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A hybrid A-star algorithm to minimise energy consumption in the pre-marshalling problem

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Agenda

- Environmental sustainability in ports
- Problem definition & literature review
- Solution heuristic development
- Computational experiments
- Case study (Green Yard Scheduler)
- Conclusions

Environmental sustainability in ports

- Sustainable port development as a priority of port authorities
- Stricter and more comprehensive environmental regulations:
  - MARPOL Convention (IMO, 1973-1997)
  - ISO 14001 (1996, 2004, 2015)
- Pressure from local, regional, and international authorities on ports to mitigate the environmental externalities of port & shipping activities.
  - Air quality improvement in port cities through reduction of GHG emissions.
  - Increasing energy efficiency of port operations
  - Reduction of vessel turnaround times at ports
- Ports are centres of high energy supply & demand activities (Acciaro et al., 2014)

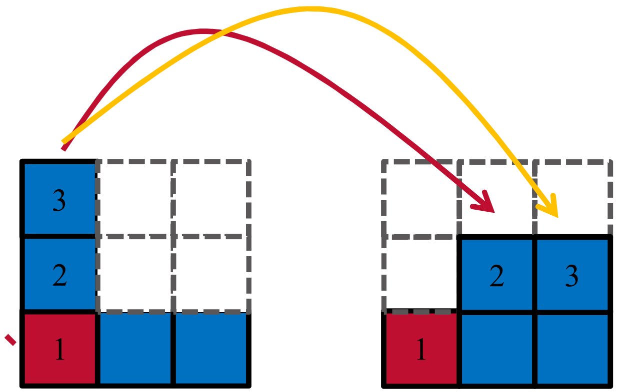
Environmental sustainability in ports

- Mitigation of emissions and minimisation of energy consumption of container terminal operations through operational practices
- Rubber tyred cranes (RTGs) were responsible for about 63% of fuel consumption and 45% of CO_2 emissions of all handling equipment at Noatum Container Terminal Valencia in 2011 (Martinez-Moya et al., 2019).
- Reduction of vessel turnaround times are essential as vessels are the main contributors to end-to-end maritime supply chain GHG emissions (Gibbs et al., 2014)
- Smooth and fast cargo transfer between container yard and berth
- Prevention of non-productive container movements in the container yard (Choe et al., 2011)
- “**Pre-marshalling**” during off peak hours to prepare the container yard for loading and prevent **“reshuffles”**.

Problem definition

What is a reshuffle?

Numbers inside the containers indicate their priority orders



To reach container 1, 2 and 3 must be reshuffled. Both movements are non-productive

How does pre-marshalling work?

Reorder containers during off-peak hours to eliminate reshuffles during loading/retrieval in a yard bay

Why is pre-marshalling needed?

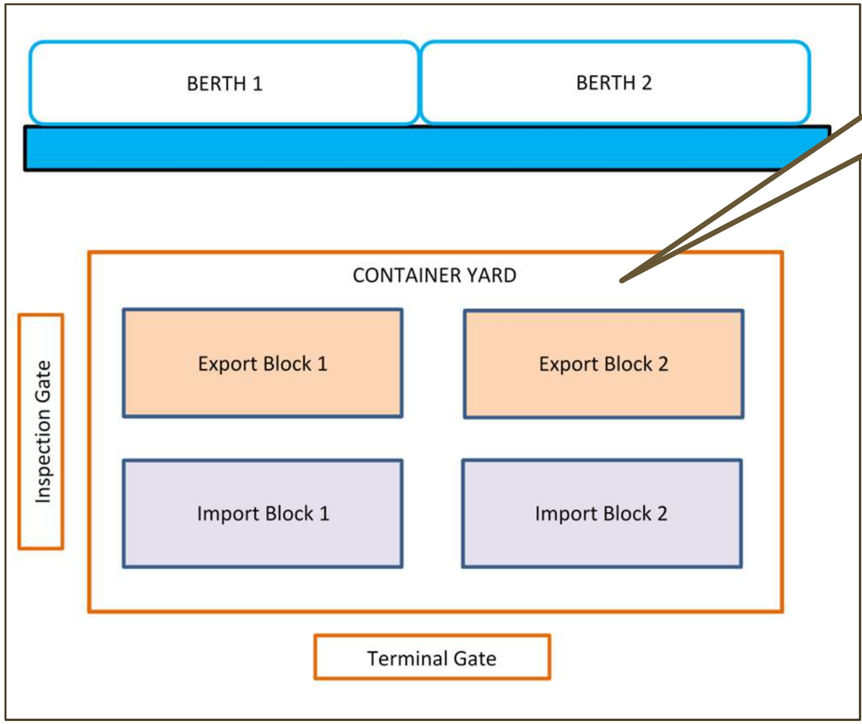
Scarcity of empty yard slots
Random container arrivals
Imprecise container information

