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SCHEDULING DRAYAGE OPERATIONS IN SYNCHROMODAL TRANSPORT

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CONTENTS

Motivation

● Drayage operations in synchromodal transport

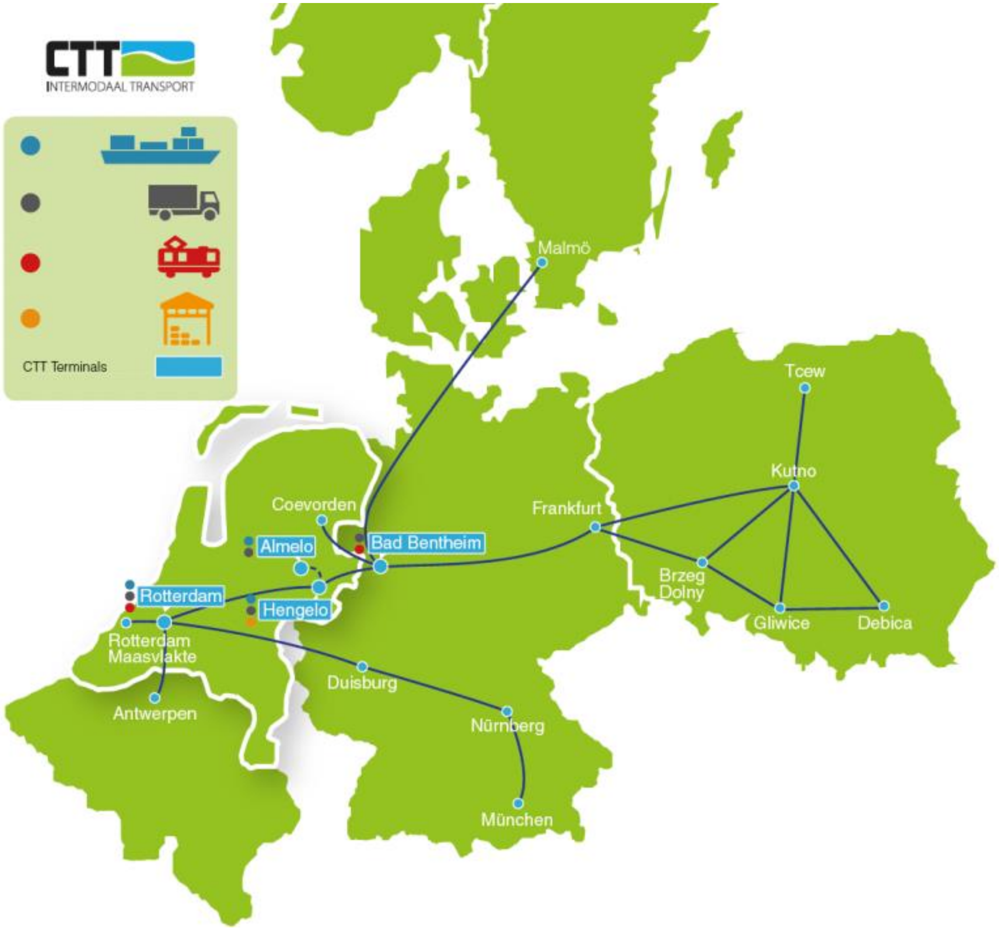
●● A MILP model and matheuristic solution

