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Study of travel behavior of vessels in narrow waterways using AIS data – A case study in Sabine-Neches Waterways

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ABSTRACT

This paper proposed an AIS data based method of studying travel behavior of vessels when passing through a hotspot in a narrow waterway, by building their trip information within this hotspot. With trip information, all trips in a hotspot can be divided into three categories: inbound, outbound and moored. The last one refers to the trips that have ever stopped in a hotspot. Such stopping behavior is expected to be different from those directly passing through a hotspot without any stopping. If not excluding these trips, the revealed behavior pattern may be bias, especially when considering speed distributions. This proposed method was applied to the three hotspots in the Sabine-Neches Waterways (SNWW), identified through the analysis of vessel conflicts along the whole SNWW using AIS data collected in the whole year of 2012: more than 10% of total vessel conflicts occurred within these three hotspots. We also investigated the distributions of flow speeds and densities, as well as their relationships at these hotspots, respectively. The findings reveal the travel patterns of inbound and outbound trips passing these three hotspots in the SNWW, considering the heterogeneous behavior of different types of vessels. These revealed patterns also help examine the risk of vessel collisions at these three spots, respectively.

1. Introduction

Since 2002, new ships and all sea-going vessels that have 300 gross tons or more, as well as all passenger vessels are required to equip an automatic identification system (AIS) on board. The AIS transmits the sailing status information between vessels, and from vessels to shore or vice versa. Therefore, AIS helps vessels “see” each other in the channel, and the waterway management agency can also monitor the status of vessels. The AIS data contains the detailed and consecutive temporal and spatial information of a vessel, as well as real maneuvering behavior of a vessel (such as speed, course, etc.). For this reason, recently, AIS data are widely used in the waterway transportation research, including the risk analysis of vessel collisions, vessel travel behavior, etc.

In many existing models, it is important to know vessel behavior and the interactions between vessels. Since AIS data provides the navigation details of vessels, the relative speed, angle and distance can be revealed between two vessels. Such information about vessel interaction serves as input to many models. Mou et al. (2010) developed linear regression models based on AIS data to evaluate the risk of vessel collisions in the North Sea off the Port of Rotterdam, based on two indicators: closest point of approach (CPA) and time to closest point of approach (TCPA) between two vessels. These two factors well reflect the risk of vessel collisions in a given waterway: if the CPA between two vessels are small, then the risk level is high for these two vessels to collide each other. Using AIS data, Weng et al. (2014a, 2014b) investigated the frequency of vessel conflicts in Singapore Straits, which occurs when one vessel enters or will enter the domain of another in a short time (30 s) if neither change their behavior. They defined a vessel's domain as a circle with three times of this vessel's length. Actually, the definition of a vessel's domain varies in the literature. Fujii and Tanaka (1971) defined an elliptical domain, where the major and minor radii are 4 and 1.6 times of the length of the vessel, respectively; and Qu et al. (2011) proposed the fuzzy quaternion ship domain. Kujala et al. (2009) developed a collision model to study the risk of vessel collisions and groundings in the Gulf of Finland, requiring the information of relative speeds between vessels. Montewka et al. (2010) developed models to calculate the probability of three types of vessel collisions: overtaking, head-on and crossing, where information of vessel interaction is required. Zhang et al. (2015) proposed a vessel conflict ranking operator (VCRO) model which is based on a survey among maritime experts to rank the risk of various situations about the interaction between two vessels: relative speed, angle, and distance.

AIS data can be also used to investigate the travel behavior of vessels

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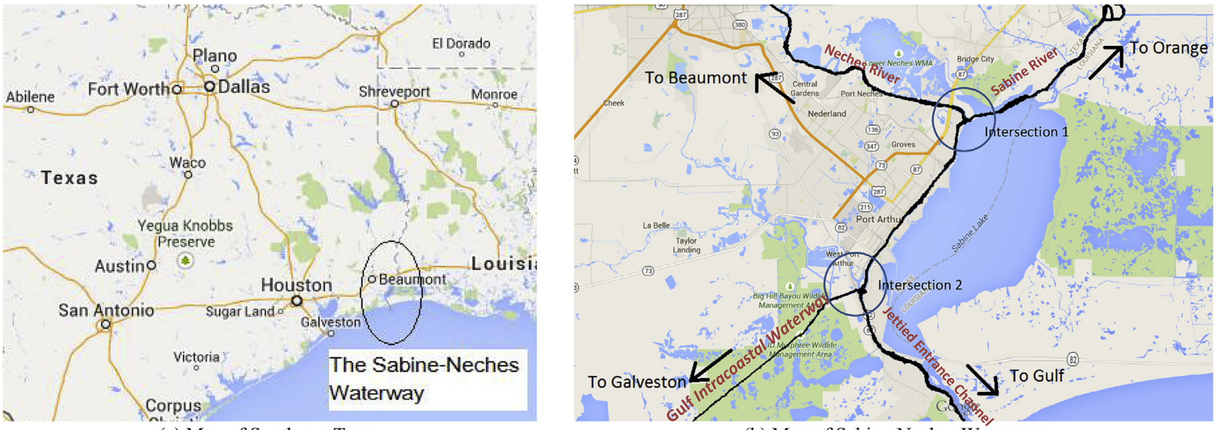