(Kang et al., 2006; Lee and Chao, 2009; Choe et al., 2011).

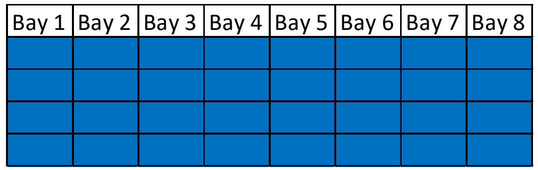
Problem definition

Common terminology

***Blocks** (or streets) are collections of container bays*

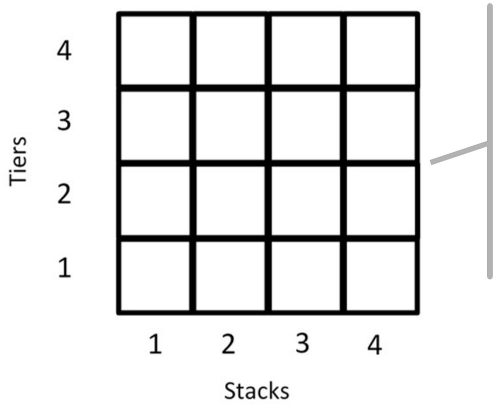


Container terminal layout



Each column is a bay

***Bay**: A rectangular configuration of container slots divided column-wise into stacks and row-wise into tiers.*



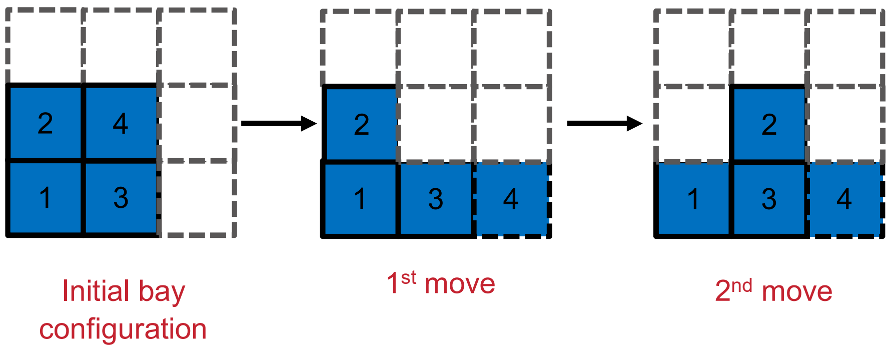
4 x 4 = 16 container slots

Problem definition

Determine the minimum number and sequence of container moves that results in an ordered bay

Solution: 2 container moves with the sequence (2,3) (1,2)

An "unordered" bay configuration: 2 blocks 1, and 4 blocks 3



An "ordered" bay configuration: None of the containers are blocked by others.

