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Efficient Algorithms for Berth Allocation Optimization

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Berth Allocation & Scheduling Problem (BASP)

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Classification #1: Spatial organization

BASPs

DBASP
Discrete

- Predefined berths
- Each berth accommodates exactly one vessel

CBASP
Continuous

- No predefined berths
- Area: continuous space where a vessel can be docked

HBASP
Hybrid

- Predefined berths
- Depending on the vessel lengths, a single vessel may occupy multiple berths, or two or more vessels may be docked in the same berth

Classification #2: Anticipated arrival time

BASPs

dyn-BASP
Dynamic

Dynamic arrival scenario:

some vessels may not yet be in the port, but their estimated arrival time is known

st-BASP
Static

Static arrival scenario:

vessels are already in the port and ready for service

Optimal & Non-Optimal Berth Allocation

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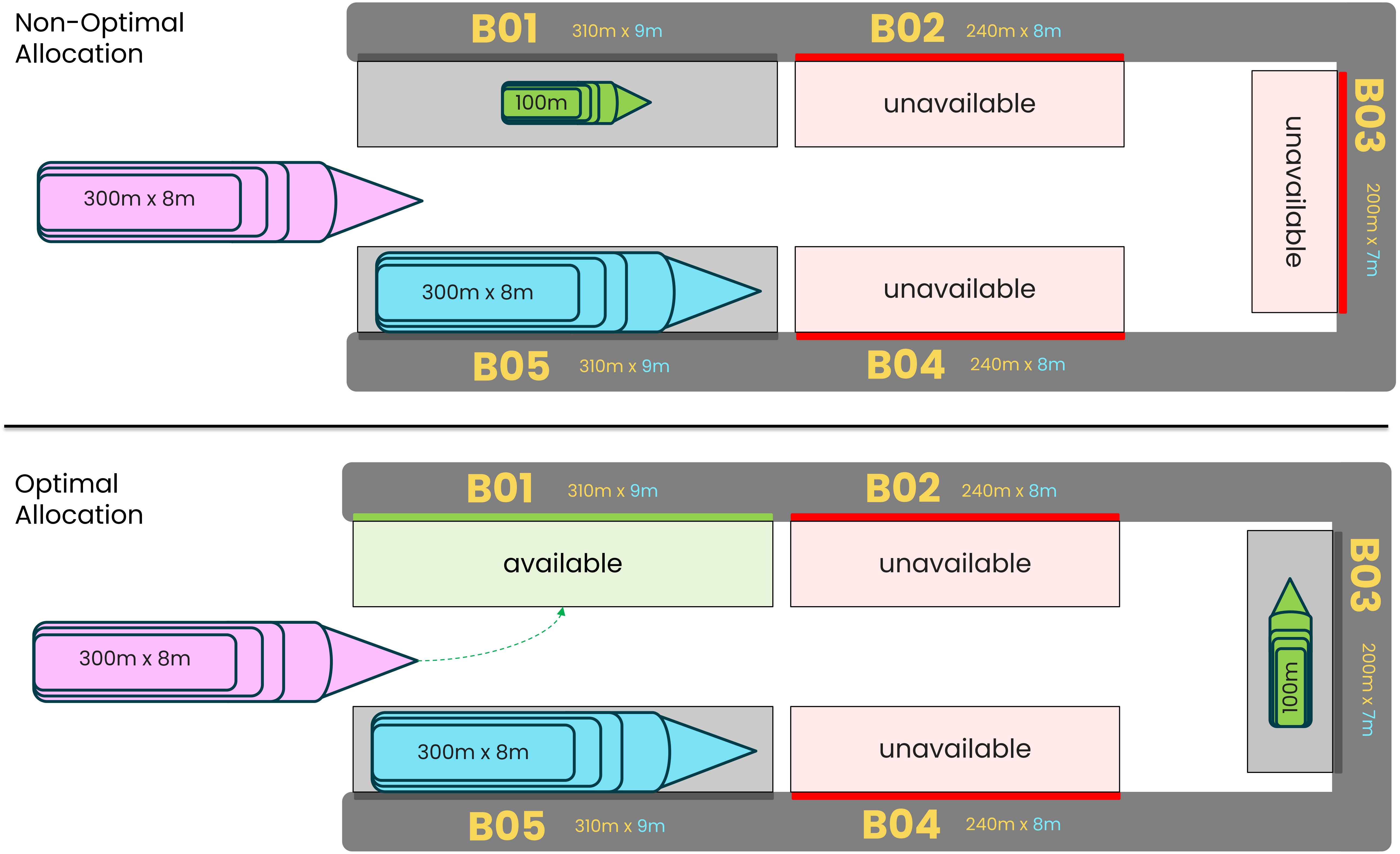
1. Vessel labeled with two dimensions: length x draught
2. Berth labeled with its name and two dimensions: maximum length and draught
3. Berth color: corresponds to a different type depending on whether the berth is :
    - Occupied
    - Unavailable (available but with insufficient dimensions)
    - Available (with adequate dimensions)