●●● Proof-of-concept experiments

●●●● What to remember

MOTIVATION: LOGISTIC SERVICE PROVIDER IN TWENTE

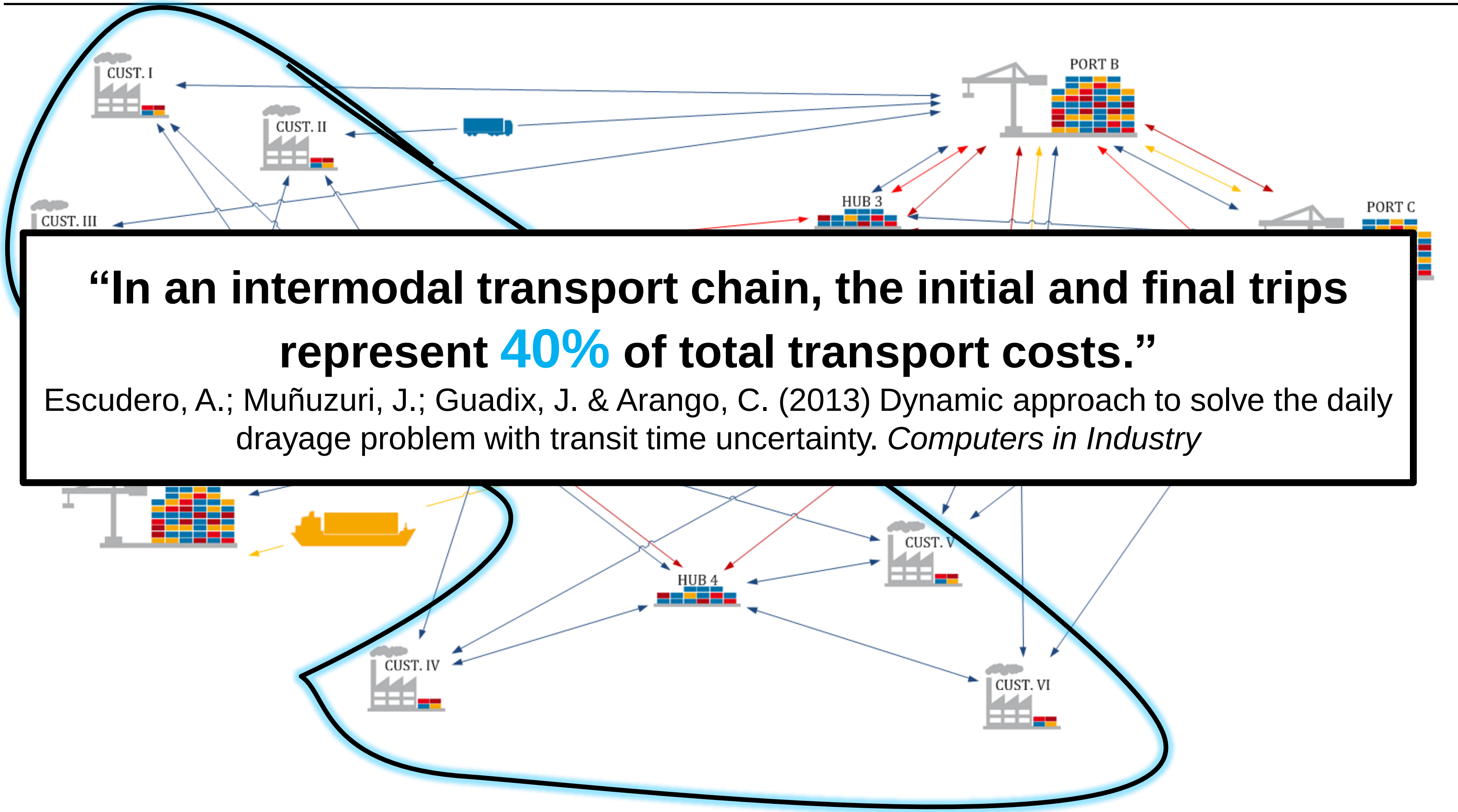
TRANSPORT OF CONTAINERS TO/FROM THE HINTERLAND



*Source of artwork: Combi Terminal Twente (CTT) www.ctt-twente.nl

MOTIVATION: EFFICIENCY OPPORTUNITIES

DRAYAGE COSTS IN INTERMODAL/SYNCHROMODAL TRANSPORT COSTS

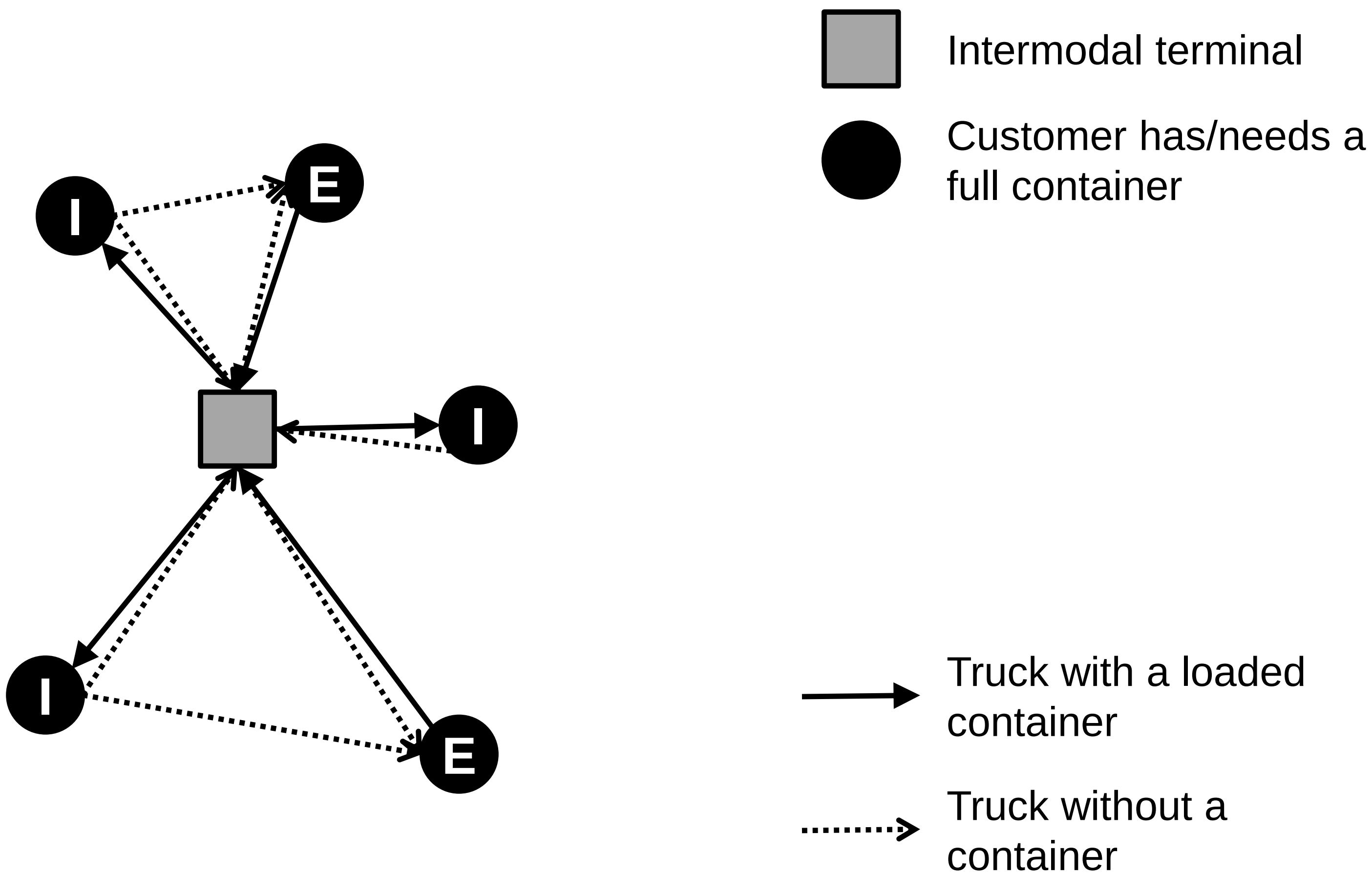


"In an intermodal transport chain, the initial and final trips represent 40% of total transport costs."

Escudero, A.; Muñuzuri, J.; Guadix, J. & Arango, C. (2013) Dynamic approach to solve the daily drayage problem with transit time uncertainty. *Computers in Industry*

