

Inland Waterway Mobility and Safety

*A Case Study in Sabine-Neches
Waterway*

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Inland Waterway Mobility and Safety -- A Case Study in Sabine-Neches Waterway

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ABSTRACT

This study investigates the vessel-traffic characteristics and navigational conflict patterns along the Sabine Neches Waterway (SNWW) using the Automatic Identification System (AIS) data. The SNWW is a major transportation corridor in Southeast Texas. It identifies conflict-prone locations, compares conflict patterns using domain models, and examines how vessel conflicts may affect navigational safety and channel operations. AIS data from June 2025 were processed, cleaned, integrated, and spatially analyzed. Vessel positions, speeds, courses, dimensions, and timestamps were used to identify interactions among actively moving vessels. A vessel conflict was identified when a surrounding vessel was within or predicted to enter the safety domain of a reference vessel. Vessel conflicts were classified as crossing, head-on, and overtaking, respectively. Two types of ship domains: circular and elliptical domain models were applied to investigate vessel conflict frequency. Spatial grid analysis was then used to calculate conflict frequencies, conflict rates, and hotspot locations. Most identified conflicts occurred when one vessel was already within another vessel's domain. Crossing conflicts were the most frequent encounter type. It was found that the most prominent hotspots were located near Port Neches turning basins, the channel northeast of Port Arthur, major channel intersections, and the Taylor Bayou Channel. These locations combine constrained geometry, turning movements, intersecting traffic flows, and substantial commercial-vessel activity. Further, with the revealed level of vessel conflicts and trip numbers in the channel, the capacity of the channel was also estimated based on the concern of navigation safety. The study updates the earlier vessel conflict assessments using recent AIS data (June 2025) and focuses specifically on actively moving vessels. It integrates synchronized vessel-pair analysis, two vessel-domain geometries, conflict frequency, and spatial conflict rates within one framework. *The findings can support traffic monitoring, vessel scheduling, speed management, safe navigation, and infrastructure planning at high-risk channel sections, thereby improving maritime safety and transportation efficiency.*

Keywords: vessel conflicts, AIS data, Sabine-Neches Waterway, ship domain

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1. INTRODUCTION

Maritime transportation handles over 80% of global trade. Deep draft inland waterways are critical components of global maritime transportation networks, enabling the movement of large cargo volumes and supporting economic development in various regions. The rapid expansion of the shipping industry has highlighted the critical role of efficient port and terminal management in maintaining maritime safety and security, reducing congestion, and improving operational efficiency (Kabir et al., 2024; Ma et al., 2025). Ensuring navigational safety in narrow waterways is a major challenge for maritime authorities and researchers. Maritime collisions remain one of the major safety concerns in global shipping. The restricted maneuvering space and high traffic density in the narrow waterways increase the likelihood of maritime accidents. Vessel accidents in narrow waterways may include collisions, allisions, grounding, fires, explosions, and other incidents (Wu et al., 2016). A collision occurs when two moving vessels strike one another, whereas an allision occurs when a moving vessel impacts a fixed object such as a bridge, dock, etc. (Wu et al., 2016). Vessel accidents can occur due to several factors, which are generally classified into five categories of geometric conditions, traffic characteristics, weather conditions, vessel design, equipment failures, and human factors (Trucco et al., 2008; Li et al., 2012).

The number of reported shipping incidents involving vessels over 100 gross tons decreased from 3,353 cases in 2024 to 2,818 cases in 2025, representing an approximate 16% reduction. Despite this overall decline, the frequency of maritime incidents remains substantial, and collisions and allisions continue to be a major concern in the shipping industry. In 2025, machinery damage or failure was identified as the leading cause of shipping incidents, accounting for 1,505 cases. This was followed by vessel collisions with 260 cases, fire or explosion incidents with 218 cases, and grounding with 202 cases. These statistics suggest that although the industry has achieved improvements in overall safety performance, vessel-to-vessel collision and navigation-related accidents remain important risk categories, particularly in congested waterways and high-traffic maritime regions (Allinaz commercial, 2026).

To mitigate the risk of collisions, numerous researchers have developed models to predict, assess, and quantify the probability of vessel collisions (Rawson and Brito, 2021). Among these approaches, the ship domain concept has been widely used as a fundamental framework for evaluating ship interactions and navigational safety. The ship domain describes the minimum surrounding area that a vessel requires to maintain safe navigation and avoid close encounter with other vessels (Liu et al., 2021). This concept is particularly important in restricted waterways, such as straits, canals, and port areas, where traffic density is high and maneuvering

space is limited. As a result, ship domain models have become an essential method in collision risk assessment and maritime traffic safety analysis (Goerlandt and Montewka, 2015; Weng and Yang, 2015; Zhang et al., 2016). Since the ship domain concept was first introduced (Fujii and Tanaka, 1971), numerous ship domain model has been developed, differing in their geometric shapes and the factors considered in their formulation (Zhao et al., 1993; Smierzchalski and Michalewicz, 2000; Szlapczynski and Szlapczynska, 2017). These models commonly consider factors such as vessel size, maneuverability, environmental conditions, speed, traffic intensity, and navigator experience (Zhao et al., 1993; Dinh and Im, 2016). These models are generally classified into three main groups: empirical models, knowledge-based models, and safety analysis-based models (Szlapczynski and Szlapczynska, 2017). In knowledge-based models, information is typically obtained from navigators or domain experts to define the ship domain (Fiskin et al., 2020; Zhu et al., 2001). In safety-analysis-based models, the domain is developed by considering different safety-related criteria and analytical assumptions. In empirical models, AIS data are commonly used to derive ship domains from observe vessel behavior (Du et al., 2021; Fujii and Tanaka, 1971; Goodwin, 1975; Hansen et al., 2013; Pietrzykowski and Magaj, 2017; Wang and Chin, 2016). The size of a ship domain may vary depending on several factors, including the vessel's physical characteristics, the applicable COLREGs encounter situation, maneuverability, the human element, etc. (Tu et al., 2017).

Ship domain models have been widely applied in studies of navigational safety, vessel conflict identification, and collision risk assessment. Mou et al. (2010) proposed a circular domain, and Fujii (1971) proposed an elliptical ship domain. Wielgosz and Pietrzykowski (2022) used expert surveys and ship-handling simulations to find out the preferred safety area for navigators and the actual safety area used during real encounters. Rawson and Brito (2021) analyzed millions of AIS-based vessels encounters and used a random forest model to predict critical passing distances under different conditions. Their model incorporated factors such as vessel size and speed, encounter type, distance from shore, ports, traffic separation schemes, wind, and time of day, and was then applied to identify areas with elevated vessel conflict risk. Kundakçı, Nas, and Guçma (2023) developed an empirical ship domain model for coastal waters using 11 months of AIS data from the Northern Aegean Sea.

