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An anchorage planning strategy with safety and utilization considerations

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ABSTRACT

Heavy maritime traffic and the subsequent increase in vessel density in anchorages have recently become a focal issue in maritime traffic safety. In this study, we consider the problem of determining the optimal berth locations of incoming vessels in an anchorage area with the goals of maximizing utilization and minimizing the risk of accidents. We introduce novel performance metrics aimed at measuring achievement of these two goals. In this context, we propose a multi-objective optimization strategy and benchmark it against current state-of-the-art anchorage planning algorithms using real-world data as well as Monte Carlo simulations. Our results indicate that the proposed strategy yields much safer berth locations while maintaining similar utilization levels.

1. Introduction

As the world's population soars and countries increase their engagement in international commerce, seaborne shipping continues to expand as a low-cost and carbon-friendly form of transportation that currently accounts for about 90% of the world's commerce. In fact, there are currently over one hundred thousand of commercial vessels actively operating throughout the world [1]. Anchorages are effective means of dealing with maritime traffic congestion and improving the overall quality of seaborne shipping. In addition to easing maritime congestion by serving as a temporary waiting area, anchorages provide important services to vessels such as land services (fueling, legal issues, repairs, etc.), loading/ unloading of cargo, or as a refuge from bad weather conditions. Thus, in general, anchorages play a similar role for vessels as parking lots do for cars and trucks. For this reason, many countries have reserved a considerable part of sea space as anchorages. Coupled with the increasing number of trade routes and the growing demand of global commerce for seaborne shipping, the efficient and safe operation of anchorages have become a crucial task.

Of particular interest is the Ahırkapı anchorage located at southern entrance of the Istanbul Strait, which is illustrated in Fig. 1. In the figure, the diamond-shaped icons represent the anchored vessels detected by radar while the square icons show the vessels detected by Automatic Identification System (AIS). With the Istanbul Strait being one of the most congested restricted waterways in the world, the Ahırkapı anchorage plays a pivotal role in the overall efficiency and safety of international maritime traffic in the Istanbul Strait.

Heavy maritime traffic and the subsequent increase in ship density in anchorages have recently become a focal issue in maritime traffic safety. For instance, a recent study by Aydogdu et al. [3] indicates that while only 20% of all maritime accidents that occurred in Istanbul between 2000 and 2003 took place in the Ahırkapı Anchorage, this number increased to 56% between 2008 and 2011. This high number of accidents in the Ahırkapı anchorage has raised significant safety concerns among local maritime authorities [3]. Accidents in anchorages not only result in potential human casualties and physical damage to vessels, but they also make anchorages partially unavailable until clearance of the accident and thus dramatically hamper overall maritime traffic. Thus, safety issues have become an even more crucial factor in anchorage planning.

Anchorage planning can loosely be defined as determining berth locations of incoming vessels that are optimal with respect to certain performance metrics. Previous academic research on anchorage planning has primarily focused on maximizing the number of vessels that can be placed inside the anchorage. Yet, we are not aware of any existing studies that consider any safety aspects of anchorage planning. Thus, our goal in this work is to contribute to anchorage planning research by incorporating safety considerations along with utilization improvement. Specifically, our contribution in this study is two-fold: (1) we introduce novel performance metrics aimed at measuring safety in anchorage planning, and (2) we propose a multi-objective optimization strategy in order to maximize utilization of the anchorage area and minimize risk of accidents at the same time. Our strategy is called MOAP, which stands for "Multi-Objective

