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INTEGRATED SCHEDULING IN SYNCHROMODAL TRANSPORT

Arturo E. Pérez Rivera & Martijn R.K. Mes

Department of Industrial Engineering and Business Information Systems
University of Twente, The Netherlands

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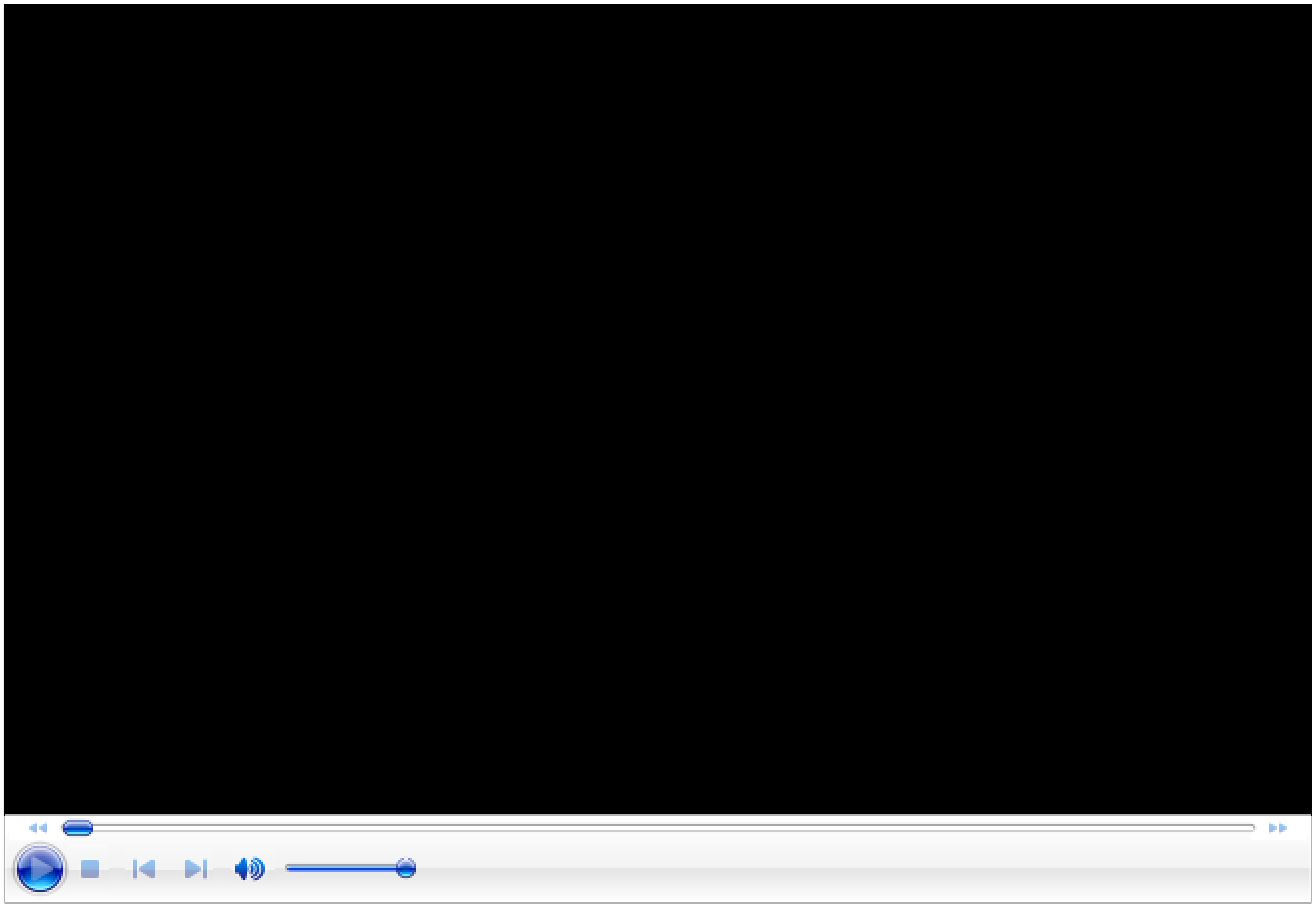
- Integrated scheduling of drayage and long-haul transport:
  - *MILP and MDP models*
- Combination of two heuristic approaches:
  - *A matheuristic and ADP algorithm*
- Preliminary results
- What to remember

SYNCHROMODAL FREIGHT TRANSPORT

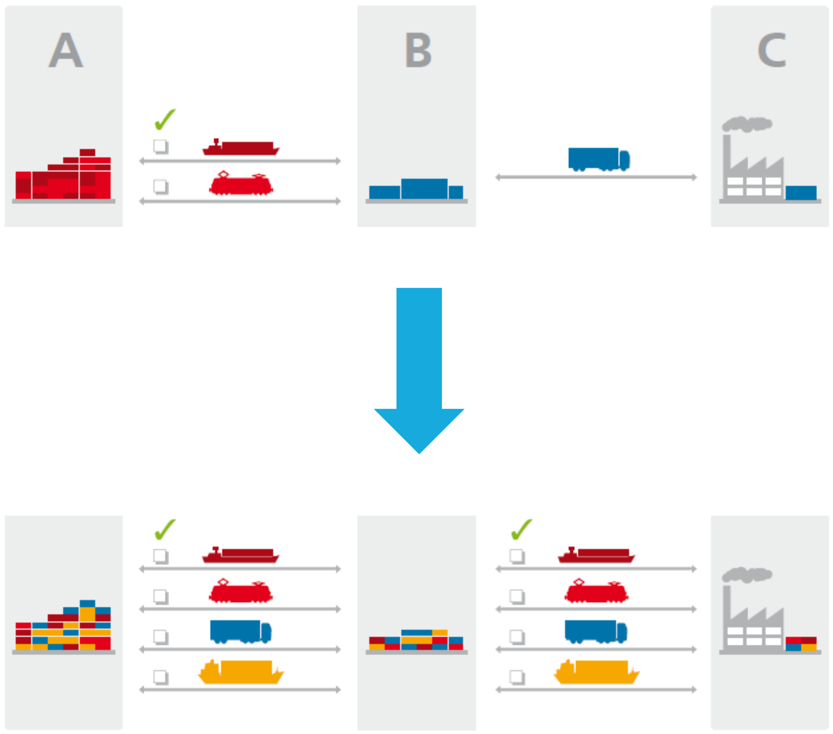
WHAT IS SYNCHROMODALITY?