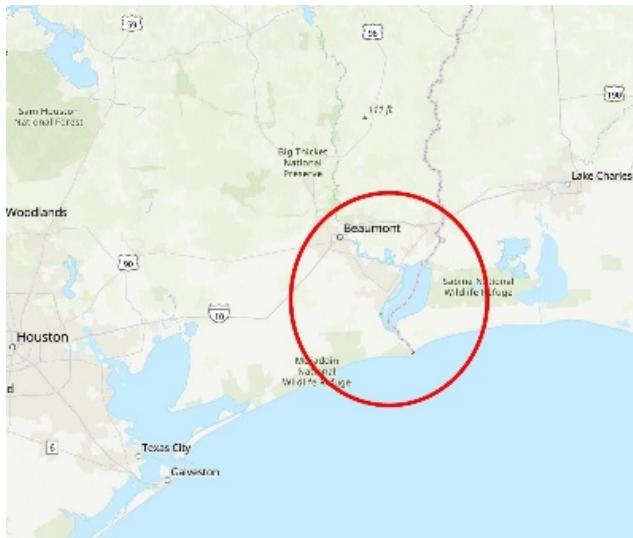
This study investigates the navigation mobility and safety of the Sabine-Neches Waterway (SNWW) in Southeast Texas. It particularly focuses on vessel collision risk as a case study in critical infrastructure protection. Southeast Texas is widely recognized as a critical energy gateway for the United States, characterized by its extensive petrochemical infrastructure and highly active maritime transportation network. SNWW serves as a key transportation corridor that supports major energy and industrial activities in the region (see Figure 1(a)). This waterway

was dredged and widened in 1912 from two natural rivers, the Sabine River and the Neches River, as shown in Fig. 1b (Weston, 2010). SNWW includes approximately 97 miles of navigation channel with varying depths for deep- and shallow-draft vessels. It connects the Gulf of America to the ports of Port Arthur, Beaumont, and Orange through the Sabine and Neches Rivers. SNWW is the second-longest deep-draft navigation channel in the U.S. Gulf Coast and plays a vital role in national energy and defense operations. The SNWW ranks the first in the U.S. for crude oil imports and supports approximately 55% of the nation's Strategic Petroleum Reserve. The Port of Beaumont ranks as the 5th largest port by waterborne tonnage, while the Port of Port Arthur ranks 16th nationally (USACE, 2025).

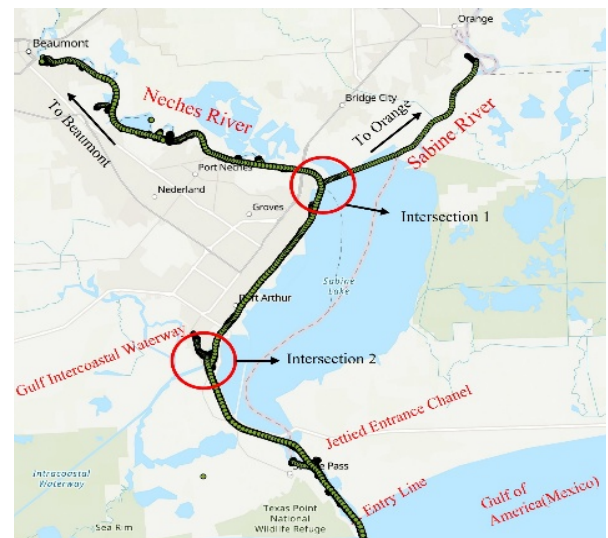
SNWW also serves 4 major refineries and a large LNG facility. The SNWW navigation system includes a deep-draft channel with depth generally ranging from 30 ft (9.1 m) to 42 ft (12.8 m). Most major channel sections maintain a depth of 40 ft (12.2 m) to 42 ft (12.8 m) to support large commercial vessels. The channel is now under a deepening project, aiming to deepen the channel from its current depth of 40 ft (12.2 m) to a new depth of 48 ft (14.6 m) (SNND, 2022). The channel is 40 ft (12 m) deep and 400 ft (122 m) wide in the Neches River section, while it is 42 ft (13 m) deep and 500–800 ft (152–244 m) wide in the jettied entrance channel, which can accommodate oil tankers and other large vessels (see Figure 1). The second route goes to the Port of Orange in the northeast via the Sabine River, which is 30 ft (9 m) deep and 200 ft (61 m) wide (USACE, 2010).

Safe navigation in narrow waterways such as SNWW is a key concern for authorities in Southeast Texas. Southeast Texas is highly susceptible to frequent hurricanes and tropical storms, such as Hurricane Harvey in 2017, Tropical Storm Imelda in 2019, and Hurricane Beryl in 2024, which have repeatedly disrupted transportation in SNWW. In addition, the limited channel width constrains vessel maneuverability in different sections of this channel, which can increase the risk of collision and allision. Given the SNWW's critical economic importance and heavy vessel traffic, it is essential to investigate the mobility and safety of ship traffic in this channel. Wu et al. (2016) analyzed AIS data from the SNWW to describe vessel traffic patterns and identify locations with frequent vessel conflicts. They used both the circular and elliptical ship domains to investigate vessel conflicts in March and June 2012, respectively. However, it remains unclear whether these locations continue to represent the most critical areas under current traffic conditions. Moreover, in their study, they provided limited consideration of conflict involving only actively moving vessels and the relationship between vessel conflicts, traffic exposure, and channel capacity. Therefore, this study uses the recent available AIS data in June 2025 to identify conflicts among moving vessels, compare current hot spots with those previously reported, calculate conflict rates across the channel segments, and evaluate channel

utilization and operational capacity. The study contributes an updated and integrated framework that links navigational safety with waterway performance and supports the identification of segments requiring operational or infrastructure improvements. The primary objective of this study is to identify and evaluate vessel-conflict patterns across different sections of the SNWW, including changes in critical hotspots and conflict rates among moving vessels, while also examining their implications for channel capacity. With such knowledge, it can help us better understand the navigation situation of the channel, as well as support traffic monitoring, vessel scheduling, and safe navigation at high-risk channel sections, thereby improving maritime safety and transportation efficiency.



(a) Map of Southeast Texas



(b) Map of Sabine Neches Waterway

Figure 1 Inland channel of Sabine-Neches Waterway in Southeast Texas

In recent years, AIS data have been increasingly used to determine ship domains (Goerlandt et al., 2017; Pietrzykowski and Uriasz, 2009; Pietrzykowski and Magaj, 2016, 2017). The implementation of AIS on December 31st, 2004, by the International Maritime Organization (IMO) on all large ships exceeding 300 gross tons, as well as all passenger vessels, has provided a valuable data source for maritime traffic studies (Rong et al., 2024). AIS enables the automatic transmission of static and spatial-temporal information of ships at regular intervals of 2 to 10 seconds between ships and shore-based stations. Static data includes the Maritime Mobile Service Identity (MMSI), ship type, and ship size. Meanwhile, dynamic data transmits information such as timestamp, position, speed over ground (SOG), course over ground (COG), and draft of ships over specific time intervals through a transmitter.

1.1 Review of Data

In this study the daily AIS data has been downloaded from the website marinecadastre.gov. This website covers all waterways in the U.S, divided into 20 zones. The SNWW is located in zone 15, covering a section of the Gulf, most sections of the Mississippi River, part of Lake Superior, and other waterways. Daily AIS records (CSV format) from Zone 15 during June 2025 were downloaded. The daily AIS data were subsequently aggregated into a monthly dataset using Python and then imported into a PostgreSQL database with a geographic information system (GIS) package – PostGIS embedded, which offers a library of spatial functions. Therefore, many spatial functions can be directly applied for spatial analysis. Finally, ArcGIS was used to extract AIS records corresponding exclusively to the SNWW study area, as illustrated in Fig. 2.