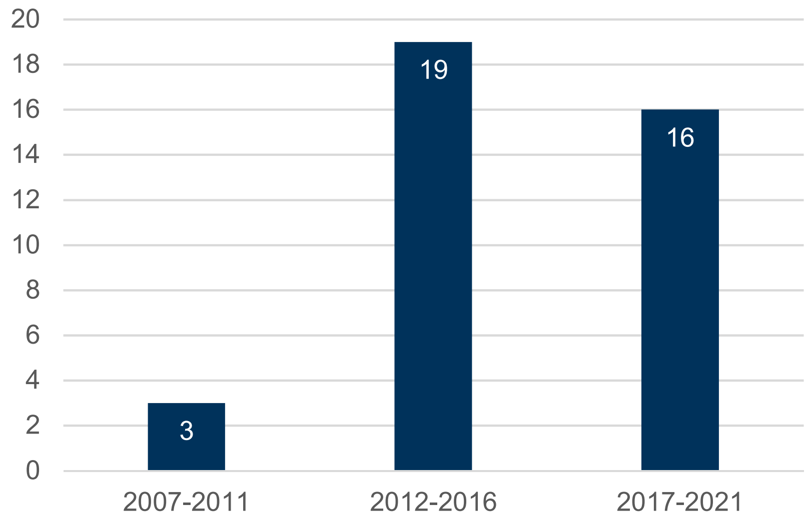
Move container 4 from stack 2 to stack 3