**Source of video: Dutch Institute for Advanced Logistics (DINALOG) www.dinalog.nl*

SYNCHROMODAL FREIGHT TRANSPORT
WHAT ARE ITS CHARACTERISTICS?

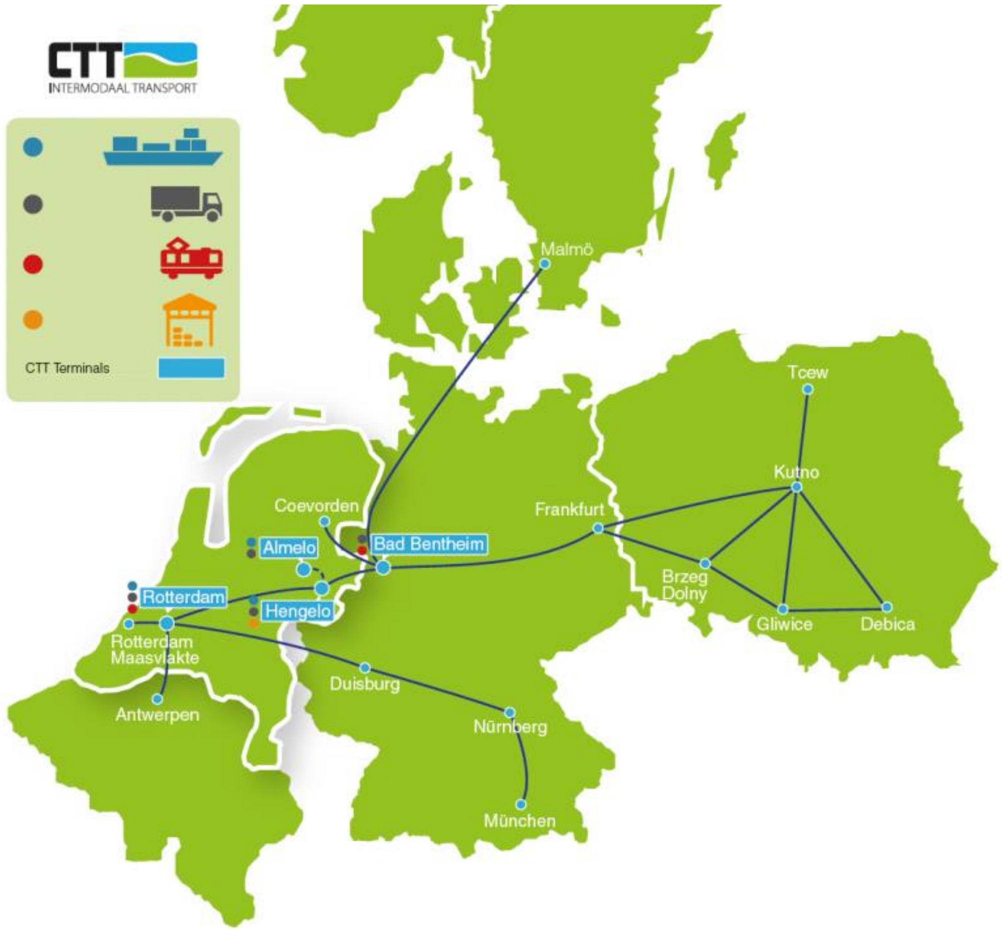
- ***Mode-free booking*** for all freights.
- ***Network-wise scheduling*** at any point in time.
- ***Real-time information*** about the state of the network.
- ***Overall performance*** in both network and time.