After filtering the AIS data based on SNWW borders, an aggregate data analysis was conducted based on the AIS data of June 2025 to investigate the waterway transportation features of SNWW. The number of AIS data points filtered for the whole month of June 2025 is 1,048,575, and the total number of vessels is 295. Based on Google Earth, 197 docks were identified in the SNWW. To ensure data integrity and accuracy, outliers and duplicate data were carefully checked and removed. After eliminating error points, ship trips were extracted using methods developed in Wu et al. (2020). A total of 2060 trips were extracted from AIS records during the study period, from June 1st to July 1st, 2025. Among these trips, 152 were identified as tankers and cargo ship trips, including 77 outbound trips and 75 inbound trips. The trips starting from the entry line (**Error! Reference source not found.**b) to destination docks are defined as inbound trips, and those starting at destination docks to the entry line are regarded as outbound trips.



Figure 2 SNWW Border

Based on the AIS data, we also analyzed the distributions of vessel types and lengths. Table 1 shows the distribution of vessel types based on AIS records. Our findings indicate that tugs are the most common type, accounting for 51.5% of all ships, followed by tankers at 22.4% and Cargo ships at 8.72%, representing a major vessel category operating within SNWW. This distribution of vessels reflects the industrial characteristics of the region, particularly its energy-intensive maritime activities. These vessels are generally characterized by relatively large drafts, which limit their navigational flexibility and restrict maneuverability within the waterway. Also, to compare this result with our previous study based on the 2012 AIS data collected in SNWW, the distribution of vessels is fairly the same.

The vessel's length plays an important role in navigation and maneuvering within the channel. As reported in Table 2, the observed vessel's length ranges from 7 to 300 m. On average, vessels between 20 and 30 m account for the largest share of the fleet, representing 23.05%, followed by vessels longer than 200 meters, which account for 20.68%. Vessels between 150-200 meters also represent a considerable share, accounting for 16.61%. Vessels shorter than 10 meters account for 1.36%, suggesting that smaller vessels are relatively rare in our study. In contrast, 47.8% of vessels are longer than 100 meters, indicating the strong presence of large vessels within the study area.

Table 1 Number of vessels under different vessel types in June 2025

Tug	Cargo	Tanker*	Operational**	Fishing etc.***	Passenger	Other/Not Specified
152	26	56/10	5	14	4	28

* Number of cargos and tankers carrying dangerous materials are specified after “/”, and the number before “/” refers to the number of cargos or tankers carrying non dangerous materials.

** Includes dredging, underwater operational vessels.

*** Includes recreational, search and rescue vessels.

Table 2 Percentage distribution of vessel lengths in the SNWW (June 2025)

0-10m†	10-20m	20-30m	30-50m	50-100m	100-150m	150-200m	≥200m	No Data
1.36	16.61	23.05	4.41	5.08	10.51	16.61	20.68	1.69

† The category indicates the length larger than 0 and no more than 10 m. The same rule applied to other categories. “No data” refers to the AIS data without vessel length data.

Finally, the distribution of vessel speed in the SNWW during June 2025 was studied, as shown in Table 3. The results indicate that vessel traffic within the study area is primarily characterized by low operating speeds. On average, 83.25% of AIS records correspond to speeds below 0.5 knots, suggesting that most AIS data were recorded during a vessel was stopped, moored, or moving very slowly near docks. In contrast, a much smaller proportion of AIS data reflects the movements of vessels. It reflects that most AIS data are redundant, not useful for vessel conflict analysis. Therefore, our algorithm of vessel conflict analysis excludes most AIS data, which can help significantly improve computational efficiency.

Table 3 Percentage distribution of vessel speeds in the SNWW (June 2025)

<0.5 knots	0.5-5 knots	5-10 knots	10-15 knots	<15 knots	No Data
83.25	5.39	9.83	0.51	0.21	0.81

Although tugs account for the largest share of vessels operating within the SNWW, this study focuses on large ships, including tankers and cargo vessels, because their greater dimensions and deeper drafts reduce navigational flexibility and limit maneuverability within the channel. These characteristics make large vessels particularly sensitive to channel geometry, traffic interactions, and other navigational constraints.

2. METHODS

2.1 Vessel Conflict Occurrence

Collision risk in restricted waterways is commonly evaluated using the ship-domain concept (Zhao et al., 1993; Pietrzykowski, 2008; Wang, 2010; Goerlandt and Kujala, 2014). A ship domain represents the surrounding area that a navigator seeks to keep clear of other vessels or fixed objects to maintain safe navigation (Goodwin, 1975). In this study, the ship safety domain (or ship domain) refers to the predefined area surrounding a reference vessel that should remain free of other vessels to maintain safe navigation. The term safety area refers to the physical area enclosed by the boundary of this ship domain. Therefore, the two terms describe the same spatial region in the present analysis. To avoid ambiguity, the term ‘ship domain’ is used consistently throughout the remainder of the paper. A vessel conflict is defined as a situation in which one vessel, referred to as the surrounding vessel, enters or is predicted to enter the safety area of another vessel, referred to as the reference vessel. The frequency of such events can serve as an indicator of potential collision risk (Mou et al., 2010). Mou et al. (2010) defined a circular

domain with a radius equal to 3.0 times the vessel length, whereas Fujii and Tanaka (1971) proposed an elliptical domain with major and minor radius equal to 4.0 and 1.6 times the vessel length, respectively. The elliptical domain is more sensitive to interactions between vessels traveling on similar or opposing courses and therefore well suited to narrow, relatively straight channel sections. In contrast, the circular domain provides uniform coverage in all directions and is more appropriate for curved sections, turning areas, and intersections where vessels may approach from multiple directions. Since the SNWW includes both types of navigational environments, both circular and elliptical domain models were applied to evaluate vessel-conflict frequency throughout the waterway (Wu et al., 2016). In this study, similar methods from our previous study (Wu et al., 2016) were used to re-evaluate the hotspots of the SNWW using the recent AIS data. By comparing the results, we can better understand the navigation risk in the SNWW, and further to estimate the capacity of the SNWW.

An AIS-based procedure was developed to evaluate vessel interactions and potential conflict risk along the SNWW. AIS data provides real-time spatial and temporal information, including position, speed over ground (SOG), course over ground (COG), heading, identification, type, and length, enabling vessel interactions within a channel to be analyzed at the microscopic, vessel-pair level. Each AIS record for vessel i at time t can be represented as: $R_i^t = [x_i^t, y_i^t, v_i^t, \alpha_i^t, L_i]$, where x_i^t is the longitude or projected x-coordinate of vessel i at time t , y_i^t is the latitude or projected y-coordinate of vessel i at time t , v_i^t is the speed over ground of vessel i at time t , α_i^t is the course over ground of vessel i at time t , and L_i is the length of vessel i . Similarly, the state of the vessel j is denoted as $R_j^t = [x_j^t, y_j^t, v_j^t, \alpha_j^t, L_j]$. In this study, vessel j is designated as the reference vessel and vessel i as the surrounding vessels.