Move container 2 from stack 1 to stack 2

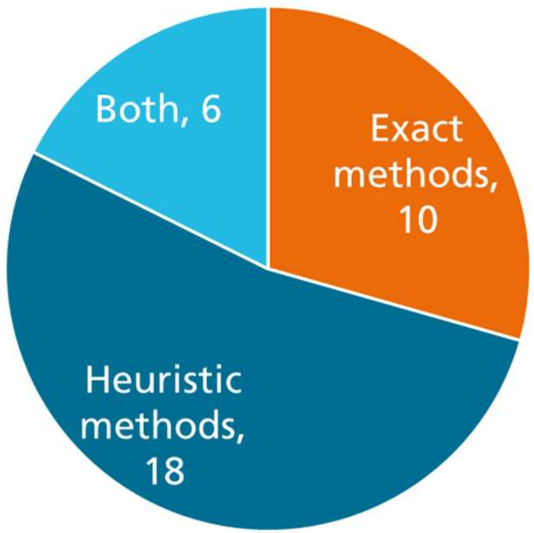
Literature review

Highlights from the literature

Number of studies per 5 years



Breakdown by solution method*



38 studies in total

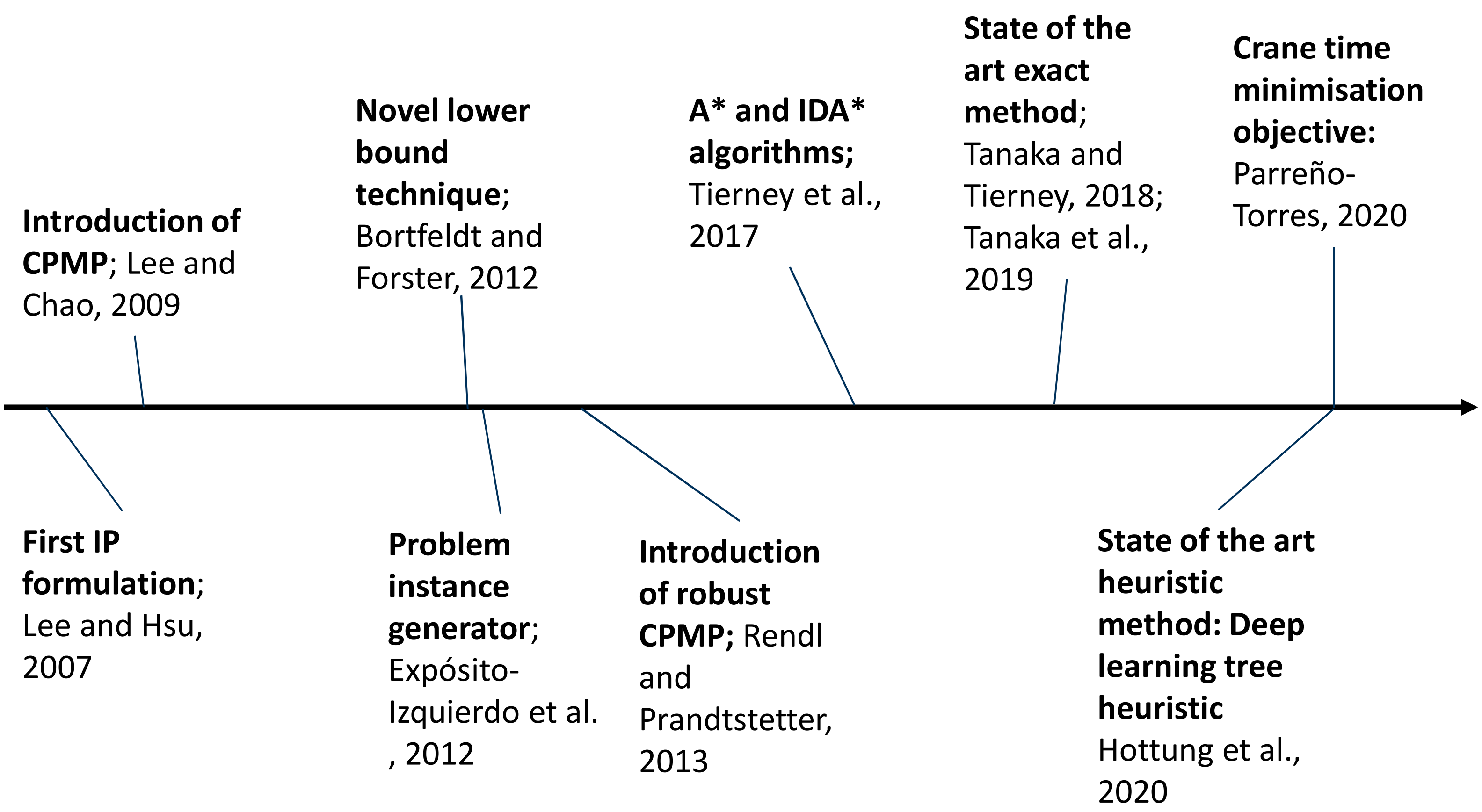
*Journal articles only

Most popular journal: **9** papers in

European Journal of Operational Research (EJOR)

Literature review

Timeline of the pre-marshalling problem literature



Problem definition

(Source: https://www.termavi.com/en/multimedia-2/)

Container pre-marshalling problem with sustainability considerations

For a given initial bay configuration and the (retrieval) priority order of the containers, determine the sequence of the container movements so as to minimize **the total energy consumption of the yard cranes** and **achieve an *ordered* bay.**

Problem definition

Assumptions:

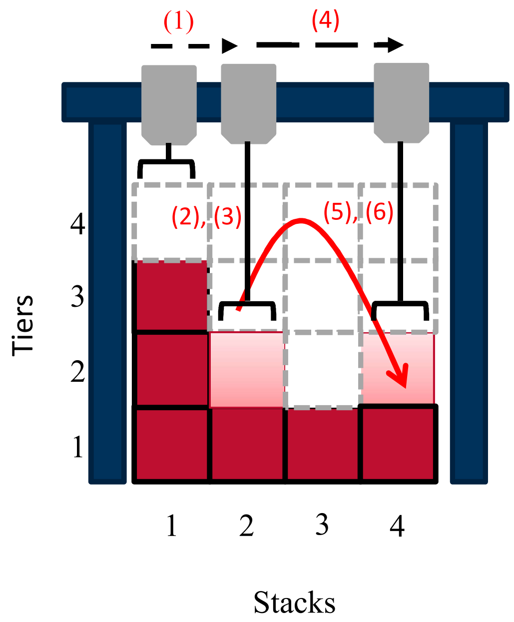
- All containers are assumed to be of the same size and dimensions (1 TEU).
- The priority order of the containers for retrieval is known in advance.
- Only one crane operates on the bay, and only a single container can be moved at a time.
- The number of containers in the bay does not change during the pre-marshalling operation.
- All stacks and tiers in the bay are identical.
- Each slot can contain at most one container.
- The unit idle and operational energy consumption of the cranes are known and constant for each container.