Previous Work

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Focus of recent studies: primarily on the application of BASP in marine container terminals

Two principal approaches:

1. **Exact methods:** Provide optimal solutions but tend to be computationally intensive and slower
2. **Heuristic and Meta-heuristic methods:** Offer faster solutions with high-quality results, though they are not always optimal

Trade-off

exact methods prioritize precision, while heuristics prioritize speed and practicality

Exact Algorithms : MILP formulation for dyn-DBASP

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Objective Function :

$$\min \sum_{i=1}^{n_s} t_i^t \qquad (1)$$

Subject to :

$$\sum_{i=1}^{n_s} x_{ij} = 1, \quad \forall i \in S \qquad (2)$$

$$s_i \geq t_i^a, \quad \forall i \in S \qquad (3)$$

$$s_i + M(1 - x_{ij}) \geq s_k + t_k^h + t_k^b - M(1 - x_{kj}), \quad \forall i > k \in S, \quad \forall j \in B \qquad (4)$$

$$l_i^s x_{ij} \leq l_j^b, \quad \forall i \in S, \quad \forall j \in B \qquad (5)$$

$$d_i^s x_{ij} \leq d_j^b, \quad \forall i \in S, \quad \forall j \in B \qquad (6)$$

$$t_i^t = s_i + t_i^h + t_i^B, \quad \forall i \in S \qquad (7)$$

$$t_i^B \geq x_{ij}\, t_i^b, \quad \forall i \in S, \quad \forall j \in B \qquad (8)$$

(1) Objective function aims to minimize the total service time for all ships

(2) Ensures that each vessel is assigned to a berth

(3) Ensures that the service start time cannot be earlier than the arrival time

(4) ensures that there is no spatial or temporal overlap. If two vessels are assigned to the same berth, the second vessel can only be served after the first has departed.

(5) & (6) ensure that the vessel's dimensions (length and draught) are appropriate for the berth to which it has been assigned

(7): total time for each vessel is determined by the service start time, increased by the handling time and the approach and departure time from the berth

(8) The time required for the vessel to approach the berth depends on the berth's location within the port

dyn-DBASP(M-opt) – Experimental Evaluation

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By examining constraint (4): $s_i + M(1 - x_{ij}) \geq s_k + t_k^h + t_k^b - M(1 - x_{kj}), \quad \forall i > k \in S, \quad \forall j \in B \qquad (4)$

We can find an optimal value for **M** by minimizing the following quantity: $\mathbf{M} = \min_{i,k}\left\{\max_{k}\left\{t_k^a + t_k^h + \max_k\{t_k^b\}\right\} - \min_i\{t_i^a\}\right\}$

Experimental Evaluation

Data: generated using information from a previous study.
Exact solutions: obtained using the **CPLEX Optimizer** and **Branch & Cut method**.