Two types of vessel domains are studied in this research: circular and elliptical ship domains to examine the effect of different safety spaces on the conflict identification. Figure 3 shows these two domains based on models defined by Mou et al. (2010) and Fujii and Tanaka (1971). In the circular domain approach, the safety area around a vessel is represented by a circle centered at the reference vessel's position. The radius of the circular domain is defined as three times the reference vessel length ($R_i = 3 \times L_i$). Therefore, the circular domain applies the same safety distance in all directions around the vessel.

In the elliptical domain approach, the safety area around the vessel is represented by an ellipse. Unlike the circular domain, the elliptical domain provides a longer safety distance on the sides. In this method, the major radius of the ellipse is defined as four times the reference vessel length ($a_i = 4 \times L_i$), while the minor radius is defined as 1.6 times the reference vessel length ($b_i = 1.6 \times L_i$), where a_i is the major radius of elliptical domain and b_i is the minor radius of the

elliptical domain (see Figure 3). It is expected that the elliptical domain better represents navigation behavior in narrow and relatively straight channels.

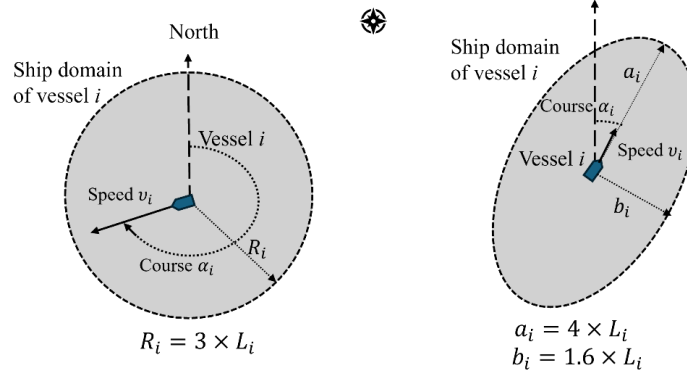


Figure 3 Circular and Elliptical ship domain

For each vessel pair, the spatial and kinematic relationship was evaluated using AIS-derived variables, including relative distance, relative speed, relative angle, and course difference. As shown in Equation (1), the relative distance was calculated to determine whether the surrounding vessel had entered the reference vessel's domain. Equations (2) and (3) were subsequently applied to determine the relative motion of the vessel pair and identify whether the vessels were approaching one another or moving apart.

$$D_{ij}^t = \sqrt{(x_i^t - x_j^t)^2 + (y_i^t - y_j^t)^2} \quad (1)$$

$$|\vec{v}_{ij}^t| = \sqrt{(|\vec{v}_i^t| \cos \alpha_i^t - |\vec{v}_j^t| \cos \alpha_j^t)^2 + (|\vec{v}_i^t| \sin \alpha_i^t - |\vec{v}_j^t| \sin \alpha_j^t)^2} \quad (2)$$

$$\theta_{ij}^t = \cos^{-1} \left[1 - \frac{\left(\frac{|\vec{v}_i^t| \sin \alpha_i^t - |\vec{v}_j^t| \sin \alpha_j^t}{|\vec{v}_{ij}^t|} - \frac{x_j^t - x_i^t}{D_{ij}^t} \right)^2 + \left(\frac{|\vec{v}_i^t| \cos \alpha_i^t - |\vec{v}_j^t| \cos \alpha_j^t}{|\vec{v}_{ij}^t|} - \frac{y_j^t - y_i^t}{D_{ij}^t} \right)^2}{2} \right] \quad (3)$$

where D_{ij}^t is the relative distance between vessel i and vessel j at time t , (x_i^t, y_i^t) and (x_j^t, y_j^t) are the locations of vessels i, j at time t , respectively, and then let $\vec{v}_i^t, \vec{v}_j^t$ and α_i^t, α_j^t are the speeds and courses of vessels i, j at time t , respectively. A vessel conflict was identified when one vessel was either already located inside another vessel's domain or was predicted to enter the domain within a short time interval if both vessels maintained their current speeds and courses.

The relative angle calculated using Equation (3) ranges from 0° to 180° and characterizes the relative motion between a vessel pair. Values of $\theta_{ij}^t < 90^\circ$ indicate that the two vessels are moving closer to one another, whereas $\theta_{ij}^t > 90^\circ$, indicate that they are moving apart. Figure 4

presents the relative-motion configurations of the vessel (j), defined as the reference vessel, and the vessel (i), defined as the surrounding vessel, as determined by their relative positions, courses and speeds.

When vessels (i) and (j) travel on the same course, such that ($\alpha_i^t = \alpha_j^t$), their relative motion depends on their respective speeds. If the reference vessel (j) is positioned ahead of the surrounding vessel (i) and the surrounding vessel travels at a higher speed, ($|v_i^t| > |v_j^t|$), then $\theta_{ij}^t = 0$. This condition indicates that vessel (i) is closing vessel j and may result in a rear-end collision if neither vessel changes its course or speed (Figure 4(a)). Conversely, when the reference vessel travels faster than the surrounding vessel, ($|v_i^t| < |v_j^t|$), the relative angle is $\theta_{ij}^t = 180^\circ$, indicating that the separation distance between vessels is increasing (Figure 4(b)).

For vessels proceeding in opposite directions, such that ($\alpha_i^t = -\alpha_j^t$), a relative angle of ($\theta_{ij}^t = 0^\circ$) indicates that the vessels are moving toward one another (see Figure 4(c)). Conversely, $\theta_{ij}^t = 180^\circ$ indicates that the vessels are moving away from one another while proceeding in opposite directions (see Figure 4(d)).