(*Lee and Hsu, 2007; Lee and Chao, 2009; Wang et al., 2015; 2017; Tierney et al., 2017; Tanaka and Tierney, 2018*)

Problem definition

- The proposed mixed integer programming model is formulated by partially adopting the classical pre-marshalling problem formulation proposed by Parreño-Torres et al. (2019).
- The crane energy consumption of a single container movement is calculated by considering six crane manoeuvres:

1. Movement of the crane's trolley from its previous position to the source stack s
2. Lowering of the spreader to the topmost container of stack s
3. Hoisting of the topmost container with the spreader
4. Movement of the crane's trolley from s to the target stack k
5. Lowering of the spreader to place the container on top of stack k
6. Hoisting of the spreader back to the trolley



Hybrid A-star algorithm

- A hybrid of A-star and genetic algorithms is proposed to solve the problem.
- A-star algorithm is a well-known pathfinding algorithm and was proposed to solve the conventional pre-marshalling problem (Exposito-Izquierdo et al., 2012; Tierney et al., 2017)
- In a graph of **nodes**, iteratively construct the shortest path between a **starting location** and a **destination** using a function on the sum of **exact and estimated costs** (distances):

$$f(n) = g(n) + h(n)$$

$g(n)$: The exact cost from start to node *n*

$h(n)$: The estimated cost from node *n* to destination

Hybrid A-star algorithm

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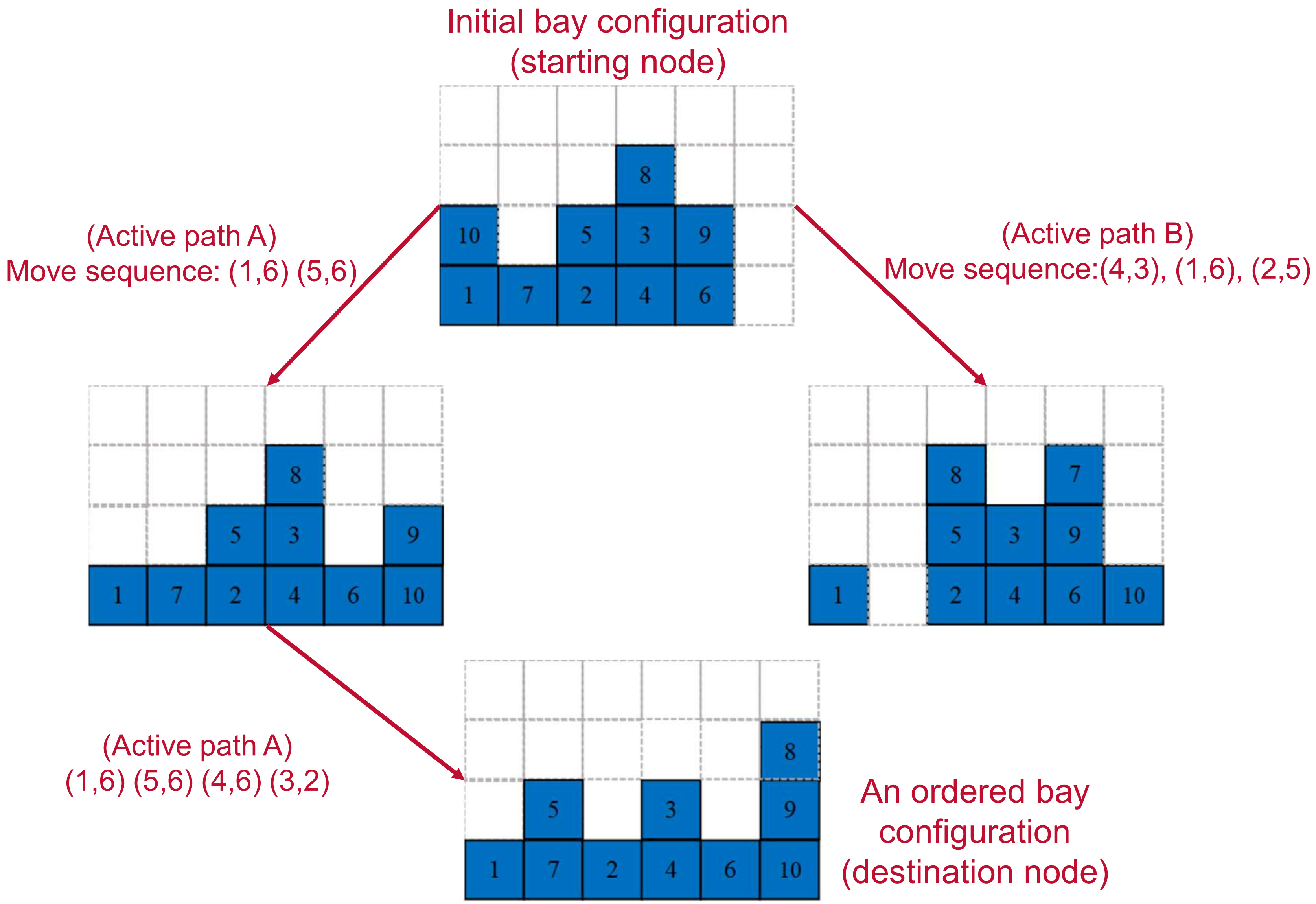
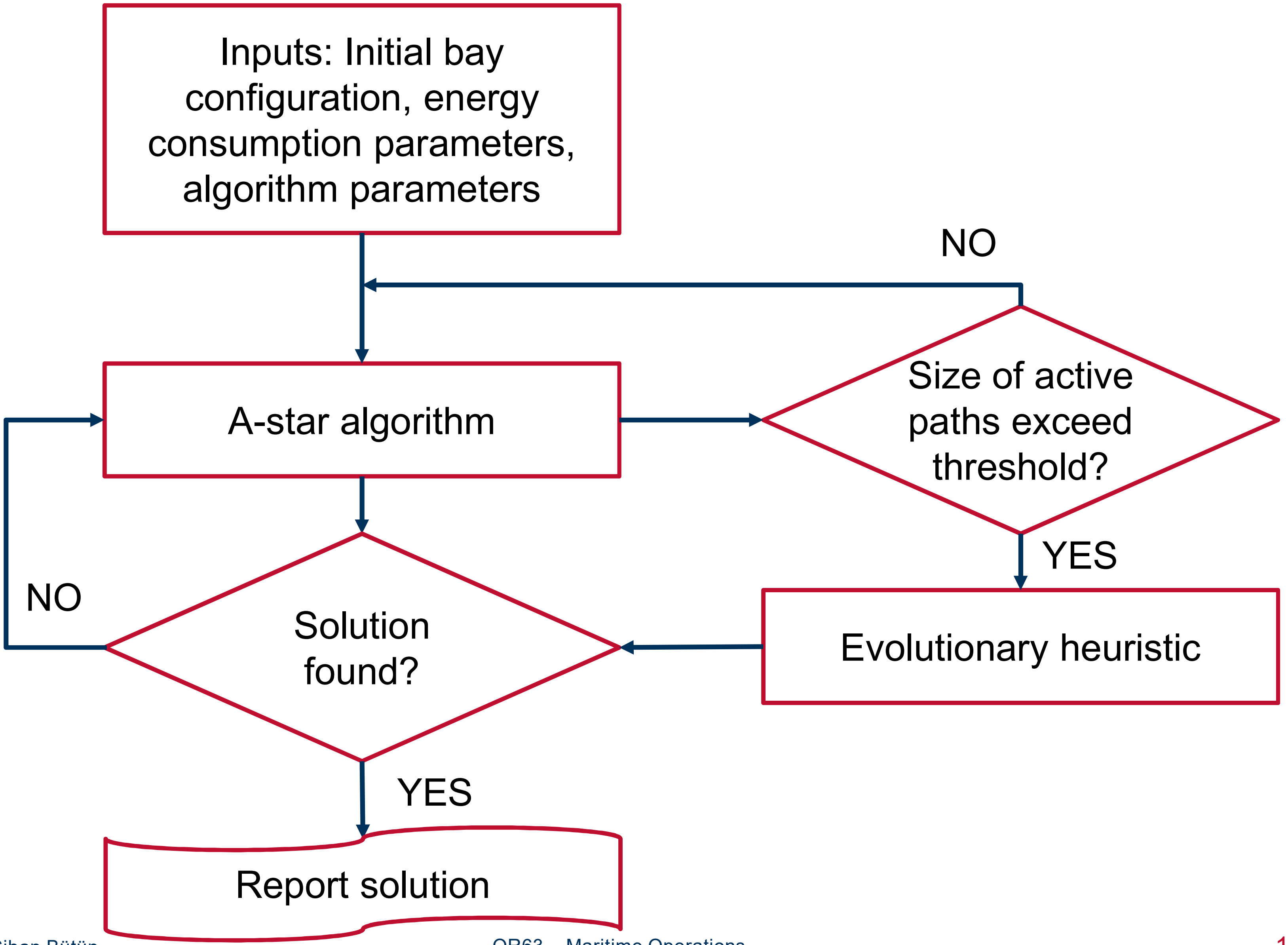