**Source of artwork: Europe Container Terminals "The future of freight transport". www.ect.nl*

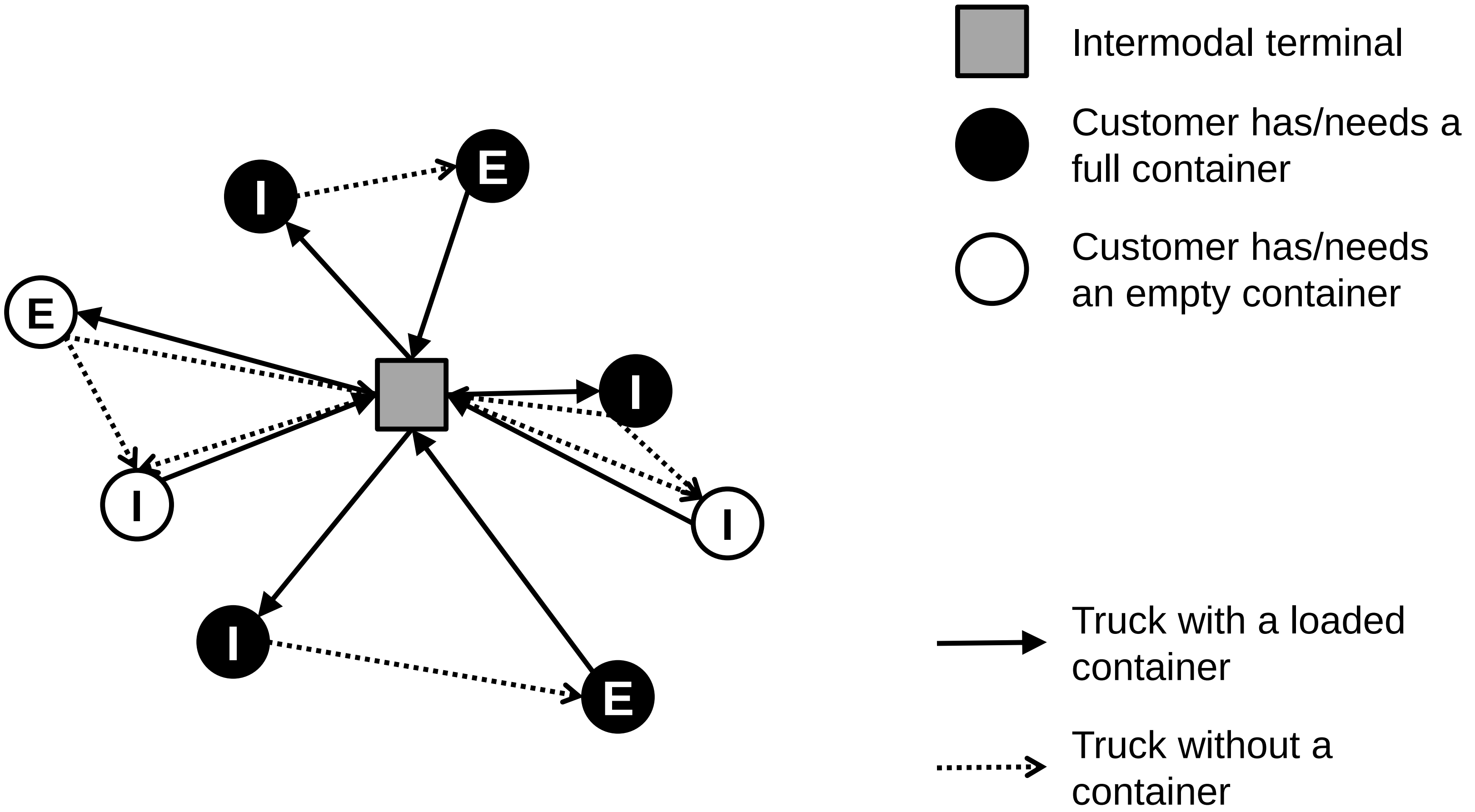
DRAYAGE OPERATIONS
THE BASIC CASE: EXPORT/IMPORT FULL-CONTAINER JOBS



I: Import , E: Export

DRAYAGE OPERATIONS

ADDING EMPTY-CONTAINER JOBS



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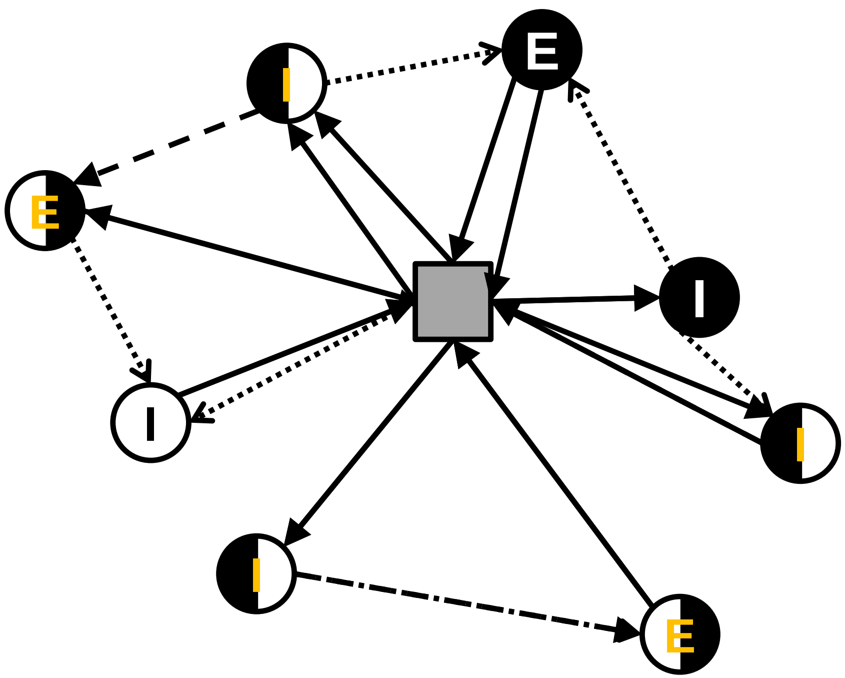
DRAYAGE OPERATIONS

ADDING *COMPLETE* JOBS



Intermodal terminal

Customer has/needs a full container

Customer has/needs an empty container

Customer complete end-haulage

Customer complete pre-haulage

Truck with a loaded container

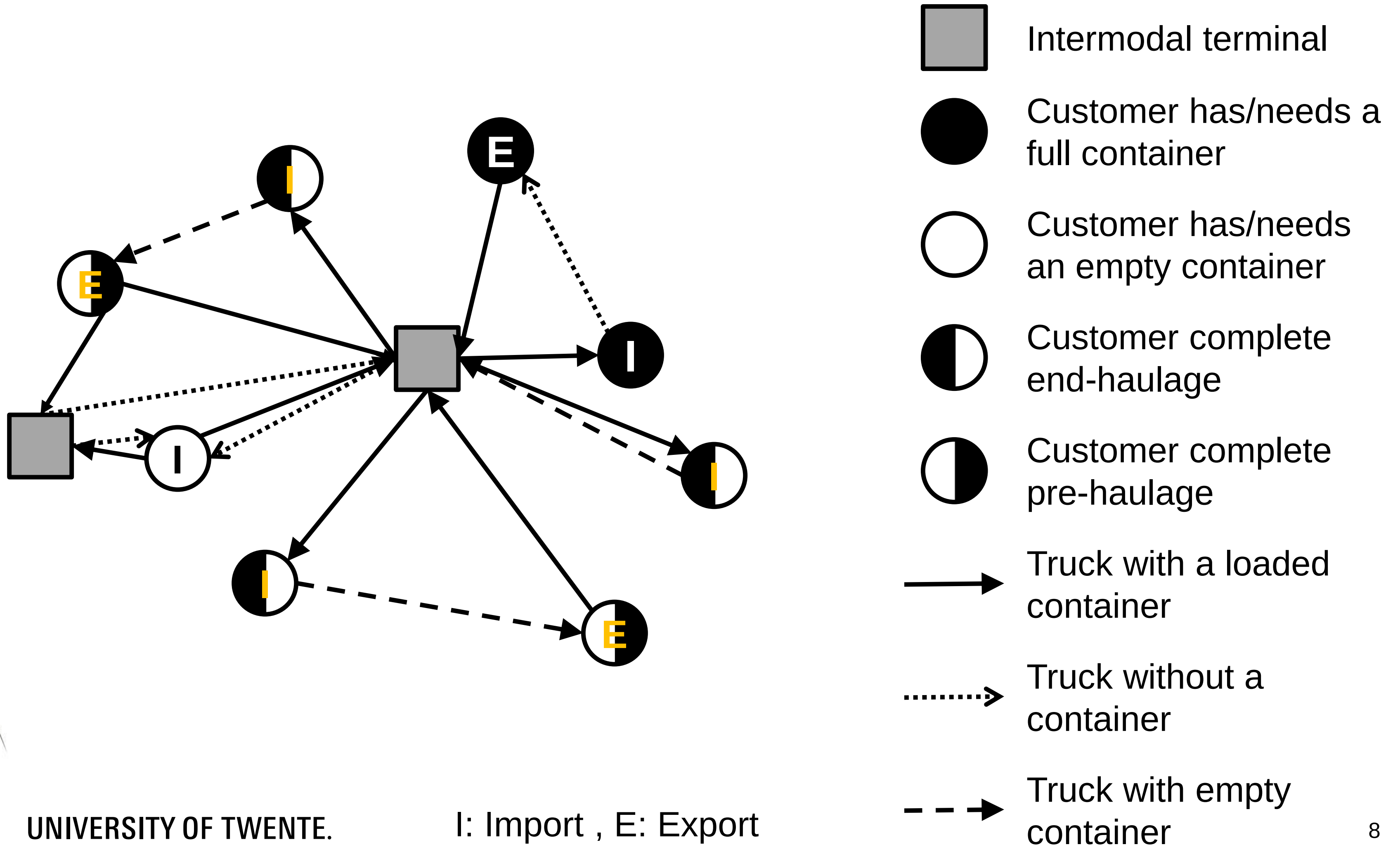
Truck without a container

Truck with empty container

I: Import , E: Export

DRAYAGE OPERATIONS

ADDING MULTIPLE TERMINALS (AND FLEXIBLE JOBS)