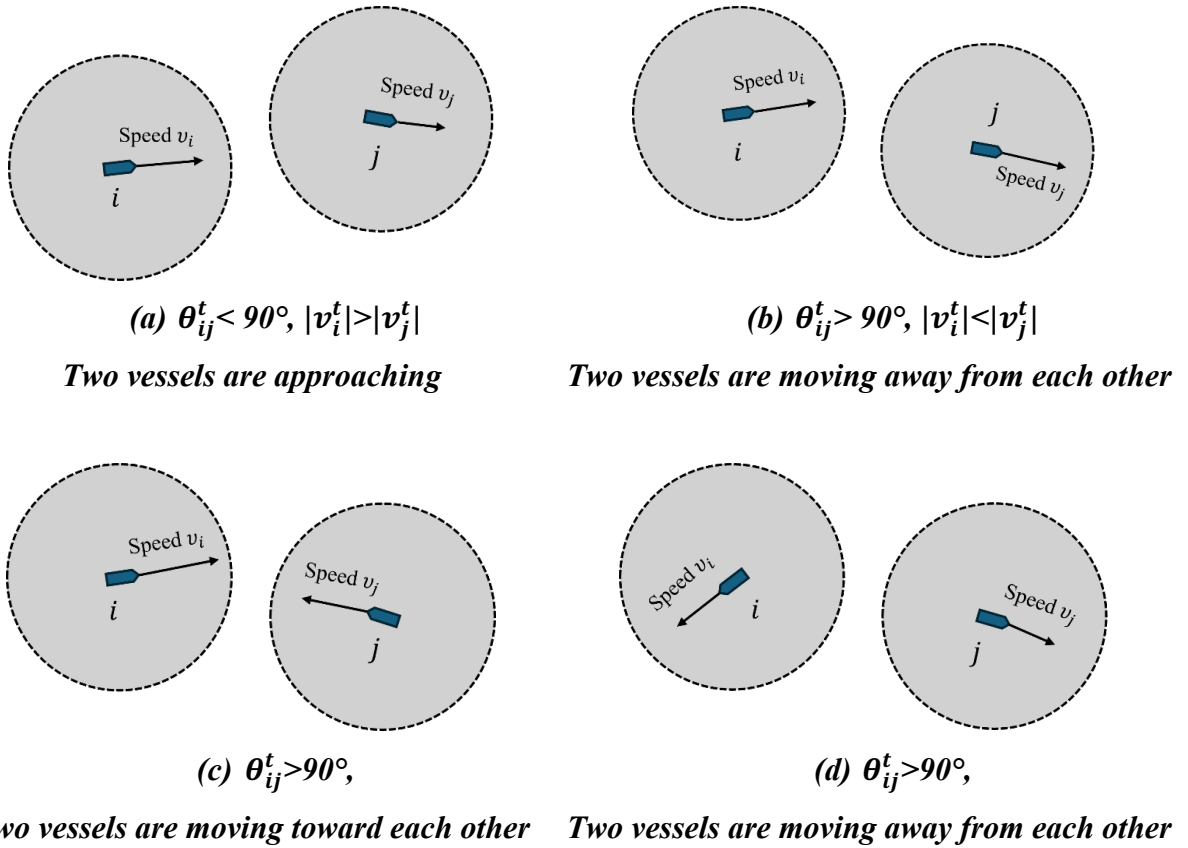


Figure 4 Relative positioning of reference vessel j and surrounding vessel i at time t

To address the challenge of identifying potential vessel conflict, the proposed method evaluates whether a surrounding vessel is expected to enter the reference vessel's domain within a specified prediction time interval. At time (t), vessel (j) is designated as the reference vessel and vessel (i) as the surrounding vessel. The likelihood of vessel (i) entering the domain of vessel (j) is evaluated based on their relative motion and geometry of the reference vessel's domain when the relative angle indicates that vessel (i) is moving toward vessel (j). As shown in Figure 5(a), a conflict occurs when vessel (i) crosses the boundary of vessel (j)'s domain within a short time interval Δt (Weng et al., 2014a). The relative distance traveled by vessel (i) during this interval is expressed as $|\vec{v}_{ij}^t| \Delta t$. If $|\vec{v}_{ij}^t| \Delta t > L_{ij}^t$, vessel (i) is expected to pass Point A and enter the domain of vessel (j) within Δt , indicating a potential vessel conflict. Here, L_{ij}^t denotes the distance from the current position of vessel (i) to the first intersection of its relative-motion path with the circular domain boundary. Following Weng et al. (2014a), this distance is calculated as

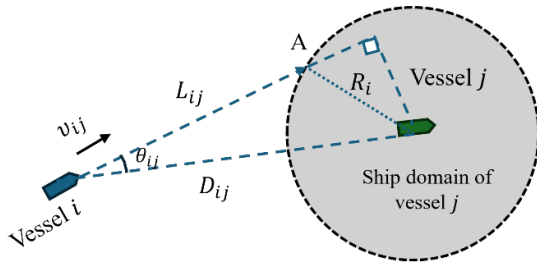
$$L_{ij}^t = (D_{ij}^t \cos \theta_{ij}^t) - \sqrt{R^2 - (D_{ij}^t \sin \theta_{ij}^t)^2}, \text{ if } R > D_{ij}^t \sin \theta_{ij}^t$$

where $R > D_{ij}^t \sin \theta_{ij}^t$ indicates that the relative-motion path intersects the circular domain. Conversely, when $R < D_{ij}^t \sin \theta_{ij}^t$, the perpendicular distance from the reference vessel to the projected relative-motion path exceeds the domain radius. Therefore, vessel (i) will not enter the domain of vessel (j), as illustrated in Figure 5(b).

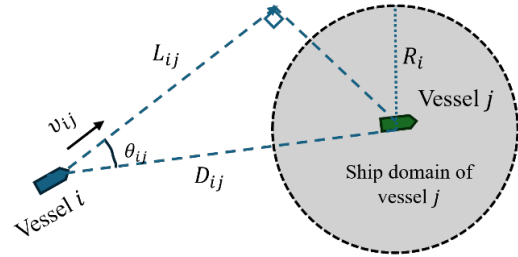
For the circular vessel domain, the relative angle may also be used as an initial screening criterion to exclude vessel pairs that cannot result in conflict. As shown in Figure 5(c), when $\theta_{ij}^t \geq 90^\circ$ vessel (i) is not moving toward the domain of vessel (j). At $\theta_{ij}^t = 90^\circ$, the relative-velocity vector is tangent to the circular boundary, represented by Line AB in Figure 5(c), whereas values greater than 90° indicate that the distance between the vessels is increasing. Thus, when vessel (i) is initially outside the circular domain and $\theta_{ij}^t \geq 90^\circ$, vessel (i) will not enter the domain if both vessels maintain their current speeds and courses.

This screening rule cannot be directly applied to an elliptical domain because the distance from the reference vessel to the domain boundary varies with direction, as shown in Figure 5(d). Accordingly, conflict identification for an elliptical domain requires projecting the relative position of vessel (i) at time $t + \Delta t$, assuming both vessels maintain their current speeds and courses. The angular coordinate $\emptyset$ of the projected position is then determined, followed by the corresponding radial distance r from the center of the ellipse to its boundary. If the predicted relative distance between the two vessels at $t + \Delta t$ is less than r , vessel (i) is considered to have entered the domain of vessel (j), indicating a potential vessel conflict. Figure 5 illustrates the

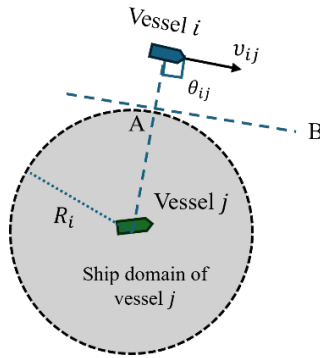
vessel-conflict determination at time t .