Hybrid A-star algorithm

- Evolutionary metaheuristics in pre-marshalling literature: Perez-Rodriguez et al. (2019), Hottung and Tierney (2016), Gheith et al. (2016).
- A-star algorithm slows down with difficult problem instances.
- Use of evolutionary mechanisms to intensify the search on promising partial solutions.
- Design of an evolutionary heuristic to be implemented if the size of active partial solutions (i.e. paths) in A-star reach a pre-determined threshold.
- The evolutionary heuristic implements genetic operators (parent selection, crossover, several mutation operators) on a selected elite set of partial solutions.

Hybrid A-star algorithm



Computational experiments

Experiment instances:

Source	# of stacks	# of tiers	Containers
Lee and Hsu (2007)	6	4	14
Expósito-Izquierdo (EI) et al. (2012)	4	4	8 /12 / 16
	7	4	7 / 14 /28
	10	4	10 / 20 / 40
This paper	6	4	10 / 15 / 20
Use case Spanish terminal	6	4	Various

Computational experiments

Comparison of computation times

Source	# of stacks	# of containers	Computation time (s)	
			CPLEX	**Hybrid A-star algorithm**
Butun et al. (2021)	6	10	3.70	0.00
Butun et al. (2021)	6	15	1,607.53	0.07
Butun et al. (2021)*	6	20	14,400.00	16.00
Lee and Hsu (2007)	6	14	732.19	4.21
El et al. (2012)	4	8	9.53	0.00
El et al. (2012)	4	8	4.19	0.00
El et al. (2012)	4	8	2.95	0.00
El et al. (2012)	4	8	2.41	0.00

Computational experiments

Comparison of computation times (cont'd)

Source	# of stacks	# of containers	Computation time (s)	
			CPLEX	Hybrid A-star algorithm
El et al. (2012)	7	14	9.53	0.00
El et al. (2012)	7	14	4.19	0.00
El et al. (2012)	7	14	2.95	0.00
El et al. (2012)	7	14	2.41	0.00
El et al. (2012)*	10	20	14,400.00	3.96
El et al. (2012)	10	20	12,175.41	0.02
El et al. (2012)	10	20	1,375.91	0.17
El et al. (2012)	10	20	446.08	0.01

Computational experiments

Comparison of energy consumption with different objective functions

Source	# of stacks	# of containers	Objective function: Minimise moves		Objective function: Minimise crane's energy consumption	
			Energy (kWh)	Moves	Energy (kWh)	Moves
Butun et al. (2021)	6	10	35.19	4	33.53	4
Lee and Hsu (2007)	6	14	74.28	9	69.24	9
El et al. (2012)	10	20	50.15	6	47.91	6
Spanish container terminal	6	15	64.50	8	62.50	8

Case study (DSS)

PortForward project funded under EU Horizon 2020 program (2018-2021)

