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A traveling salesman problem with pickups and deliveries and stochastic travel times: An application from chemical shipping

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ABSTRACT

This paper introduces a single-ship routing problem with stochastic travel times that is faced by a chemical shipping company in the Port of Houston. We take into explicit consideration the uncertain waiting times associated with the terminals inside the port, and the resulting inefficient transits caused by severe congestion. We show that the problem can be modeled as a stochastic *Traveling Salesman Problem with Pickups and Deliveries* (TSPPD), in which the goal is to find the route within the port with maximized probability that its total length does not exceed a threshold. We show that it is important to properly address the inefficient transits, and that including uncertainty in the travel times can have an impact in the choice of optimal route inside a port. We further show that the layout of the relevant terminals as well as their distances to the anchorage are important drivers of such impact. We conclude with the suggestion that one can use the proposed model and method to find a set of alternative routes, followed by a re-evaluation process since our method encompasses an approximation that underestimates the variation of the route completion time.

1. Introduction

Maritime transportation (Christiansen, Fagerholt, Nygreen, & Ronen, 2007) is the backbone of globalization and cross-border transport networks that support supply chains and enable international trade. In 2015, world seaborne trade volumes were estimated to have exceeded 10 billion tons, which accounted for over 80 percent of total world merchandise trade (UNCTAD, 2016). It is customary to divide maritime transportation into several sectors by cargo types, e.g., container shipping, dry bulk (iron ore, coal, grain, etc.) and liquid bulk (petroleum/crude oil, liquefied natural gas, chemicals, etc.). The chemical shipping market belongs to the liquid bulk sector, and includes the carriage of a range of products such as organic and inorganic bulk liquid chemicals, vegetable/animal oils and fats and clean petroleum products. Worldwide, seaborne trade in the chemical sector accounted for 1.82% of the total trade volume at sea and was estimated at 998 millions ton-miles in 2016 (UNCTAD, 2016). One distinct characteristic that separates chemical shipping from other major sectors in the tanker market (characterized by the usage of different types of tankers to provide transport services), such as oil and gas, is that the shipments are relatively small. A typical chemical tanker can have 15 to over 50 segregated tanks allowing the carrier to transport cargoes of different product types on one single tanker, and the cargoes in these tanks can be designated to a number of different charterers (customers). This special characteristic of chemical shipping has given rise to the issue of in-port transits made by chemical tankers as they typically make multiple “terminal calls” during a single port call (a stop or visit at the port to service the cargoes therein). Common to most chemical shipping companies, as a result, are the inefficiencies involved in their port calls and longer time spent in ports.

Odfjell, a leading company in the chemical shipping sector, is no exception. According to Hammer (2013), Odfjell vessels are spending 44% of their available time in port. Therefore, optimizing port call operations and thereby reducing time spent in ports are in their best interest, as more efficient port calls would increase the transport availability of the ships. Arnesen et al. (2017) made one of the first contributions on this topic, considering a single ship servicing numerous terminals and aiming to find an optimized route with shortest time spent in port. The authors modeled the problem as a *Traveling Salesman Problem with Pickups and Deliveries, Time Windows and Draft Limits* (draft of a ship is the vertical distance between the waterline and the bottom of its hull, determining the minimum depth of water the ship can safely navigate), or TSPPD-TWDL. Fig. 1 illustrates a small example of this

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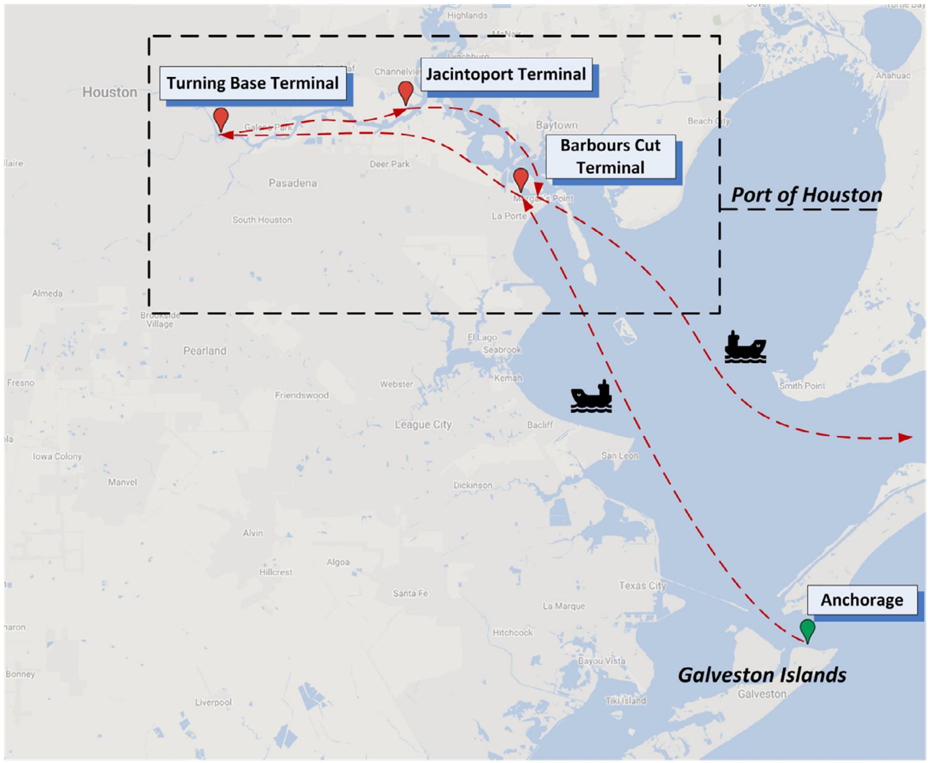