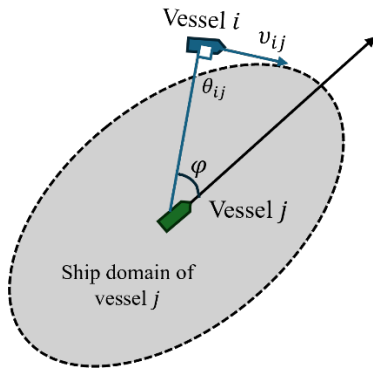
(a) *Vessel i will enter the domain of reference vessel j (Weng et al., 2014a)*



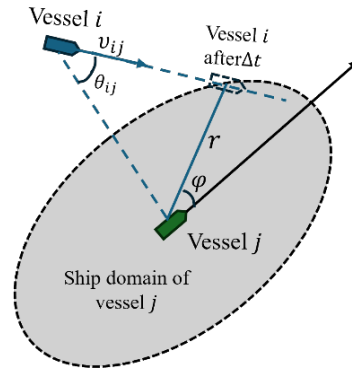
(b) *Vessel i will not enter the domain of reference vessel j (Weng et al., 2014a)*



(c) $\theta_{ij}^t = 90^\circ$ (or $> 90^\circ$) *Vessel i will not enter the circular domain of vessel j (Weng et al., 2014a)*



(d) $\theta_{ij}^t = 90^\circ$, *Vessel i may still enter the elliptical domain of vessel j*



(e) *Vessel i may still enter the elliptical domain of vessel j at $t + \Delta t$*

Figure 5 Vessel Conflict Identification at time t

2.2 Vessel Conflict Type Identification

Once vessel conflicts were identified, they were classified into three primary encounter types: head-on, overtaking, or crossing, based on the scheme proposed by Montewka et al. (2010). A head-on conflict occurs when two vessels are moving toward each other on nearly opposite courses. An overtaking conflict occurs when the courses of two vessels are traveling in approximately the same direction and one vessel approaches the other from behind. A crossing conflict occurs when the courses of two vessels intersect at an angle that is neither head-on nor overtaking. If no vessel is in the domain of any other at time t The following criteria can determine the type of conflict.

When both vessels are outside each other's domain at time (t), it is necessary to determine whether they are approaching one another by evaluating their relative motion using the relative angle, (θ_{ij}^t). The potential conflict scenario is then classified according to the following criteria. As discussed in Section 3.1, $\theta_{ij}^t \geq 90^\circ$ indicates that the vessels are moving apart and, therefore, no conflict is expected, (as shown in Figures 4(b) and 4(d). In contrast, when $\theta_{ij}^t < 90^\circ$, then vessels are approaching one another, and a potential conflict may arise, as shown in Figures 4(a) and 4(c), respectively. A vessel conflict is considered possible when $R > D_{ij}^t \sin \theta_{ij}^t$ and $|\vec{v}_{ij}^t| \Delta t > L_{ij}^t$. Once these conditions are satisfied, the conflict type can be classified according to the following criteria.

1. Overtaking conflict if $\sin \alpha_i^t \cdot \sin \alpha_j^t > 0$, and $\theta_{ij}^t \leq 10^\circ$
2. Head-on conflict if $\sin \alpha_i^t \cdot \sin \alpha_j^t < 0$, and $\theta_{ij}^t \leq 10^\circ$
3. Crossing conflict if $\theta_{ij}^t > 10^\circ$ and $\theta_{ij}^t \leq 90^\circ$

On the other hand, if one vessel is already located within the other vessel's domain at time (t), a conflict is considered to have occurred. Accordingly, Equation (4) does not need to be applied to evaluate the potential for domain intrusion. Under this condition, the vessel pair should be classified as being in conflict regardless of the value of the relative angle. For instance, when the relative angle is close to 0° , the vessels may have experienced a head-on conflict immediately before time t . Conversely, when the relative angle is close to 180° , an overtaking conflict may have occurred shortly before time t . Therefore, the previously defined conflict classification criteria are modified as follows:

1. Overtaking conflict if $\sin \alpha_i^t \cdot \sin \alpha_j^t > 0$, and ($\theta_{ij}^t \leq 10^\circ$ or $\theta_{ij}^t \geq 170^\circ$)
2. Head-on conflict if $\sin \alpha_i^t \cdot \sin \alpha_j^t < 0$, and ($\theta_{ij}^t \leq 10^\circ$ or $\theta_{ij}^t \geq 170^\circ$)
3. Crossing conflict if $\theta_{ij}^t > 10^\circ$ and $\theta_{ij}^t < 170^\circ$

where α_i^t and α_j^t are courses of vessels (i) and (j) at time t , respectively, and θ_{ij}^t is the relative

angle. These rules can be applied to elliptical domains.

2.3 Procedure for Identifying Potential Vessel Conflict Points

A key challenge in identifying vessel conflicts from AIS data is that nearby vessels do not necessarily transmit their navigational information at the same time. As a result, the velocity and course variables required for vessel (i) and (j), including $\vec{v}_i^t, \vec{v}_j^t$ and α_i^t, α_j^t , may not be available at a common timestamp t . Direct application of Equations (1)-(4) may therefore overlook nearby vessels with offset reporting times and lead to a biased estimation of conflict frequency. To address this issue, the Procedure for Identifying Potential Vessel Conflict Points (IPVCP) was developed to identify surrounding-vessel records and synchronize their navigational states at a common reference time. The resulting synchronized vessel pairs are then evaluated using the established conflict criteria to identify existing and potential vessel conflicts throughout the SNWW. The IPVCP algorithm consists of the following steps.

Step1: Selection of a reference point

For each vessel j , all AIS records are examined sequentially. Each AIS record contains a timestamp t and a geographic position (x_j^t, y_j^t) , expressed in longitude and latitude. At each iteration, the selected record is treated as a reference point j , and the corresponding vessel is designated as the reference vessel.

Step 2: Definition of temporal and spatial search buffer

A temporal buffer extending from $t - 1$ min to $t + 1$ min is defined around the reference time. The temporal buffer was set to $t \pm 1$ min because vessels commonly transmit AIS messages at intervals of approximately one minute, although the reporting interval may vary depending on vessel speed, navigational status, and equipment settings. A spatial search buffer is also constructed around the reference position (x_j^t, y_j^t) . The buffer radius is defined as:

$$r_j = \max(800m, 5L_j)$$

where L_j is the length of the reference vessel. This threshold was selected considering around 50% of the vessels in the dataset were shorter than 50 m, most vessels traveled at speed below 10 knots, and the radius of the adopted vessel domain was defined as three times the vessel length. The larger search radius provides sufficient coverage for identifying vessels that may approach or enter the reference vessel's domain within the selected prediction interval.

Step 3: Identification of surrounding vessels

AIS records belonging to vessels other than the reference are identified when their positions and timestamps fall simultaneously within the spatial and temporal buffers. A vessel associated with at least one such record is classified as an identified surrounding vessel i .

Step 4: Removal of redundant surrounding vessel records

Because multiple AIS records from the same surrounding vessel may fall within the two-minute temporal buffer, only the record with the timestamp closest to the reference time t is retained. Consequently, for each reference point, no more than one AIS record is initially selected from each surrounding vessel.

Step 5: Synchronizing of surrounding vessel states

The selected AIS record of the surrounding vessel generally does not occur at exactly the same time as the reference record. Therefore, the position, speed, and course of the vessel i are estimated at the reference time t through linear interpolation. Let t_i^k denote the timestamp of the k th AIS record of the vessel i , ordered chronologically. If $t_i^k > t$, the immediately preceding record at t_i^{k-1} is retrieved. The vessel state at time t is then interpolated using records at t_i^{k-1} and t_i^k . Conversely, if $t_i^k < t$, the subsequent record at t_i^{k+1} is retrieved, and interpolation is performed using the records at t_i^k and t_i^{k+1} .

Step 6: Identification and classification of vessel conflicts

The conflict identification method described in section 3.2 is applied to each synchronized surrounding vessel point and its corresponding reference point. The prediction interval is set to $\Delta t = 30$ s during which both vessels are assumed to maintain constant speeds and courses. The resulting candidate vessel pair is classified either as an existing conflict, when one vessel is already within the domain of the other at time t , or as a potential conflict, when the vessels are outside their respective domains, but the relative motion conditions indicate that domain intrusion may occur within the prediction interval.