**Source of artwork: European Container Terminals (ECT) – The future of freight transport (2011).*

SYNCHROMODAL FREIGHT TRANSPORT

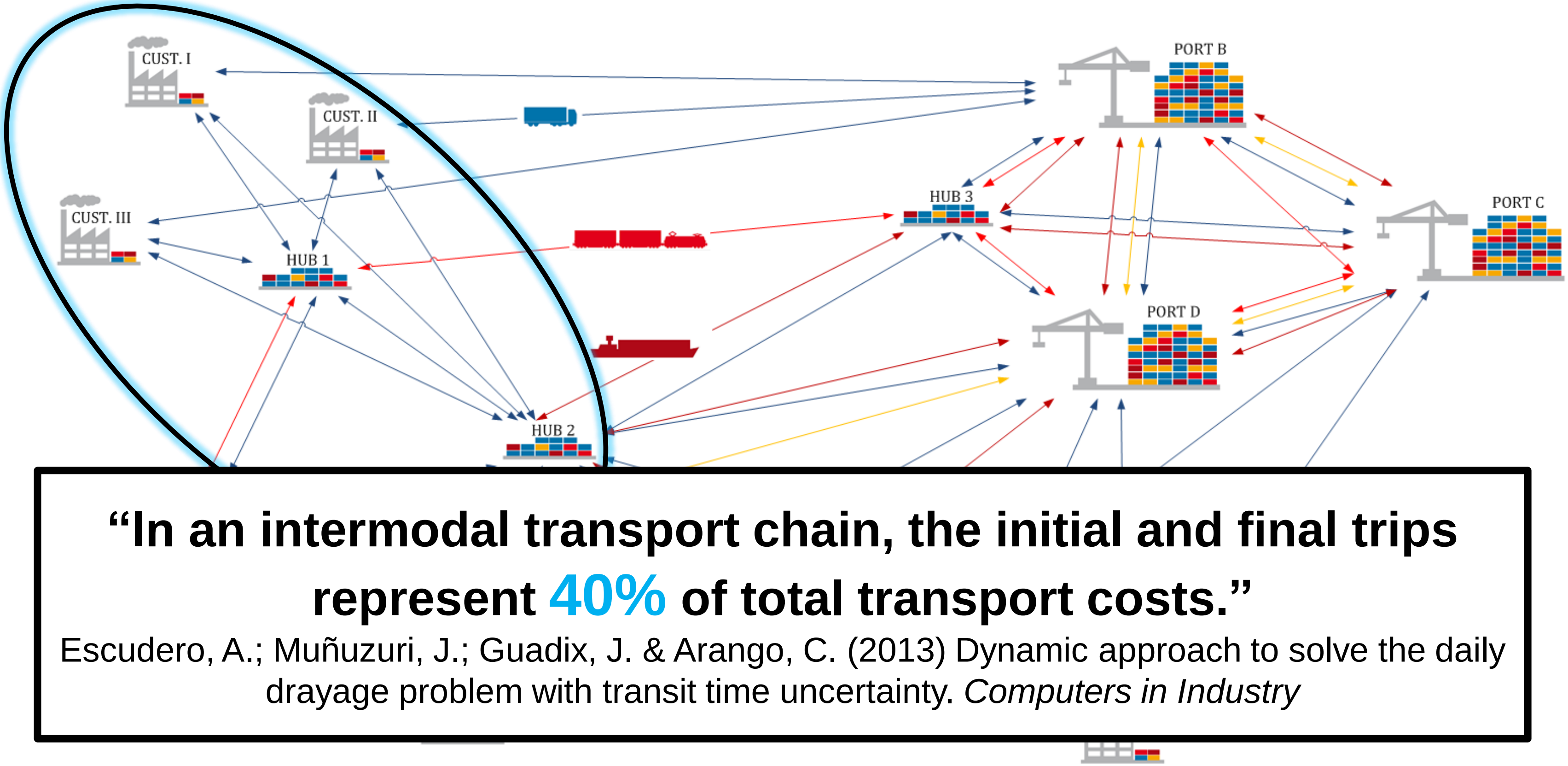
CASE: TRANSPORTATION OF CONTAINERS IN THE HINTERLAND



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

INTEGRATED SCHEDULING OF DRAYAGE AND LONG-HAUL TRANSPORT

PROBLEM DESCRIPTION



"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*

INTEGRATED SCHEDULING OF DRAYAGE AND LONG-HAUL TRANSPORT

PROBLEM DESCRIPTION

Input:

- ***Transport network***: services, terminals, schedules, durations, capacity, costs, revenues.
- ***Freight demand***: origin (or location), destination, release-day, due-day, size, type of container, etc.
- ***Probability distributions***: (1) number of freights, (2) origin, (3) destination, (4) release-day, and (5) time-window length.

Output:

- ***Schedule***: which service to use for each freight (if any).
- ***Performance***: drayage costs + long-haul costs.

MIXED INTEGER LINEAR PROGRAMMING (MILP) MODEL

OPTIMIZATION OF DRAYAGE OPERATIONS AND TERMINAL ASSIGNMENT

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

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

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

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

Important in the drayage scheduling model:

1. ***Additional objective***: terminal (long-haul) assignment cost
2. ***Different types of drayage requests***: based on truck movements required to fulfill a request
3. ***Decoupling constraints***: different truck may fulfill different movements of a single request

Based on: Pérez Rivera, A.E., Mes, M.R.K. (2017) Scheduling Drayage Operations in Synchromodal Transport. *Lecture Notes in Computer Science (forthcoming) – ICCL 2017*

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

MARKOV DECISION PROCESS (MDP) MODEL

OPTIMIZATION OF SEQUENTIAL DECISIONS UNDER UNCERTAINTY

$$\boldsymbol{S}_t = \left[\left(F_{t,d,r,k}, G_{t,d,r,k}\right)\right]_{\forall d \in \mathcal{D}, r \in \mathcal{R}, k \in \mathcal{K}}, \ \forall t \in \mathcal{T} \quad (1)$$

$$\boldsymbol{W}_t = \left[\left(\widetilde{F}_{t,d,r,k}, \widetilde{G}_{t,d,r,k}\right)\right]_{\forall d \in \mathcal{D}, r \in \mathcal{R}, k \in \mathcal{K}}, \ \forall t \in \mathcal{T} \quad (2)$$

Important in the long-haul scheduling model:

1. ***Schedule for all demand realizations*: based on probability distributions on the amount of freights and their characteristics.**
2. ***Estimate of downstream costs*: expected future costs at each stage per decision (i.e., next-stage state).**

Based on: Pérez Rivera, A.E., Mes, M.R.K. (2016) Anticipatory Freight Selection in Intermodal Long-haul Round-trips. *Transportation Research Part E: Logistics and Transportation Review.*