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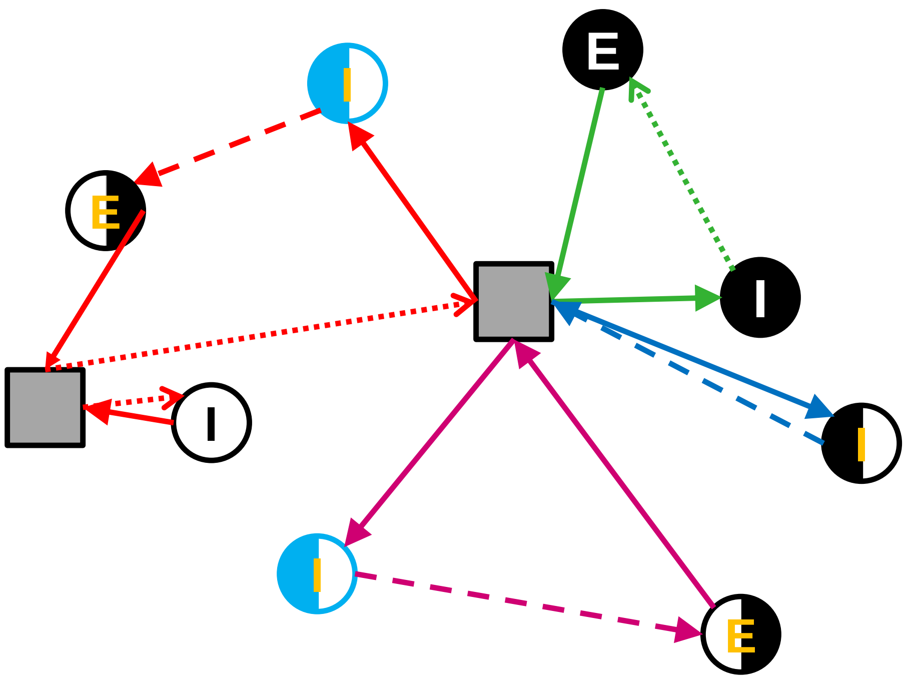
DRAYAGE OPERATIONS

DECOUPLING (I.E., POSSIBLE TO SPLIT COMPLETE JOBS IN TWO)

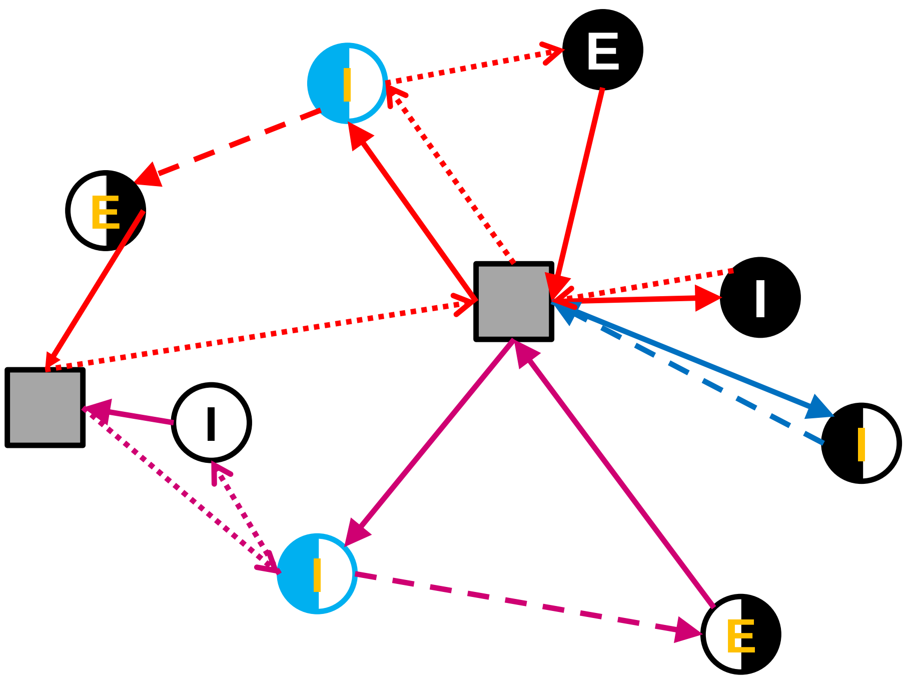


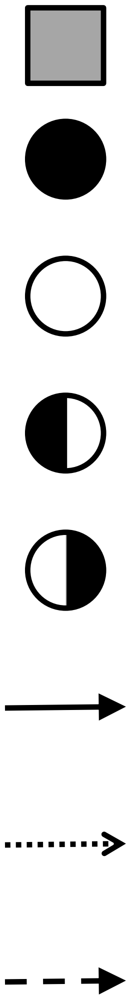
- Intermodal terminal
- Customer has/needs a full container
- Customer has/needs an empty container
- Customer complete end-haulage
- Customer complete pre-haulage
- Truck with a loaded container
- Truck without a container
- Truck with empty container

I: Import , E: Export

DRAYAGE OPERATIONS

DECOUPLING (I.E., POSSIBLE TO SPLIT COMPLETE JOBS IN TWO)





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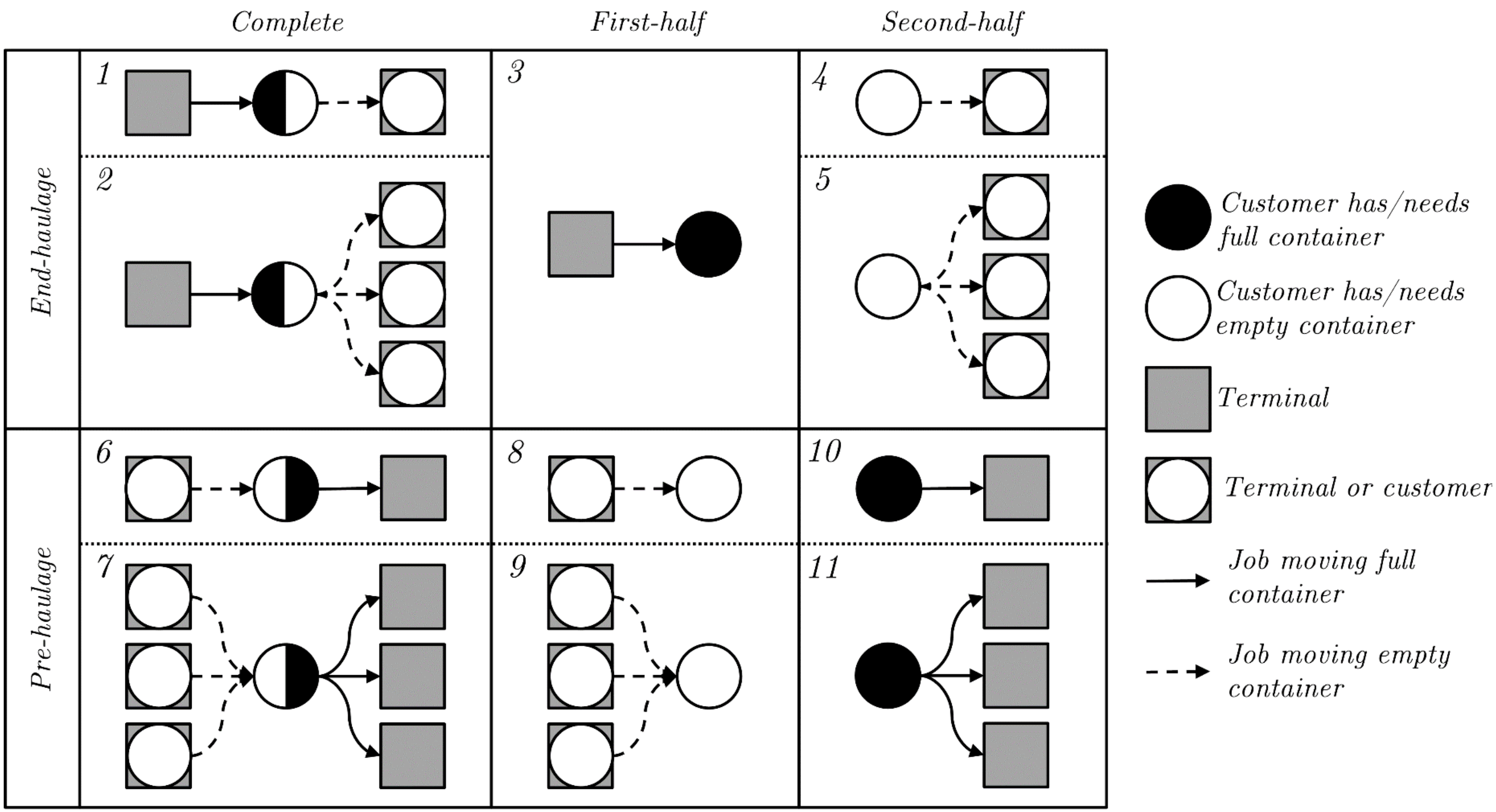
DRAYAGE OPERATIONS IN SYNCHROMODAL TRANSPORT