Step 7: Repetition for all vessel records

After all AIS records associated with the reference vessel j have been examined, the procedure is repeated for the next reference vessel. The process continues until every eligible AIS record and vessel in the dataset has been evaluated.

Another methodological consideration in this study is that reference and surrounding vessels with speeds less than 0.5 knots are excluded. This restriction reduces the likelihood of classifying two stationary vessels, such as vessels berthed at adjacent mooring, as a navigational conflict. The synchronization procedure in Step 5 is particularly important because the course of the vessel may change noticeably even over a short period. Although changes in position and speed are generally limited over small time intervals, particularly because more than 98% of the observed vessels traveled at speeds below 10 knots, directly assigning the course reported at t_i^k to the reference time t may introduce errors in the relative-motion calculations. Interpolation therefore provides a more consistent estimate of the surrounding vessel's navigational state at the reference time. Steps 1-5 generate a set of synchronized vessel pairs, referred to as candidate conflict point pairs. Step 6 is then used to determine whether each pair represents an existing within-domain conflict or an out-of-domain encounter that may develop into a conflict when $|\vec{v}_{ij}^t|\Delta t > L_{ij}^t$. When a vessel has entered the domain of another vessel, the encounter is classified exclusively under the within-domain scenario. Although the same vessel pair may previously have been classified as an out-of-domain encounter, only its within-domain status is retained at the time of domain intrusion to avoid duplicate classification.

3. RESULTS

3.1 Vessel Conflicts

AIS data collected for the month of June 2025 was used to analyze vessel-conflict patterns in the SNWW. A total of 295 vessels were identified during the study period. However, because the SNWW accommodates a substantial number of tugs and other small vessels, as reported in Table 2, the analysis focuses primarily on larger vessels, i.e., tankers and cargo ships. Collisions involving these vessels may result in more severe operational disruptions, environmental damage, and safety consequences.

Vessels with a length of at least 50 m were designated as reference vessels, whereas vessels with a length of at least 20 m were considered surrounding vessels. This filtering criterion emphasized interactions involving larger commercial vessels, including tankers and cargo vessels, while still accounting for smaller vessels that could interact with them. In addition, only vessels traveling at speeds greater than 0.5 knots were included in the analysis. AIS records associated with stationary vessels, particularly those stopped at docks, were excluded to ensure that the analysis represented active vessel movement. Table 4 shows the number of reference and surrounding vessels identified, using circular and elliptical domains, respectively.

Table 4 Number of reference and surrounding vessels using circular and elliptical domains

Domain	Reference vessels			Surrounding vessels		
	Total	Tankers	Cargos	Total	Tankers	Cargos
Circular	141	57	20	184	41	16
Elliptical	141	57	20	184	41	16

Table 5 Frequency of vessel conflicts based on circular and elliptical domains, respectively

Scenario	Out-of-domain				Within domain			
	Crossing	Head-on	Overtaking	Total	Crossing	Head-on	Overtaking	Total
Circular	425	247	40	712	5583	547	430	6560
Elliptical	280	201	22	503	6050	941	626	7617

Note: based on the AIS data of June 2025

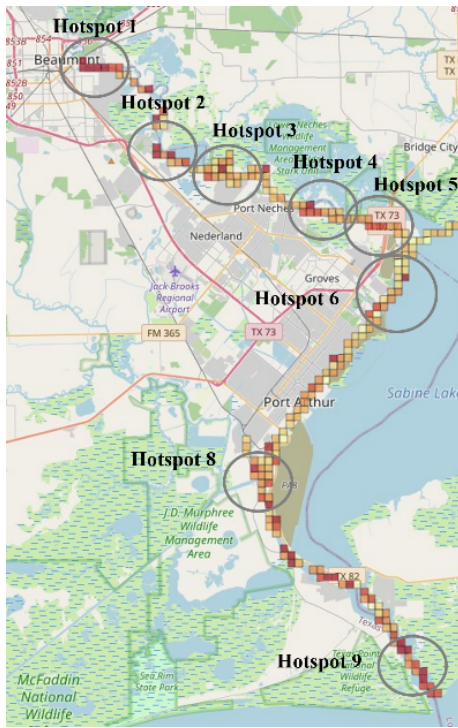
There were 66 tankers and 25 cargos detected in this channel in June 2025, and among them, 57 tankers and 20 cargos are identified as reference vessels. Moreover, among the surrounding vessels, 184 vessels are identified, of which 41 and 16 are tankers and cargo vessels. It is shown that a ship domain's shape is insignificant for identifying the reference and surrounding vessels.

Table 5 presents the frequencies of three types of vessel conflicts under two scenarios (based on the AIS data of June 2025), using either circular or elliptical domains, respectively. It is seen that the number of vessel conflicts that occurred under the within-domain scenario is much more than that under the out-of-domain scenario in the SNWW. The reason is that the SNWW is a narrow channel with many docks along the channel. A notable difference can be observed between the results from the circular and elliptical domains. Under the out-of-domain scenario, the frequencies of head-on and overtaking conflicts identified using elliptical domains were substantially lower than those obtained using circular domains. In contrast, under the within-domain scenario, the elliptical domain produced considerably higher frequencies for these conflict types.

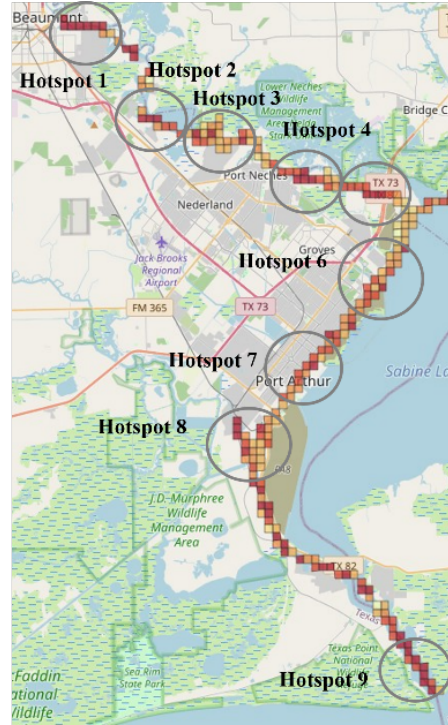
This difference can be attributed to the dimensions assigned to the two domain shapes. The radius of the circular domain was defined as three times the length of the reference vessel, whereas the major axis of the elliptical domain was defined as four times the vessel length. The results therefore suggest that a considerable number of vessel pairs traveled along similar courses while maintaining longitudinal separations between approximately three and four reference vessel lengths. This pattern is consistent with the characteristics of the SNWW, which includes extensive sections of relatively straight and narrow navigational channel, as shown in Figure 1.

For purposes of comparison, Figure 6 reports the vessel conflict risk from the previous study using 2012 AIS data of the SNWW, based on the circular and elliptical ship domains, respectively (Wu et al., 2016). Lighter colors represent lower conflict rates; while darker colors indicate higher conflict rates. 9 hotspots have been identified with high rates of vessel conflicts.