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0305-0548/

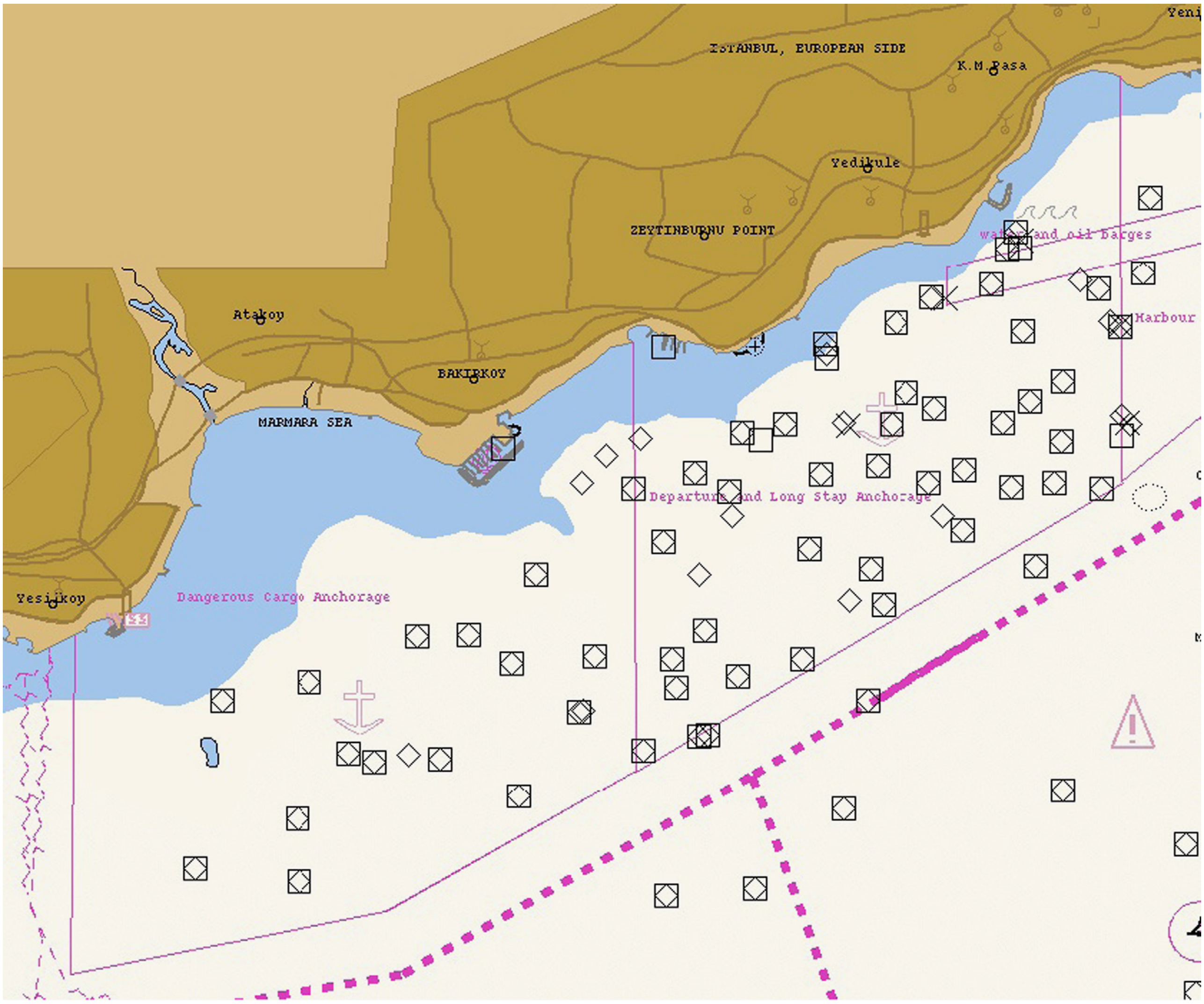

Fig. 1. Ahırkapı anchorage where vessels are depicted by squares.

Anchorage Planner". In order to be able to evaluate and compare different anchorage planning algorithms, we develop and implement an anchorage simulation system. Within this system, we benchmark MOAP against the current state-of-the-art anchorage planning algorithms using real-world data from the Ahırkapı anchorage as well as synthetic data obtained via Monte Carlo simulations. Our results indicate that MOAP yields significantly safer solutions while maintaining similar utilization levels.

The rest of this manuscript is organized as follows: Section 2 describes the anchorage planning problem in detail and discusses previous work on anchorage planning and disk packing in general. Section 3 defines our performance metrics in order to assess utilization and safety levels in anchorages. Section 4 introduces the MOAP strategy and Section 5 describes details of our anchorage simulation system. Section 6 presents our computational experiments and simulation results. Section 7 provides a summary and our conclusions followed with several directions for future research.

2. Problem description and previous work

Anchorages typically operate around the clock and vessels arrive and leave on a regular basis. Efficient anchorage management entails a large number of issues and our focus in this study is specifically limited to anchorage planning. To this end, accommodating maximum number of vessels inside the anchorage is certainly one of the major objectives of efficient anchorage planning, but it is certainly not the only one. Determination of the berth location for an incoming vessel that minimizes the risk of collisions with other vessels inside the anchorage, for instance, is a major objective as well.

An anchorage can be modeled as a polygon-shaped sea space adjacent to land. Open sea edges from which a vessel can enter the anchorage are called the *entry side* of the anchorage. According to our interviews with Istanbul Strait authorities, arrival and departure paths of vessels inside the anchorage area are required to be perpendicular to the entry side. Vessels are allowed to maneuver inside the anchorage area only at the minimum level for mandatory reasons such as to avoid collision with other vessels. Thus, vessels must minimize their navigation path length from the entry side to their berth locations upon entry and vice versa upon departure.

Even though a vessel's anchor is dropped at a specific position, the exact location of the vessel is largely determined by environmental conditions such as winds, waves, and currents. Given the anchor position, an associated safe anchorage circle for the vessel can be computed using simple geometry as shown in Fig. 2. Specifically, radius of this circle is a function of the vessel's length, anchor chain length, and the sea depth at the anchor position. Let the sea depth be denoted by D and the vessel length be denoted by L. An appropriate length for the anchor chain is then given by $25\sqrt{D}$ [8], and the anchorage circle radius can be calculated by the Pythagorean theorem