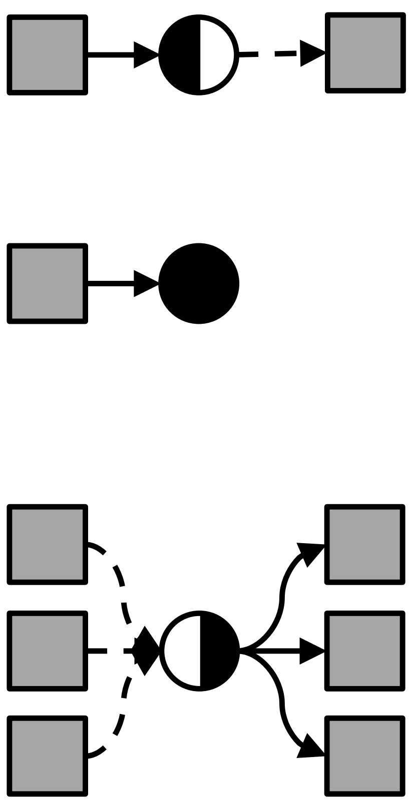
CATEGORIZATION OF JOBS



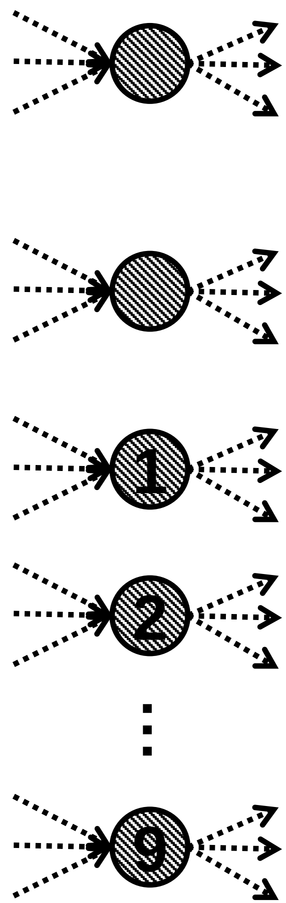
MODELING DRAYAGE OPERATIONS

MODELING JOBS USING MIXED-INTEGER LINEAR PROGRAMMING (MILP)

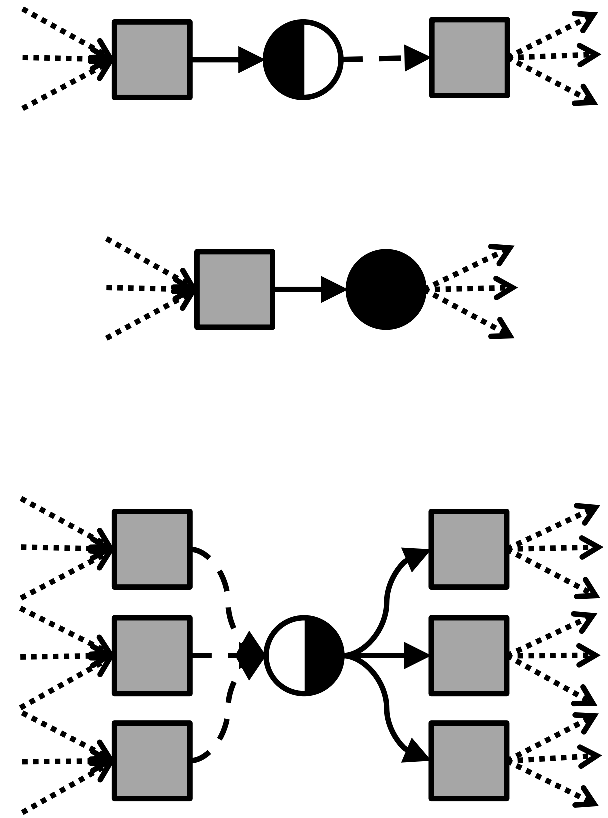
Example job



Jobs as ***nodes***



Jobs as ***arcs***



MODELING DRAYAGE OPERATIONS: FTPDPTW BASE

FULL TRUCKLOAD PICKUP AND DELIVERY PROBLEM WITH TIME-WINDOWS (FTPDPTW)

$$\min z(x) = \underbrace{\sum_{k\in K}\left(C_k^F \cdot \sum_{j\in\delta'^+(B_k)} x_{B_k,j,k}\right) + \sum_{k\in K}\sum_{(i,j)\in A'} C^V_{i,j,k}\cdot x_{i,j,k}}_{\text{Trucking costs}} \quad (1a)$$

$$+ \sum \sum \sum C^A_{i,j} \cdot x_{i,j,k}$$

$$E_i \le w_i \le L_i,\ \forall\, i \in V \quad (1h)$$

$$\sum_{k\in K} \left(x_{i,j,k}\cdot(w_i + S_i + T^T_{i,j} - w_j)\right) \le 0,\ \forall\, i,j \in V \quad (1i)$$

$$\sum_{k\in K} \left(x_{B_k,j,k}\cdot T^T_{B_k,j}\right) \le w_j,\ \forall\, j \in V \quad (1j)$$

New elements in the FTPDPTW model:

1. ***Additional term in the objective***: terminal (long-haul mode) assignment cost
2. ***Two type of arc-constraints***: job assignment and flow-conservation
3. ***Decoupling constraints***: separation of job-arcs and their time-windows

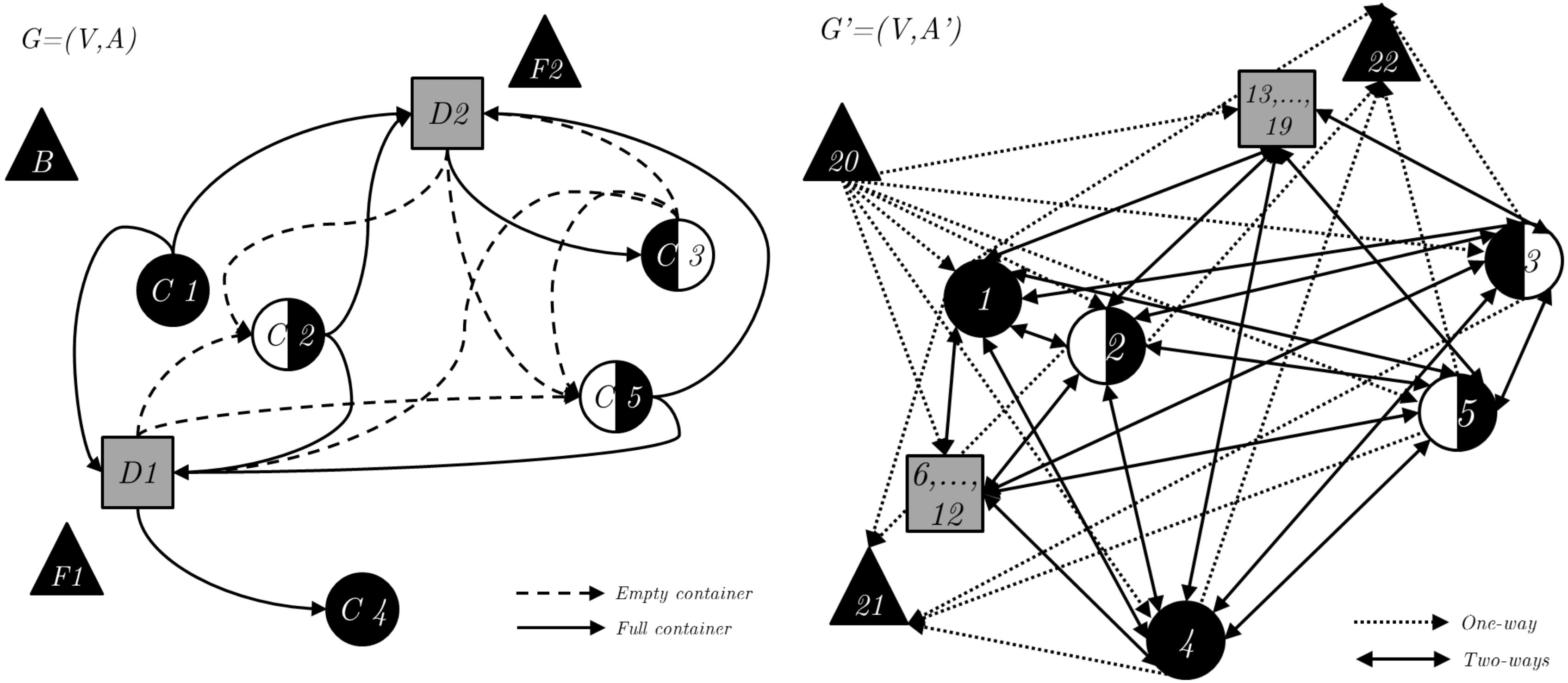
$$\sum_{k\in K}\sum_{j\in\delta'^+(i)} x_{i,j,k} \le 1,\ \forall\, i \in V^D \quad (1f)$$

