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Combinatorial Relaxation Bounds and Preprocessing for Berth Allocation Problems

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Abstract

We investigate an optimization problem in container ports, for which previous models based on generalized set partitioning formulations have been studied. We describe two combinatorial relaxations based on computing maximum weighted matchings in suitable graphs, providing dual bounds and a variable reduction technique.

Keywords: Dual bounds, matching, probing, port operations, maritime logistics.

1 Introduction

In this work, we discuss graph-theoretical results for a discrete optimization problem in maritime logistics. The Berth Allocation and Quay Crane Assignment Problem (BACAP) aims to allocate berthing position/time, and a number of quay cranes (QCs) for arriving vessels in a seaport container terminal. Feasible assignments in the BACAP need to fulfil requirements on desired berthing period and position, and an agreement on the QCs availability.

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Recent work formulate variations of this problem as a Generalized Set Partitioning Problem (GSPP) [1,2], where each column represents a feasible assignment for a vessel, and its cost is a linear combination of deviations from desired berthing and QCs allocation. The algorithms in [1] solve a GSPP model after generating all variables *a priori*. Effective variable reduction techniques are central in their effective results. The work of [2] stems from a similar approach, though they assume different application modeling and instances.

We demonstrate two novel dual bounds and, as it is done in [1], extend them into a preprocessing technique. The results can be exploited in algorithms building on variable enumeration approach [1,2]. Our companion full paper describes computational experiments, and a branch and cut algorithm separating valid inequalities from set partitioning and packing relaxations.

2 Set partitioning formulations for BACAP

We describe next the GSPP model for the BACAP presented by [1]. Let V be the set of vessels, T be the set of time slots in the horizon, and L be the set of berthing positions in the quay. Define $P = T \times L$, and K as the number of available QCs. Let Ω denote the complete set of feasible assignments; note that $|\Omega| \leq (|V| \times |P| \times K)$ since feasible assignments respect each vessel requirements in a problem instance. Decision variables $y \in \mathbb{B}^{|\Omega|}$ indicate which assignments are used in the solution. The coefficient matrices are as follows. $A \in \mathbb{B}^{|V|\times|\Omega|}$ associates each column j with a single vessel. $B \in \mathbb{B}^{|P|\times|\Omega|}$ represents berthing (time, space) positions: $b_{p,j}$ is one iff position $p \in P$ is used in y_j. An element of $Q \in \mathbb{Z}^{|T|\times|\Omega|}$ determines how many QCs are used by y_j in time period t. Then, the BACAP is defined as follows.

$$\min \sum_{j\in\Omega} c_j y_j \quad (1) \qquad \sum_{j\in\Omega} a_{ij} y_j = 1 \ \forall i \in V \quad (2) \qquad \sum_{j\in\Omega} q_{tj} y_j \leq K \ \forall t \in T \quad (4)$$

$$\text{subject to } (2,3,4,5) \qquad \sum_{j\in\Omega} b_{pj} y_j \leq 1 \ \forall p \in P \quad (3) \qquad y_j \in \{0,1\} \ \forall j \in \Omega \quad (5)$$

Set partition constraints (2) ensure that all vessels are served by exactly one assignment, while set packing in (3) forbid overlapping in time/space slots. Inequalities (4) guarantee that QCs availability in the terminal is respected.

3 Weighted matching in two interesting graphs

The GSPP formulations and algorithms we refer to are based on two steps: enumerating feasible assignments for individual vessels *a priori*, and solving the resulting model with a MIP solver. We consider next two suitable graphs,