$F_{t,d,0,k} = \ldots$

$$F_{t,d,r,k} = F_{t-1,d,r+1,k} + \widetilde{F}_{t,d,r,k}, \ \Big| r \geq 1 \quad (4c)$$

$$F_{t,d,r,K^{max}} = \widetilde{F}_{t,d,r,K^{max}}, \quad (4d)$$

$$G_{t,d,0,k} = G_{t-1,d,0,k+1} - x^{G}_{t-1,d,k+1} + G_{t-1,d,1,k} + \widetilde{G}_{t,d,0,k}, \ \Big| k < K^{max} \quad (4e)$$

$$G_{t,d,r,k} = G_{t-1,d,r+1,k} + \widetilde{G}_{t,d,r,k}, \ \Big| r \geq 1 \quad (4f)$$

$$G_{t,d,r,K^{max}} = \widetilde{G}_{t,d,r,K^{max}}, \quad (4g)$$

$$\forall d \in \mathcal{D}, \ r \in \mathcal{R}, \ r+1 \in \mathcal{R}, \ k \in \mathcal{K}, \ k+1 \in \mathcal{K}$$

$$= \min_{\boldsymbol{x}_t} \left(C\left(\boldsymbol{S}_t, \boldsymbol{x}_t\right) + \mathbb{E}\left\{ V_{t+1}\left(S^M\left(\boldsymbol{S}_t, \boldsymbol{x}_t, \boldsymbol{W}_{t+1}\right)\right)\right\}\right)$$

$$= \min_{\boldsymbol{x}_t} \left(C\left(\boldsymbol{S}_t, \boldsymbol{x}_t\right) + \sum_{\omega \in \Omega} \left(p^{\Omega}_{\omega} \cdot V_{t+1}\left(S^M\left(\boldsymbol{S}_t, \boldsymbol{x}_t, \omega\right)\right)\right)\right) \quad (7)$$

COMBINATION OF TWO HEURISTIC APPROACHES

A MATHEURISTIC FOR THE MILP AND ADP ALGORITHM FOR THE MDP

Matheuristic: iteratively solves restricted (or adapted) versions of the MILP.

Approximate Dynamic Programming (ADP) algorithm: iteratively estimates the downstream costs using simulation.

Algorithm 1 Static Matheuristic

Require: Graph $\mathcal{G}$ and associated parameters

Initialize best solution
while Stopping criterion not met **do**
  Get MHOs (7), (8), and (9)
  Build adapted MILP
  Solve adapted MILP
  if Current solution $\leq$ Best solution **then**
    Best solution = Current Solution
  end if
end while
return Best solution

Pérez Rivera, A.E., Mes, M.R.K. (2017) **Scheduling Drayage Operations in Synchromodal Transport.** *Lecture Notes in Computer Science (forthcoming) – ICCL 2017*

Algorithm 1 ADP Algorithm

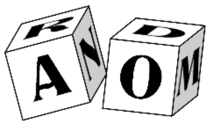
Initialize $\left[\overline{V}_t^0\right]_{\forall t \in \mathcal{T}}$
for $n = 1$ **to** N **do**
  $S_0^n := S_0$
  for $t = 0$ **to** $T^{max} - 1$ **do**
    $x_t^{n*} := \arg\max_{x_t^n \in \mathcal{X}_t^R} \left(R_t\left(x_t^n\right) + \gamma_t \overline{V}_t^{n-1}\left(S^{M,x}\left(S_t^n, x_t^n\right)\right)\right)$
    $S_t^{n,x*} := S^{M,x}\left(S_t^n, x_t^{n*}\right)$
    $\widehat{v}_t^n := \left(R_t\left(x_t^{n*}\right) + \gamma_t \overline{V}_t^{n-1}\left(S_t^{n,x*}\right)\right)$
    $W_{t+1}^n := \text{Random}\left(\Omega\right)$
    $S_{t+1}^n := S^M\left(S_t^n, x_t^{n*}, W_{t+1}^n\right)$
  end for
  for $t = T^{max} - 1$ **to** 0 **do**
    $\overline{V}_t^n(S_t^{n,x*}) := U_t^n(\overline{V}_t^{n-1}(S_t^{n,x*}), S_t^{n,x*}, [\widehat{v}_t^n]_{\forall t \in \mathcal{T}})$
  end for
end for
return $\left[\overline{V}_t^N\right]_{\forall t \in \mathcal{T}}$

Pérez Rivera, A.E., Mes, M.R.K. (2016) **Anticipatory Freight Selection in Intermodal Long-haul Round-trips.** *Transportation Research Part E: Logistics and Transportation Review (in press).*

MATHEURISTIC – ALGORITHM ILLUSTRATION

ADDING INEQUALITIES AND FIXING VARIABLES ITERATIVELY

Current solution



$$\sum_{k\in\mathcal{K}}\sum_{i\in\mathcal{V}^{\mathrm{D}}}\sum_{j\in\mathcal{V}^{\mathrm{D}}} x_{i,j,k} \le M^{\mathrm{DE}} \tag{3a}$$

$$M^{\mathrm{DE}} = \sum_{r\in\mathcal{V}^{\mathrm{R}}}\sum_{d\in\mathcal{U}^{\mathrm{D}}} B_{r,d} \,\Big|\, B_{r,d} = \begin{cases} 1 & \text{if } d \in \delta^-(r) \\ 0 & \text{otherwise} \end{cases} \tag{3b}$$

$$\sum_{k\in\mathcal{K}}\sum_{i\in\mathcal{V}_d^{\mathrm{DR}}}\sum_{j\in\mathcal{V}_d^{\mathrm{DR}}} x_{i,j,k} \le M_d^{\mathrm{DI}},\ \forall\, d \in \mathcal{U}^{\mathrm{D}} \tag{4a}$$

$$M_d^{\mathrm{DI}} = \sum_{r\in\mathcal{V}^{\mathrm{R}}}\sum_{i\in\mathcal{V}_d^{\mathrm{DR}}} B_{r,i} \,\Big|\, B_{r,i} = \begin{cases} 1 & \text{if } i \in \delta^-(r) \\ 0 & \text{otherwise} \end{cases},\ \forall\, d \in \mathcal{U}^{\mathrm{D}} \tag{4b}$$