$$w_i + S_i + T_{i,F_k} - (L_i + S_i + T_{i,F_k})\cdot(1 - x_{i,F_k,k}) \le L_{F_k},\ \forall\, i \in \delta'^-(F_k), k \in \mathcal{K} \quad (2b)$$

$$\sum_{j\in\delta'^+(i)} x_{i,j,k} - \sum_{j\in\delta'^-(i)} x_{j,i,k} = 0,\ \forall\, i \in V^C \cup V^D, k \in K \quad (1g)$$

MODELING DRAYAGE OPERATIONS

A GRAPHICAL EXAMPLE OF THE MILP MODEL



MODELING DRAYAGE OPERATIONS

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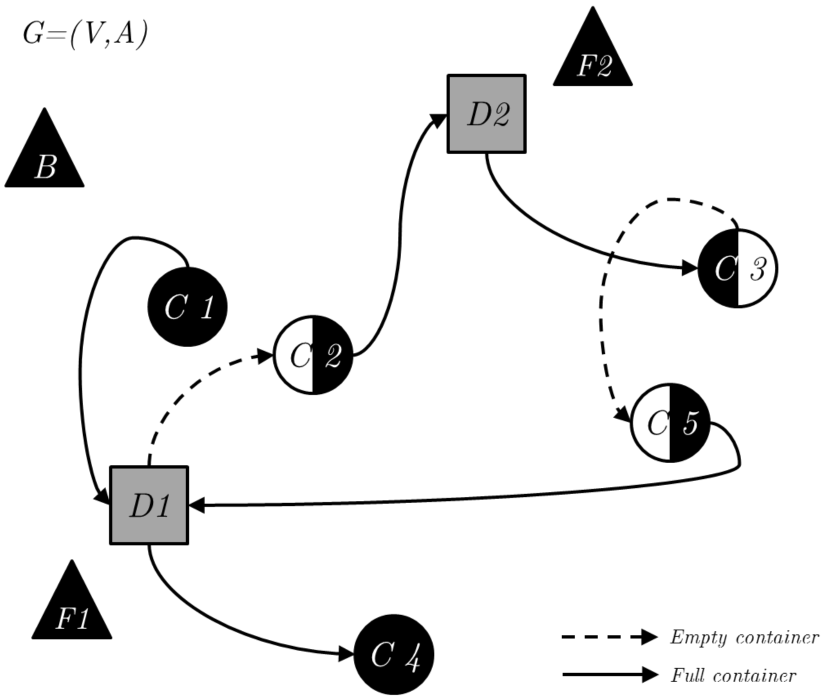
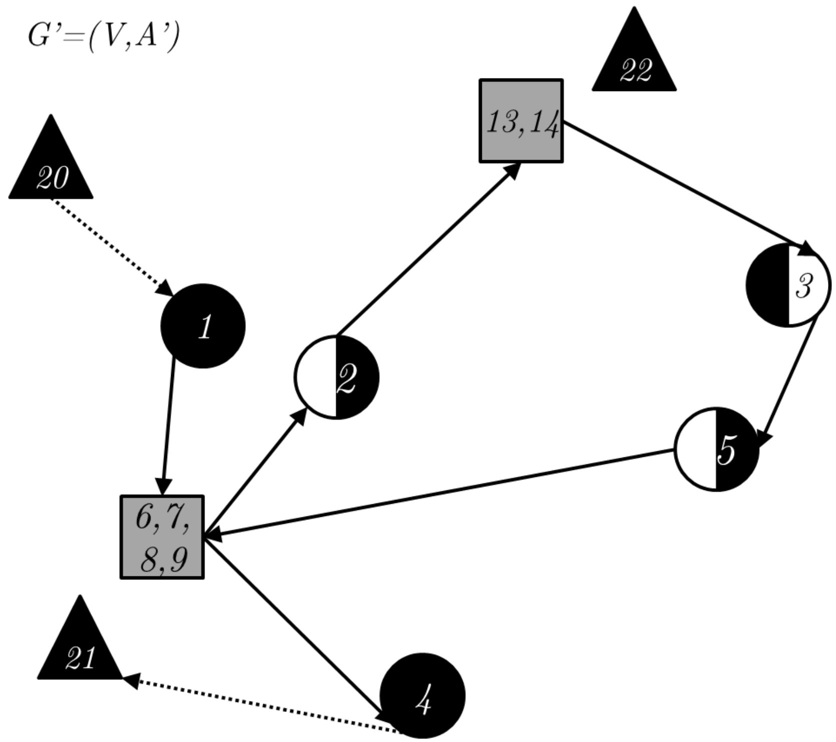