Fig. 1. Illustration of a port call. The ship approaches the Port of Houston from an anchorage point in the Galveston Bay and visits three terminals within the port.

problem in the Port of Houston. In this example the ship approaches the port via an anchorage point, and leaves the port after visiting all three terminals. In reality, as the terminals schedule vessel berthing requests on a first-come, first-serve basis, there are also waiting times at the terminals before they can accept the ship. In Arnesen et al. (2017), however, the authors simplify the problem by assuming deterministic waiting times. Hence the associated transit times between the terminals are also fixed and known.

This study addresses a similar in-port routing problem faced by the chemical shipping company Odfjell, and considers a more realistic scenario in the Port of Houston. Not mirrored anywhere else in the world, the Houston ship channel is 80 kilometers long and only 160 meters wide. Because of its layout and the recent boost in demand due to large expansions of U.S. energy and chemical companies, the channel is increasingly congested (Arnsdorf & Murtaugh, 2014). Once a vessel is inside the Galveston Islands, there is literally no place for a vessel to pull over or berth for a short time to accommodate scheduling difficulties, i.e., the vessel cannot wait “outside” or near any terminal (Kruse, 2015). Therefore, as required by the port authority, when a ship begins moving from one terminal, it must go to another terminal, the Bolivar Roads anchorage area (the Anchorage point in Fig. 1), or an offshore anchorage which is typically several miles further out to sea. This has resulted in a large number of *inefficient transits* made by chemical tankers towards layberths or anchorages due to unavailability of terminals, and a lot of time wasted in port. Statistics show that in 2014, around 18% of all transits made by chemical tankers in the Port of Houston are these inefficient transits (Kruse, 2015).

In this study, we explicitly take into account the inefficient transits due to a *special sailing pattern*, i.e., the ship will sail immediately towards the anchorage point after servicing a terminal, and only change its course back to the next terminal upon receiving the notification that the terminal is ready to accept the ship. The unavailability of a terminal is described by an *uncertain waiting time* from the point the ship leaves the previous terminal and send out the berthing request (known as a NOR, Notice of Readiness), to the point when the next terminal receiving the NOR becomes available. Hence the *travel time* taken from one terminal to the next is also uncertain, depending on the realized waiting time of the next terminal, and also on where the ship is located when the next terminal becomes available, as the ship may still be close by or it may already be “parking” at the anchorage.

In Fig. 2 we illustrate three different cases for a transit between two terminals. In all three cases a ship is leaving Terminal A and is scheduled to service Terminal B next. Assume that the ship will sail at a constant speed and that Terminal B is located on its way back from Terminal A to Anchorage. In Case 1 where the waiting time at Terminal B, w_B, turns out to be 1.5 hours, the ship has not passed Terminal B upon receiving the notification that it is ready to accept the ship. Hence the travel time is 2 hours which corresponds to a direct movement from Terminal A to Terminal B. In Case 2 where $w_B = 3$ hours, the ship has passed Terminal B but not yet reached Anchorage, the resulting travel time is then 4 hours as the ship turns around and spends one more hour retracing part of its route back to Terminal B. Finally in Case 3 where $w_B = 4$ hours, the ship has just arrived at Anchorage when it gets the green light from Terminal B and the resulting travel time becomes 6 hours. This example shows how the transit time (travel time) from one terminal to the next can be uncertain depending on the realized waiting time at the destination terminal, and on the relative locations of the origin, destination terminals and the anchorage point.

This paper presents a stochastic routing model in which the special sailing pattern described above is explicitly addressed and the travel times are uncertain. The goal is to find the route within the port with maximized probability that its total length does not exceed a threshold. In particular, given the initial cargoes on board to be delivered when entering the port, and also a number of cargoes to be picked up during the port call, we model the problem as a stochastic *Traveling Salesman Problem with Pickups and Deliveries* (TSPPD) and aim to find the route that maximizes the probability

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