Notation RSS_BB: dataset with SS-ships and BB-berths

Dataset	Details			Solving Time (sec)		
	Optimal M-value	Primal Bound	Gap (%)	Previous Model	DDBASP Model	DDBASP M-opt Model
R25_5	8.668	137.130	0%	0.29	0.21	0.16
R25_10	8.824	139.051	0%	0.51	0.41	0.4
R25_15	8.980	142.138	0%	0.45	0.3	0.27

MILP Formulation for dyn-CBASP

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Objective function

$$\min \sum_{S} C_s \quad (1)$$

Objective function aims to minimize the total berthing cost for all ships

Subject to

$$BT_s \geq ETA_s, \quad \forall s \in S \quad (2)$$

$$|BT_s - BT_{s'}| \geq SET, \quad \forall s, s' \in S \quad (3)$$

$$BP_s + L_s \leq W, \quad \forall s \in S \quad (4)$$

$$BP_s + L_s \leq BP_{s'} + M * (1 - AOS_{ss'}), \quad \forall s, s' \in S, s \neq s' \quad (5)$$

$$BT_s + HT_s \leq BT_{s'} + M * (1 - AOT_{ss'}), \quad \forall s, s' \in S, s \neq s' \quad (6)$$

$$AOT_{ss'} + AOT_{s's} + AOS_{ss'} + AOS_{s's} \geq 1, \quad \forall s, s' \in S, s \leq s' \quad (7)$$

$$WT_s = BT_s - ETA_s, \quad \forall s \in S \quad (8)$$

$$P_s = |BP_s - PBP_s| * NBC_s, \quad \forall s \in S \quad (9)$$

$$LDT_s = max\{BT_S + HT_S - ETD_S, 0\}, \quad \forall s \in S \quad (10)$$

$$C_s = WT_s * WC_s + HT_s * (HC_s + P_s) + LDT_s * LDC_s, \quad \forall s \in S \quad (11)$$

(2) The berthing time of a ship must be greater than or equal to the ETA of the same ship

(3) For safety reasons, in many ports two ships are not allowed to start the docking process at the same time

(4) A ship cannot exceed the bounds of the wharf

(5), (6) & (7) Prevent temporal and spatial overlaps, ensuring no two ships occupy the same location simultaneously

(8) The waiting cost of a ship is defined

(9) Penalty for berthing a ship in a non-preferred position

(10) The late departure cost of a ship is defined

(11) The total berthing cost of a ship depends on its waiting time, handling time, potential deviation from the preferred position, and any potential departure delay

Metaheuristic : Cuckoo Searchn for dyn-CBASP

- Inspired by the reproductive behavior of cuckoos
- Can be easily adapted for different BASP variations

Algorithm 1 Cuckoo Search Algorithm for BASP

$X[1 \dots k]$ = Generate initial population of host nests
x_{best} = Find nest with lowest fitness value in X
for $t = 1$ to max number of iterations **do**
    for $i = 1$ to k **do**
        x_{new} = perform a random walk on $X[i]$
        if fitness(x_{new}) $\leq$ fitness($X[i]$) **then**
            $X[i] = x_{new}$
        end if
    end for
    for $i = 1$ to k **do**
        if (rand(0, 1) $\leq p_a$) **then**
            $X[i]$ = Generate new host nest
        end if
    end for
    $x_{iteration\_best}$ = Find nest with lowest fitness value in in the current iteration
    if fitness($x_{iteration\_best}$) $\leq$ fitness(x_{best}) **then**
        $x_{best} = x_{iteration\_best}$
    end if
end for

A **nest** is a set of unique ship assignments for servicing

Reproduction step.
Random walk can be performed using either Normal or Lévy distribution.

Metaheuristic: Experimental Evaluation

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Data: generated using information from a previous study.
Exact solutions: obtained using the **CPLEX Optimizer**.

Planning Horizon: 1 day

#Ships	CSA		MILP		CSA
	Time(s)	Cost(€)	Time(s)	Cost(€)	Relative error
10	0.03	356	0.77	347	2.5%
15	0.0723	585	2.3	565	3.5%
20	0.1223	804	143	745	7%
25	0.1140	797	488	762	4.5%

Planning horizon: 1 week

#Ships	CSA		MILP		CSA
	Time(s)	Cost(€)	Time(s)	Cost(€)	Relative error
90	0.34	2692	83	2609	3.1%
100	0.6	3400	499	3000	13%
110	1	4373	858	3920	11.5%
120	1.1	4515	970	4045	11.6%

Future Work

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- Development of a customized model tailored to the needs of tourist ports

- Adaptation of algorithms to enable real-time berth allocation for tourist ports

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Thank you for your attention

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