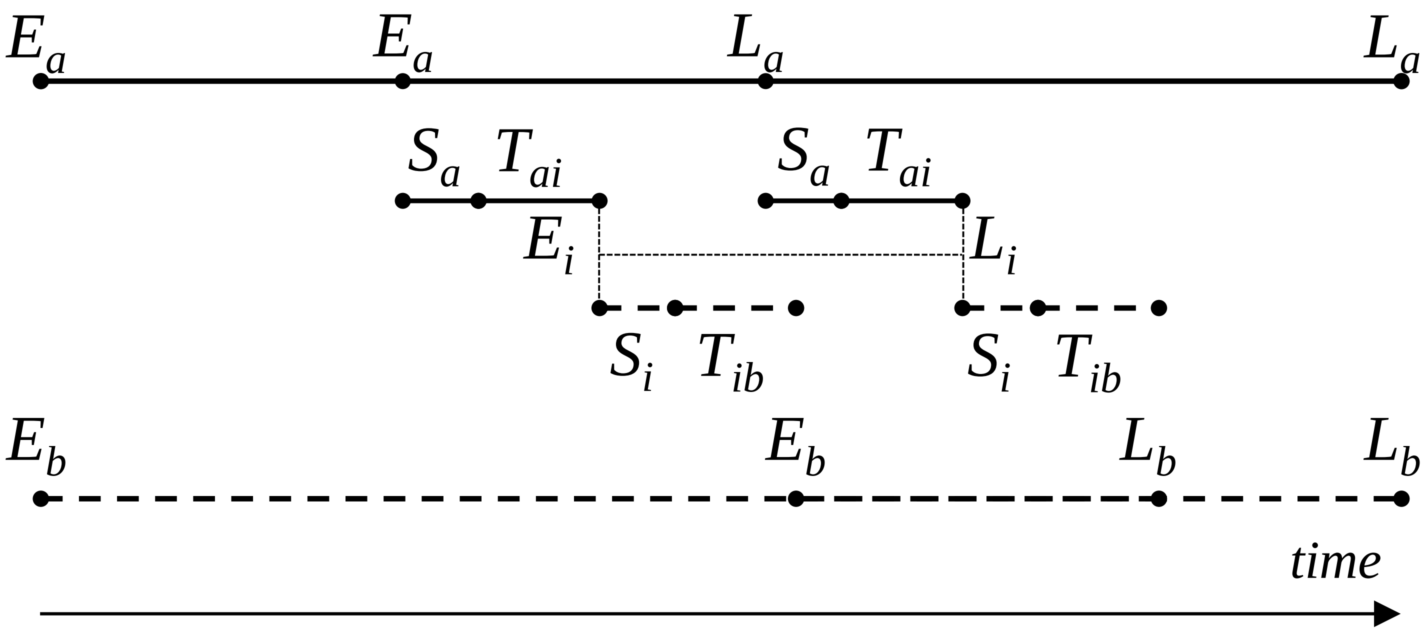


MODELING DRAYAGE OPERATIONS: IMPROVEMENTS

TIME-WINDOW PRE-PROCESSING EXAMPLE

(1) Valid Inequalities
(2) Tighter time-windows at replicated depot nodes

Example job i:



SOLVING THE MODEL: A MATHEURISTIC APPROACH

ITERATIVELY SOLVING A CONFINED VERSION OF THE MILP MODEL

Overall idea **:** confine the solution space of the MILP model using operators $\mathcal{M}$ and $\mathcal{F}$, based on an incumbent solution $\mathcal{X}^C$, for a number of iterations N.

Step 0. Get $\mathcal{G}(\mathcal{V},\mathcal{A})$, $\mathcal{G}'(\mathcal{V},\mathcal{A}')$ and $\mathcal{X}^C$.
Step 1. For $n = 1,2,\dots,N$
- Step 1a. Define $\mathcal{F}$ and $\mathcal{M}$.
- Step 1b. Fix x_{ijk} according to $\mathcal{F}$ and $\mathcal{M}$.
- Step 1c. Solve MILP and store solution.

Step 2. Return best solution found.

Static version ($\mathcal{M}$): fix arcs randomly, based on job configuration.

Dynamic version ($\mathcal{F}$ and $\mathcal{M}$)**:** fix ‘promising’ routes and fix arcs (which are not in the promising routes) randomly, based on job configuration.

SOLVING THE MODEL: STATIC MATHEURISTIC

THREE MATHEURISTIC OPERATORS (MHO)

MHO 1 **:** Remove all but two job arcs for N^{M1} random jobs.

$$x_{j,r,k} = 0, \forall k \in \mathcal{K}, j \in \delta^{-}(r) \setminus \{i, i'\} \Bigg| i = \underset{j \in \delta^{-}(r)}{\arg\min} T_{j,r} \text{ and } i' = \underset{j \in \delta^{-}(r) \setminus \{i\}}{\arg\min} T_{j,r} \tag{7a}$$

$$x_{r,j,k} = 0, \forall k \in \mathcal{K}, j \in \delta^{+}(r) \setminus \{i, i'\} \Bigg| i = \underset{j \in \delta^{+}(r)}{\arg\min} T_{r,j} \text{ and } i' = \underset{j \in \delta^{+}(r) \setminus \{i\}}{\arg\min} T_{r,j} \tag{7b}$$

MHO 2 **:** Fix the ‘cheapest’ arc between a job Type 2 and Type 7, for a N^{M2} random job-pairs.

$$\sum_{k \in \mathcal{K}} x_{r,r',k} = 1 \Bigg| r = \underset{j \in \delta^{-}(r')}{\arg\min} T_{j,r'} \tag{8}$$

MHO 3 **:** Fix the ‘cheapest’ job arc for a N^{M3} random jobs.

$$\sum_{k \in \mathcal{K}} x_{i,r,k} = 1 \Bigg| i = \underset{j \in \delta^{-}(r)}{\arg\min} T_{j,r} \quad \text{and} \quad \sum_{k \in \mathcal{K}} x_{r,i,k} = 1 \Bigg| i = \underset{j \in \delta^{+}(r)}{\arg\min} T_{r,j} \tag{9}$$

SOLVING THE MODEL: DYNAMIC MATHEURISTIC

TWO FIXING CRITERIA (FC)

FC 1 **:** Fix the N^{F1} routes from the current (before re-planning) schedule $\mathcal{X}^C$ that have the largest number of jobs.

$$\mathcal{F}^1(k^{\mathrm{C}}) = \left\{ (i,j) \in \mathcal{A} : x_{i,j,k^{\mathrm{C}}} = 1, k^{\mathrm{C}} = \underset{k' \in \mathcal{K} | \sum_{j \in \mathcal{V}} x^{\mathrm{C}}_{B_k,j,k} = 1}{\arg\max} \sum_{i \in \mathcal{V}^{\mathrm{R}}} x^{\mathrm{C}}_{i,j,k} \right\} \quad (10)$$

FC 2 **:** Fix the N^{F2} routes from the current schedule $\mathcal{X}^C$ that have the shortest traveling time.

$$\mathcal{F}^2(k^{\mathrm{C}}) = \left\{ (i,j) \in \mathcal{A} : x_{i,j,k^{\mathrm{C}}} = 1, k^{\mathrm{C}} = \underset{k' \in \mathcal{K} | \sum_{j \in \mathcal{V}} x^{\mathrm{C}}_{B_k,j,k} = 1}{\arg\min} \sum_{(i,j) \in \mathcal{A}'} x^{\mathrm{C}}_{i,j,k} T_{i,j} \right\} \quad (11)$$

PROOF-OF-CONCEPT EXPERIMENTS

EXPERIMENTAL SETUP

Instances: VRPTW from Solomon (1987) + Dutch LSP typical job-configuration ratios and three terminals.

Benchmark: Job-pairing with cheapest insertion heuristic similar to the one of Caris and Janssens (2009).

Solver: CPLEX 12.6.3 with a limit of 300 seconds.

Static Matheuristic

- Test the effect of improvements and MHOs in the MILP.
- MHO settings are based on the number of jobs.
- All jobs for a day are known.

Dynamic Matheuristic

- Test the FCs + Static Matheuristic.
- Jobs reveal dynamically in 5 stages (5x re-planning) during the first half of the day.