(a) Map of Southeast Texas

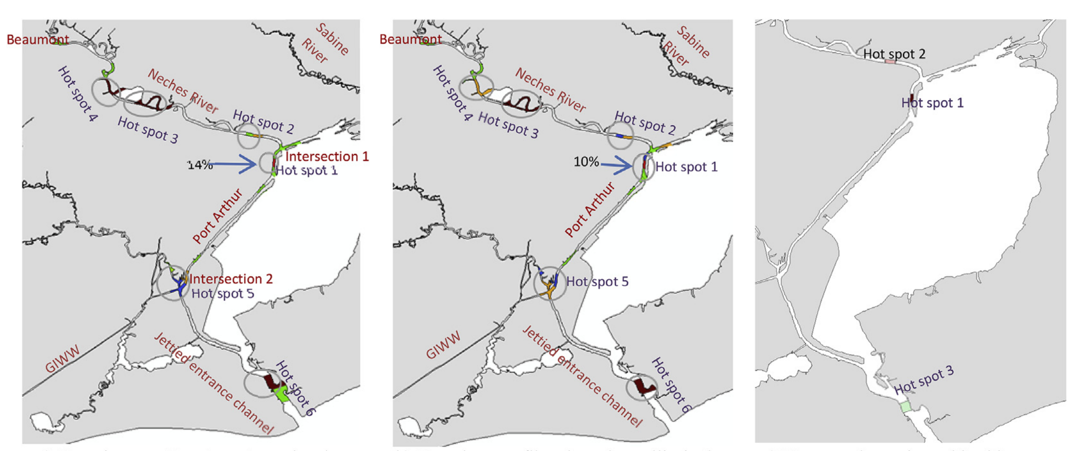
(b) Map of Sabine-Neches Waterway

Fig. 1. Inland waterways in Southeast Texas.

at waterways. Compared with numerous studies of vehicles' travel behavior in highways, only a few look at the travel behavior of vessels in waterways. For example, Xiao et al. (2015) investigated the travel behavior of vessels at two spots (one is near the Port of Rotterdam, and another is near Shanghai) based on AIS data. They studied the distributions of vessel speeds, courses, and arrival time intervals, especially for containers. Different types of vessels vary significantly in size, speed, and maneuvering behavior. Therefore, they particularly studied the behavior of containers. On the other hand, unlike vehicles' behavior in highways, at some locations in a narrow and busy waterway, some vessels may temporarily stop (i.e., moored) while others are still moving, especially when there are many big ships moving in the channel. The travel behavior of those moored vessels is expected to be quite different from those directly passing through without stopping. Therefore, the flow of vessels is expected not to be as homogenous as that of vehicles in highways. If focusing on the travel behavior of in-motion vessels at a hotspot, it is necessary to exclude those which have stopped in this spot when passing through. Meanwhile, the AIS records vessels' real status, i.e., spot speeds, courses, etc. Xiao et al. (2015) employed the speeds and courses of vessels when crossing the border line of the section of interest. However, the status at one point may not be able to fully represent the whole situation when passing through the section of interest.

This paper aims to develop a novel framework of studying the travel behavior of vessels in given "hotspots" of narrow waterways. First, we are particularly interested in hotspots located in narrow inland waterways. Different from open ocean, ships must strictly follow channels in inland waterways, such as the Sabine-Neches Waterways (SNWW), Houston Ship Channel, due to the constraint of draft – the channel was drudged out from a natural river for holding big ships. Therefore, this type of inland waterways is like highways, especially two-lane highways. This is one of the motivation of this paper: whether we can use the highway flow theory to investigate the travel behavior in waterways. However, note that the intersection of waterways is different from that of highways: no signal or stop sign. For this reason, the hotspots studied in this paper are not located in any intersection of waterways. Second, this paper particularly focuses on the travel behavior of in-motion vessels. Different from vehicles in a highway, vessels have more freedom to be moored along a waterway. Therefore, this paper proposed a method to separate the moored vessels from those in-motion (i.e., those directly passing through a spot without stopping) when studying vessels' travel behavior. Note that a hotspot is not a single point but a short section in a channel, so it is important to look at the entire travel behavior of a vessel when it passes through the entire section. Third, the behavior of some types of vessels that dominate the flow, is further studied. By doing these, the behavior of vessels can be more accurately modeled, and the impacts of those dominating vessel types can be better understood.

The "hotspots" can be determined according to the frequency of conflicts between big vessels, i.e., the frequency that a vessel enters the domain of another. In this paper, the hotspots found in the SNWW (see Fig. 1) will be used as the example of the case study. In our previous study on the SNWW, it was found that the frequency of vessel conflicts in several locations (see Fig. 2(a–b)) is consistently high by using various



a) Crossing conflicts based on circular domains using AIS data of March, 2012

b) Crossing conflicts based on elliptical domains using AIS data of March, 2012

c) Hotspots investigated in this paper

Fig. 2. Six hotspots identified in previous studies (Wu et al., 2016) and three for this study.