Green Yard Scheduler: A DSS to optimize container yard operations

Case Study

Design and develop a Housekeeping optimization module

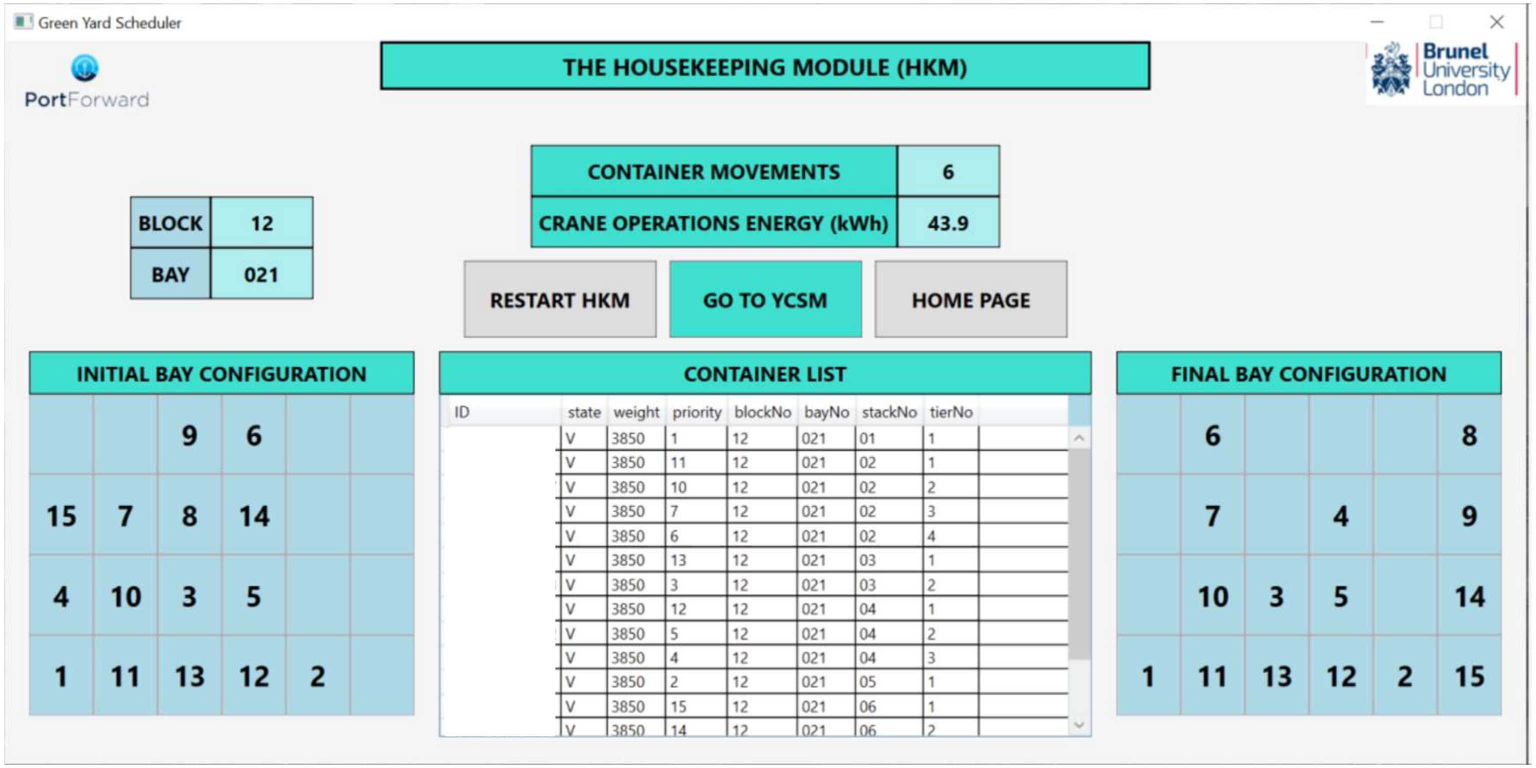
Use case: A Spanish container terminal

Case study (DSS)

Green Yard Scheduler (Graphical user interface)

Case study (DSS)

Green Yard Scheduler (Graphical user interface)



Conclusions

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- Container pre-marshalling problem with sustainability considerations is introduced.
- A hybrid A-star algorithm design is presented.
- Preliminary experiment results are discussed.

Future research:

- Do more computational experiments to observe and report the trends in results.
- Expand the research to intra-bay pre-marshalling movements.
- Combine the problem with the container terminal problems.

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Thank you for your attention! Questions, comments?

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