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

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

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

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

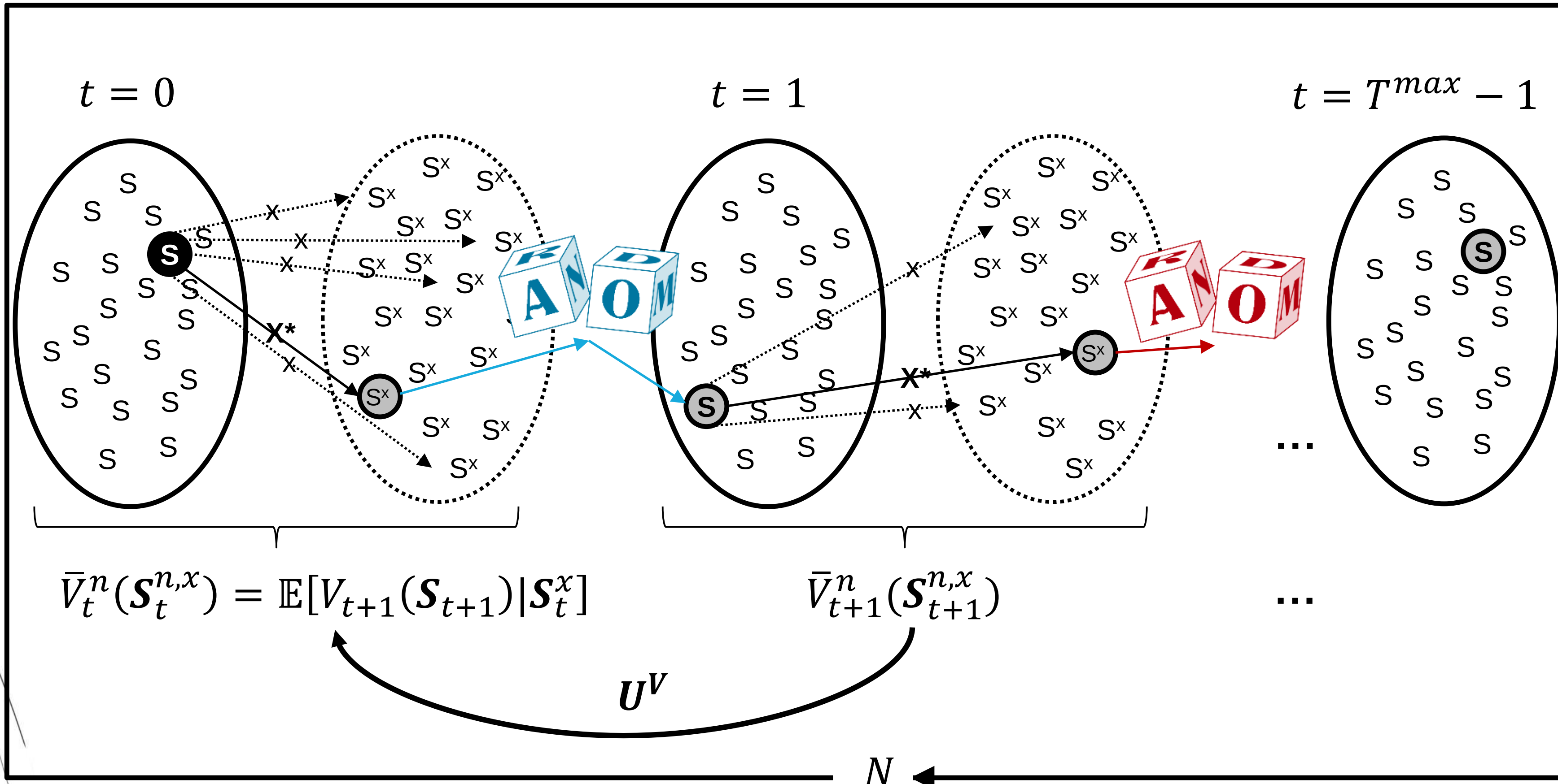
Build adapted MILP

Solve adapted MILP

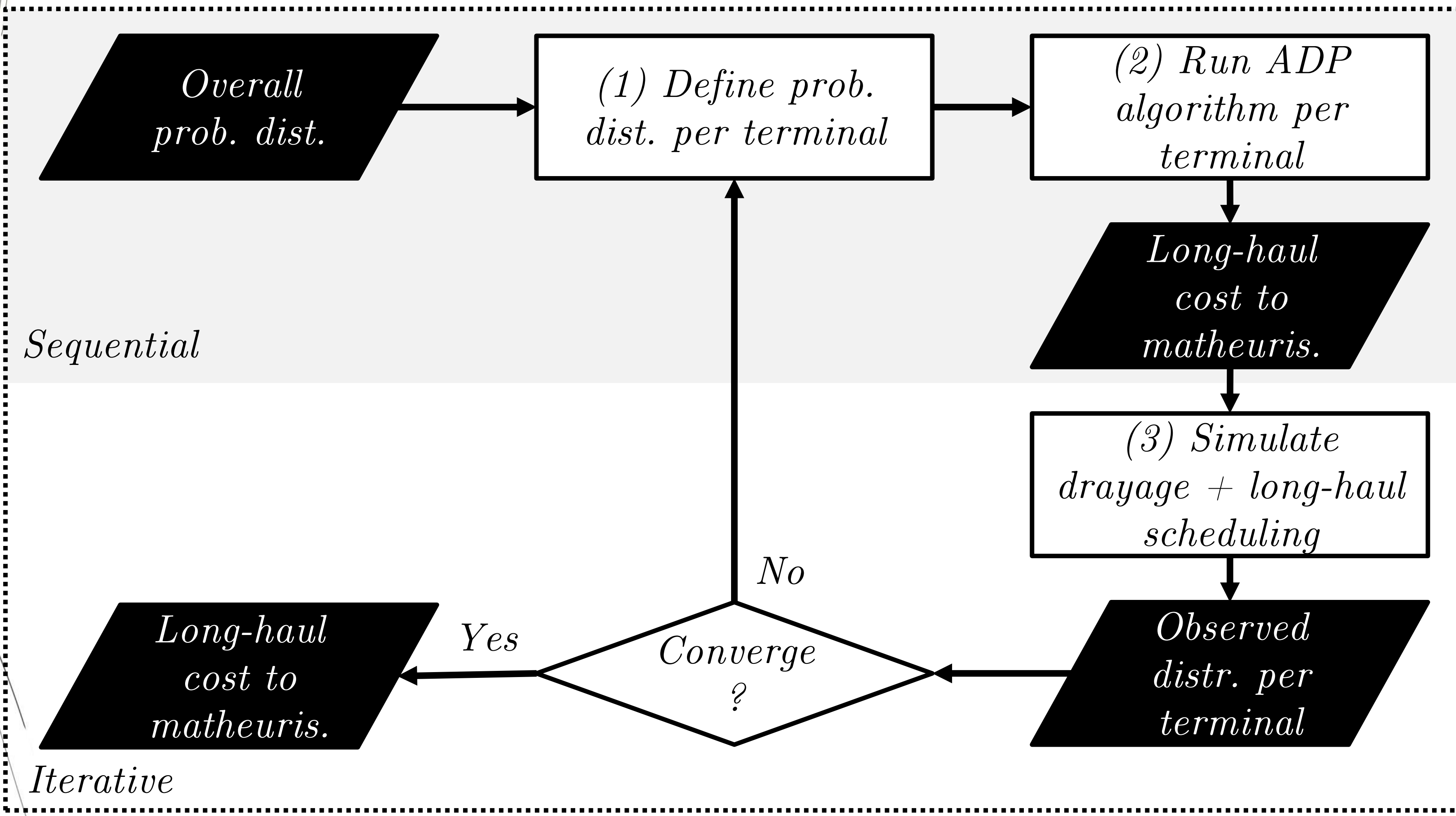
N

ADP – ALGORITHM ILLUSTRATION

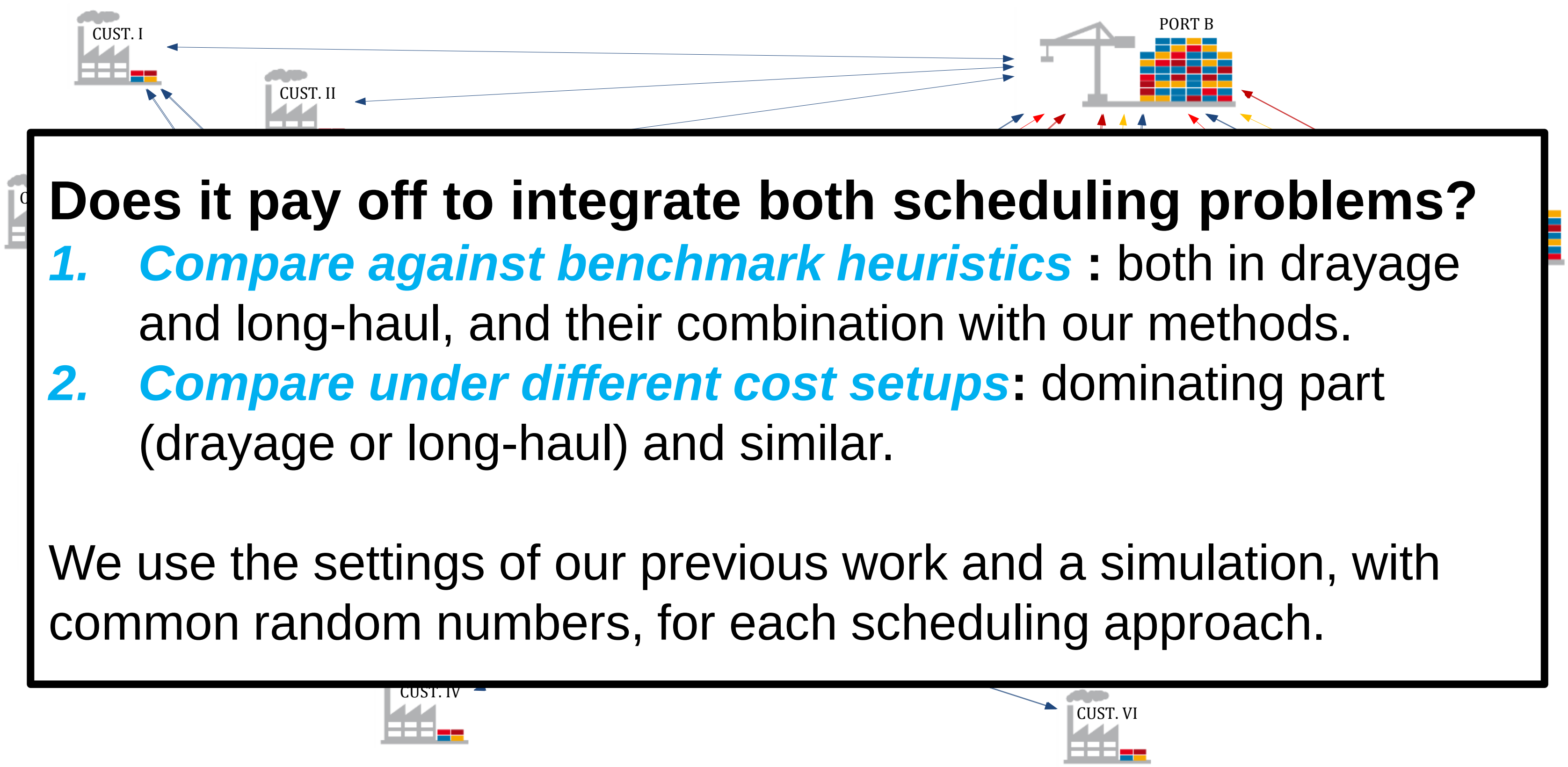
USING SIMULATION AND STATISTICAL TECHNIQUES



COMBINATION OF TWO HEURISTIC APPROACHES
SEQUENTIAL AND ITERATIVE



PRELIMINARY RESULTS
EXPERIMENTAL QUESTION



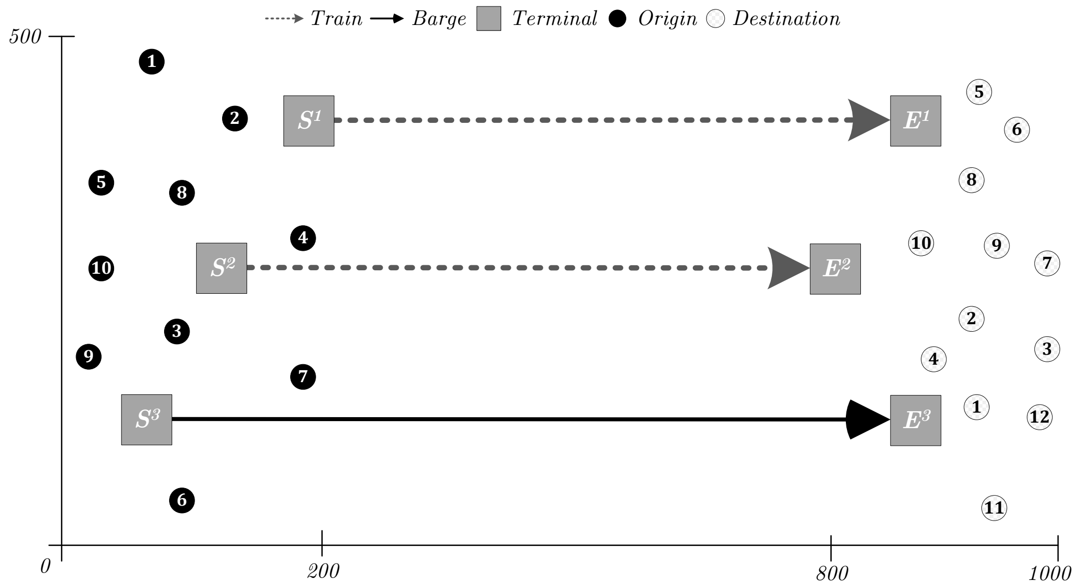
Does it pay off to integrate both scheduling problems?

1. ***Compare against benchmark heuristics*** **:** both in drayage and long-haul, and their combination with our methods.
