources: http://www.freightshuttle.com/benefits/ ; http://www.freightshuttle.com/concept

### Future Work and Vehicle Alternatives (Not yet considered)

We can model new infrastructure (tunnels, bridges, monorail)
Our model could be used as input to a discrete event simulation model
We can consider costs in the objective
Vehicle count optimization
Balancing vehicle cost and delay is possible

(Heavy-lift) Overhead-conveying system Concar (model)
Source: Arnold and Rall 1996

(Heavy-lift) Overhead-conveying system Auto-GO (model)
Source: Dimitrijevic and Spasovic 2006

Poster created by Julia Bachale