PROOF-OF-CONCEPT: STATIC MATHEURISTIC

PERFORMANCE OF THE MHOS PER INSTANCE FAMILY

Instances	BH	MILP	VIs	TWPP	MHO1	MHO2	MHO3
C1	77,960	77,926	77,960	76,924	76,829	77,926	75,189
C2	52,904	52,882	52,904	52,049	51,841	52,078	50,802
R1	111,087	111,078	110,904	107,649	107,254	107,647	107,736
R2	50,500	50,435	50,500	50,497	50,255	50,500	50,378

Clustered (C) and Random (R) locations; Short (1) and Long (2) time-windows

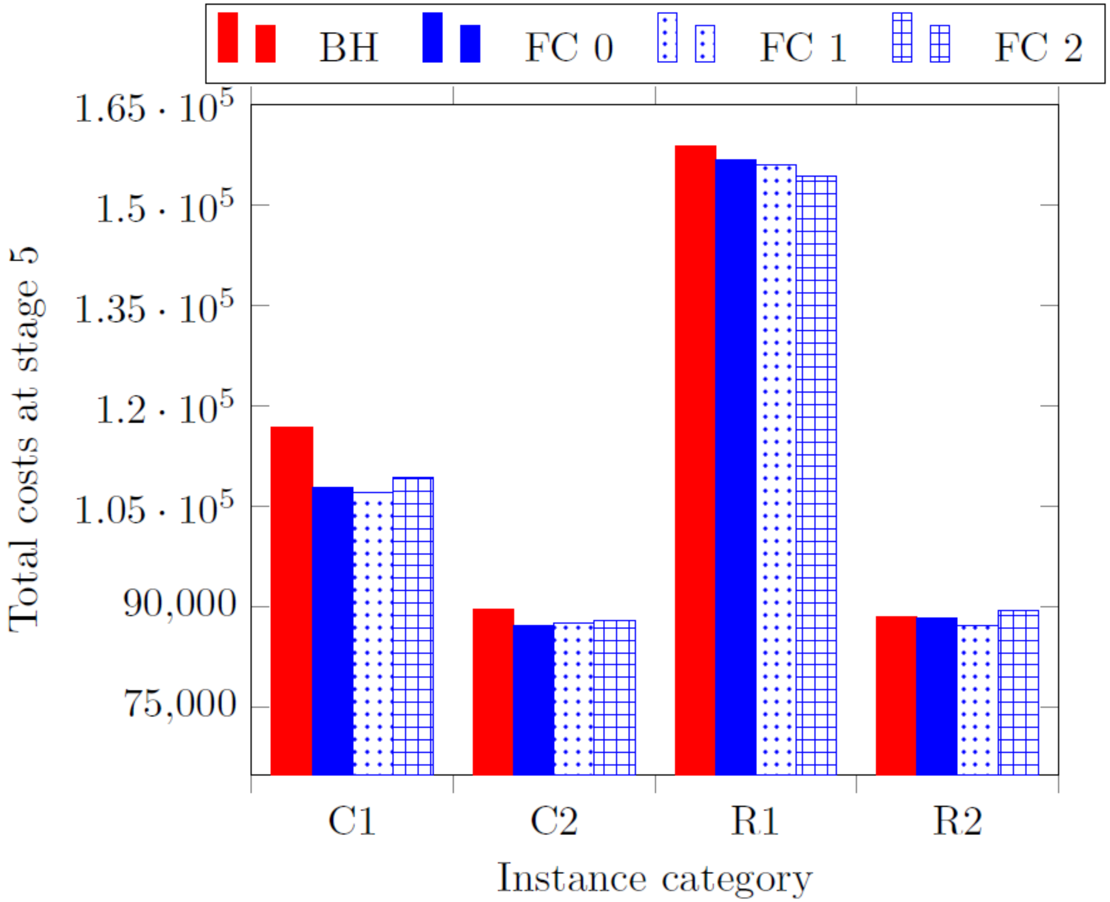
Largest cost → *Lowest cost*

Observations:

1. ***TWPP helps more the MILP than the Vis.***
2. ***MHO 3 is the best for clustered locations and MHO 1 for random locations.***
3. ***MHO 2 is worse than the TWPP.***
4. ***Savings of around 4% in all instance categories except R2.***

PROOF-OF-CONCEPT: DYNAMIC MATHEURISTIC

PERFORMANCE OF THE FCS AT RE-PLANNING STAGE 5 (END OF THE DAY)

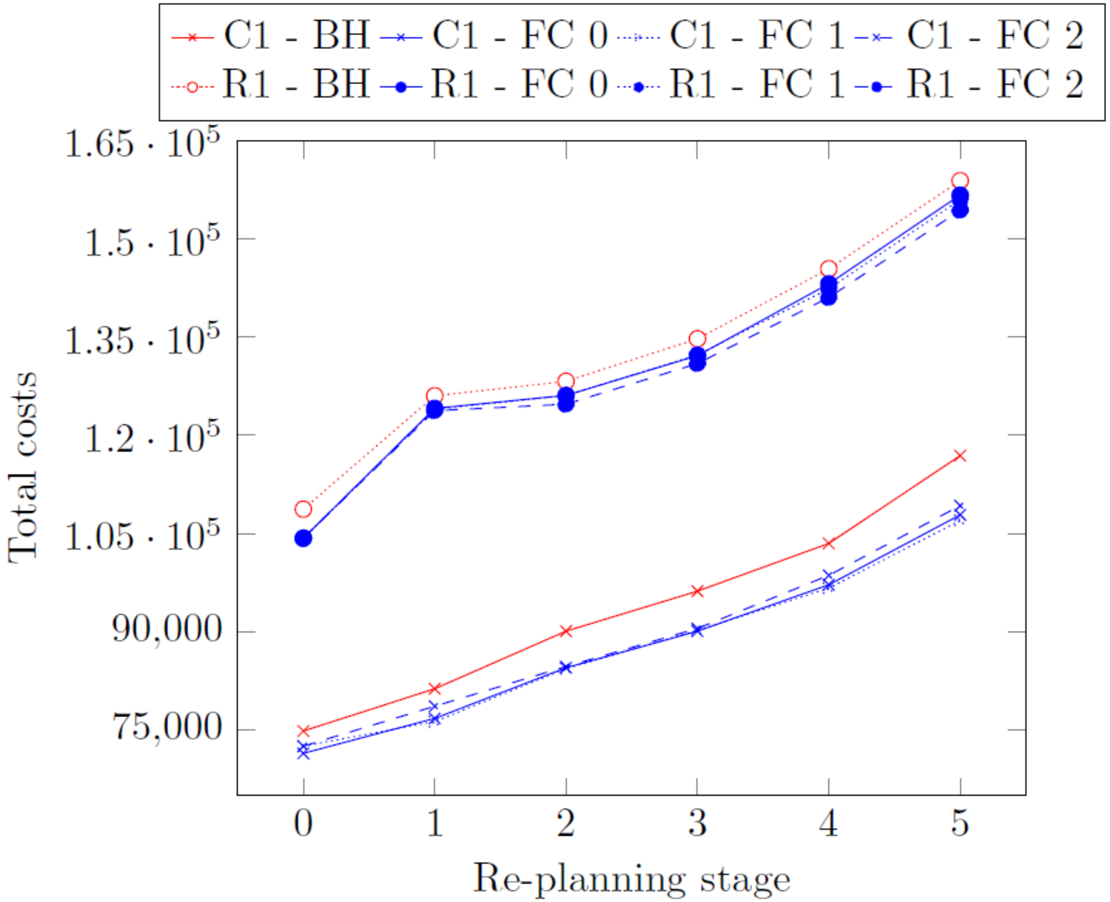


Observations:

1. ***Savings compared to the BH are in the range of 3% to 8%.***
2. ***Best FC varies per instance category.***

PROOF-OF-CONCEPT: DYNAMIC MATHEURISTIC

PERFORMANCE OF THE FCS PER RE-PLANNING STAGE



Observations:

1. ***'No' differences between FCs in some stages.***
2. ***In C1, the gap between the FCs and the BH widens in late stages.***

WHAT TO REMEMBER

- We developed a MILP model and a dynamic matheuristic to schedule drayage operations in synchromodal transport with various job categories and integrated decisions.

- Through numerical experiments, we studied the performance of our approach and observed that its gains over a benchmark heuristic were dependent on problem characteristics such as customer dispersion and re-planning stage .

- Further research about the matheuristic operators is necessary in (i) tuning with respect to problem attributes and (ii) adapting with previous iterations and solutions.

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THANKS FOR YOUR ATTENTION!

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