2. ***Compare under different cost setups*****:** dominating part (drayage or long-haul) and similar.

We use the settings of our previous work and a simulation, with common random numbers, for each scheduling approach.

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

PRELIMINARY RESULTS
PROBLEM INSTANCE SETTINGS



Network

- 25 drayage trucks
- 3 intermodal terminals and services
- 4 freights per service
- Location based costs

Freight demand

- 8 freights per day (≈Poisson dist.)
- 10 origins (uniform dist.)
- 12 destinations (uniform dist.)
- 1 to 3 days time-window (.8,.1,.1)

PRELIMINARY RESULTS

DOES INTEGRATED WORK BETTER THAN SEPARATED SCHEDULING?

Cost Setup 1	High drayage	Low long-haul	≈ 90-10
Cost Setup 2	High drayage	High long-haul	≈ 40-60
Cost Setup 3	Low drayage	Low long-haul	≈ 40-60
Cost Setup 4	Low drayage	High long-haul	≈ 10-90

Long-haul heuristic	Drayage heuristic	Cost Setup 1		Cost Setup 2		Cost Setup 3		Cost Setup 4	
		Average	Diff.	Average	Diff.	Average	Diff.	Average	Diff.
Benchmark	Benchmark	79,413.65	0%	165,668.67	0%	16,566.99	0%	102,822.01	0%
	Matheuristic	79,438.67	0%	165,672.03	0%	16,572.89	0%	102,829.34	0%
ADP Sequential	Benchmark	78,949.81	1%	161,031.21	3%	16,103.15	3%	98,184.55	5%
	Matheuristic	78,971.41	1%	161,024.50	3%	16,107.81	3%	94,751.58	8%
ADP Iterative	Benchmark	78,789.20	1%	159,425.09	4%	15,942.54	4%	96,578.43	6%
	Matheuristic	78,812.80	1%	159,440.94	4%	15,957.57	4%	96,584.96	6%

Diff. = Percent difference from using benchmark for both drayage and long-haul*

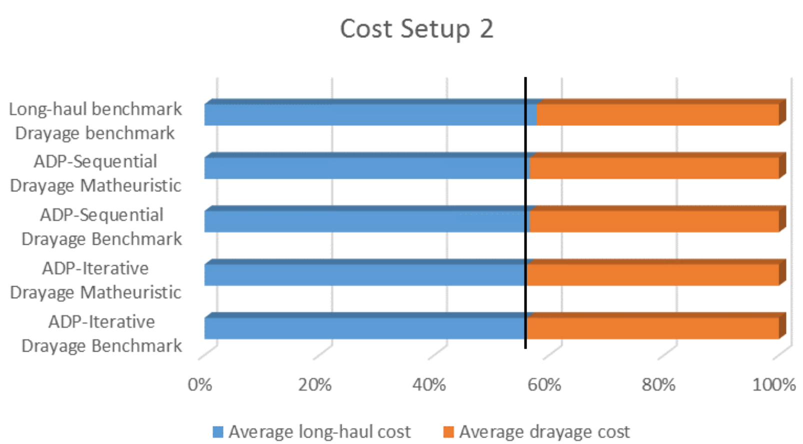
PRELIMINARY RESULTS

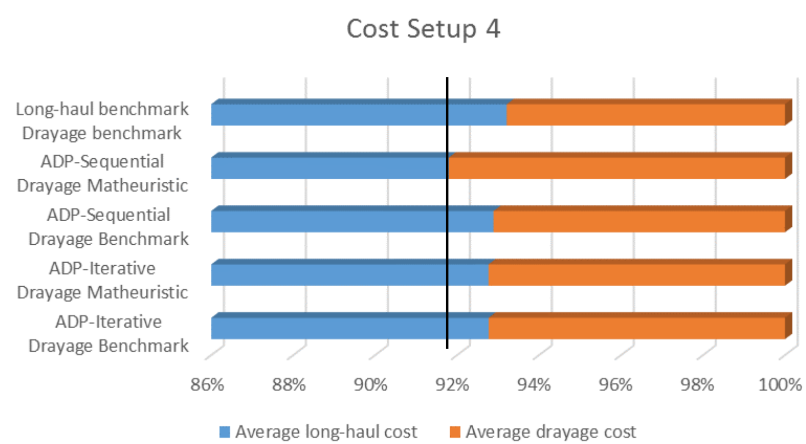
WHERE DO THE GAINS COME FROM?

Long-haul heuristic	Drayage heuristic	Cost Setup 1 Average	Cost Setup 1 Diff.	Cost Setup 2 Average	Cost Setup 2 Diff.	Cost Setup 3 Average	Cost Setup 3 Diff.	Cost Setup 4 Average	Cost Setup 4 Diff.
Benchmark	Benchmark	79,413.65	0%	165,668.67	0%	16,566.99	0%	102,822.01	0%
	Matheuristic	79,438.67	0%	165,672.03	0%	16,572.89	0%	102,829.34	0%
ADP Sequential	Benchmark	78,949.81	1%	161,031.21	3%	16,103.15	3%	98,184.55	5%
	Matheuristic	78,971.41	1%	161,024.50	3%	16,107.81	3%	94,751.58	8%
ADP Iterative	Benchmark	78,789.20	1%	159,425.09	4%	15,942.54	4%	96,578.43	6%
	Matheuristic	78,812.80	1%	159,440.94	4%	15,957.57	4%	96,584.96	6%

Diff. = Percent difference from using benchmark for both drayage and long-haul*

Percentage of total cost:





PRELIMINARY RESULTS

WHAT IF THE SEQUENTIAL HAD OTHER INITIAL PROBABILITY DISTRIBUTIONS?

"Reasonable" initial distributions:

Long-haul heuristic	Drayage heuristic	Cost Setup 1 Average	Cost Setup 1 Diff.	Cost Setup 2 Average	Cost Setup 2 Diff.	Cost Setup 3 Average	Cost Setup 3 Diff.	Cost Setup 4 Average	Cost Setup 4 Diff.
Benchmark	Benchmark	79,413.65	0%	165,668.67	0%	16,566.99	0%	102,822.01	0%
	Matheuristic	79,438.67	0%	165,672.03	0%	16,572.89	0%	102,829.34	0%
ADP Sequential	Benchmark	78,949.81	1%	161,031.21	3%	16,103.15	3%	98,184.55	5%
	Matheuristic	78,971.41	1%	161,024.50	3%	16,107.81	3%	94,751.58	8%
ADP Iterative	Benchmark	78,789.20	1%	159,425.09	4%	15,942.54	4%	96,578.43	6%
	Matheuristic	78,812.80	1%	159,440.94	4%	15,957.57	4%	96,584.96	6%

Diff. = Percent difference from using benchmark for both drayage and long-haul*

"Less-reasonable" initial distributions:

Long-haul heuristic	Drayage heuristic	Cost Setup 1 Average	Cost Setup 1 Diff.	Cost Setup 2 Average	Cost Setup 2 Diff.	Cost Setup 3 Average	Cost Setup 3 Diff.	Cost Setup 4 Average	Cost Setup 4 Diff.
Benchmark	Benchmark	79,413.65	0%	165,668.67	0%	16,566.99	0%	102,822.01	0%
	Matheuristic	79,428.84	0%	165,669.26	0%	16,581.33	0%	102,828.07	0%
ADP Sequential	Benchmark	79,704.33	0%	168,590.37	-2%	16,857.67	-2%	105,743.71	-3%
	Matheuristic	79,732.35	0%	168,592.23	-2%	16,863.57	-2%	103,521.55	-1%
ADP Iterative	Benchmark	78,789.20	1%	159,425.09	4%	15,942.54	4%	96,578.43	6%
	Matheuristic	78,812.80	1%	159,439.44	4%	15,951.94	4%	96,677.02	6%

Diff. = Percent difference from using benchmark for both drayage and long-haul*

WHAT TO REMEMBER

- We exemplified how ***drayage and long-haul decisions can be integrated*** through (i) inclusion of long-haul assignment cost in the drayage, and (ii) improved downstream cost approximations in the long-haul decisions.
- Preliminary results show that ***integrated scheduling performs better than separated scheduling*** in terms of overall costs, sometimes with larger drayage costs.
- Further ***research is needed in drayage scheduling considering long-haul transport and long-haul scheduling considering drayage operations*** for integrated scheduling in synchromodal transport.

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THANKS FOR YOUR ATTENTION!

ARTURO E. PÉREZ RIVERA

PhD Candidate

Department of Industrial Engineering and Business Information Systems

University of Twente, The Netherlands

https://www.utwente.nl/bms/iebis/staff/perezrivera/

a.e.perezrivera@utwente.nl

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