For this study, the results based on the data of June 2025 were reported in Figure 7, considering different types of vessel conflicts. Based on the circular domain, Figure 7(a)-(c) shows the three highest-ranked grid cells for each conflict type: crossing, overtaking, and head-on. The grid cells are ranked according to their percentages to the total number of conflicts of the corresponding type, with a darker color indicating a higher risk of conflicts. Hotspots 3, 4, 6, and 8 exhibit the highest risk of vessel conflicts: 3.56% in crossing at Hotspot 3, 4.16% in head-on at Hotspot 3, and 4.14% in overtaking at Hotspot 6. Hotspot 3 is located along the Neches River, slightly north of Port Neches and near the turning basin. Hotspot 4 is also located slightly south of Port Neches and near turning basin in the area. Hotspot 6 is located in the channel northeast of Port Arthur near Intersection 1; while Hotspot 8 is located along Taylor Bayou Channel.

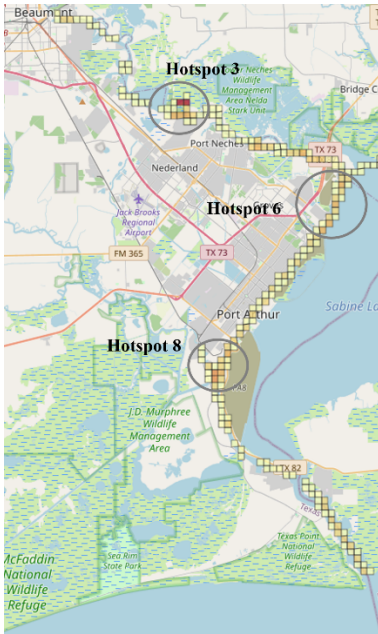


(a) Hotspots based on circular-domain

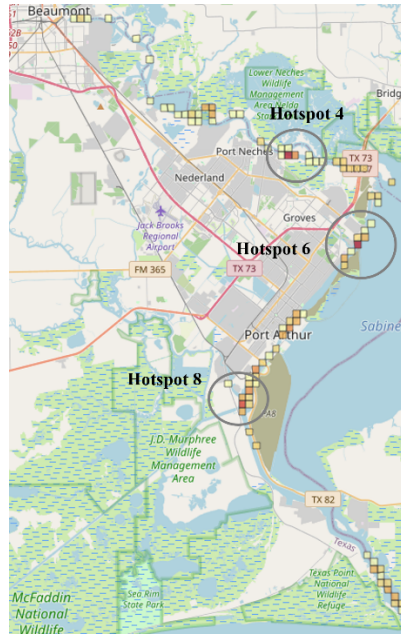


(b) Hotspots based on elliptical-domain

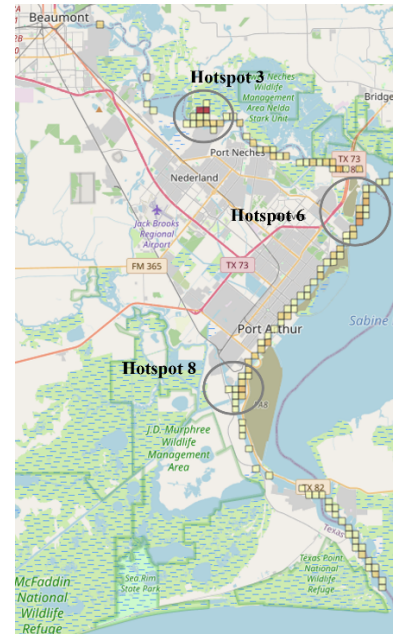
Figure 6 Vessel-conflict hotspots based on the AIS data collected in 2012 (Wu et al, 2016)



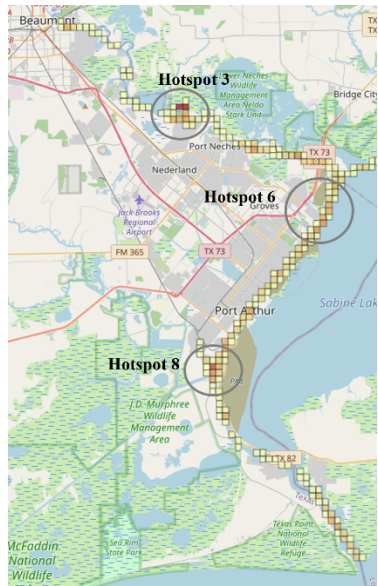
(a) Crossing conflicts based on circular domain



(b) Overtaken conflicts based on circular domain



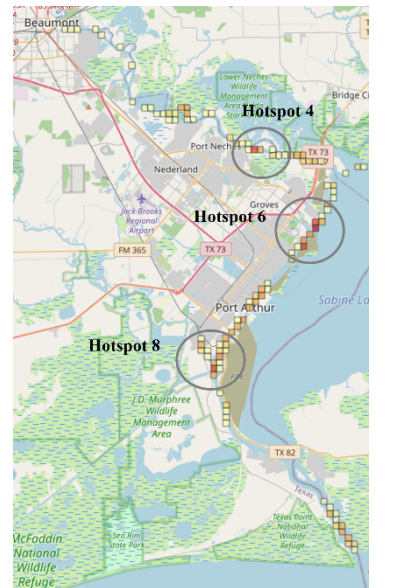
(c) Head-on conflicts based on circular domains



(d) Crossing conflicts based on elliptical domain



(e) Overtaken conflicts based on elliptical domain



(f) Head-on conflicts based on elliptical domain

Figure 7 Top three hotspots for three types of vessel conflicts in June 2025

On the other hand, based on the results from the elliptical domain, figure 7 (d-f) gives the hotspots with the largest percentages of vessel conflicts (considering three types of vessel conflicts). Interestingly, it is seen that the results are the same: we still have Hotspots 3, 4, 6 and 8. Therefore, the results are well consistent. Compared with the results based on the data of 2012 (Wu et al., 2014), as reported in Figure 6, we can see that several old hotspots become less risky, especially those close to the Gulf, the Port of Beaumont, and Port Arthur. The fact that fewer hotspots were identified may reflect the effectiveness of channel improvements, which started in 2020. Also, our previous study (Paudel et al., 2024) identified Taylor Bayou Channel as an area containing several major refineries and recording the largest number of vessel trips.

3.2 Channel Capacity

From the AIS data, we can *extract* the number of trips based on the methods based on our previous study (Wu et al., 2020). With these methods, we can determine a ship's destination dock and its arrival or departure time at/from its destination dock. With such information, we can identify the trips. The number of trips, together with the information of vessel conflicts, can give us a general picture of channel capacity.

Note that as mentioned before, we only focused on the “big” ships when considering vessel conflicts: vessels with a length of at least 50 m as reference vessels, and those with a length of at least 20 m as surrounding vessels. In the SNWW, most small boats are tugs, and there are also a few operational vessels and fish boats. They were not considered because (as reported in Table 1) tugs usually function as auxiliary vessels helping big ships maneuvering in the channel, and other ships have very small numbers compared with cargo ships and tankers. Based on the AIS data collected in June 2025, we extracted the number of inbound and outbound trips made by cargo ships and tankers in the SNWW, as shown in Figure 8. For inbound trips, the mean and median are both 2.5 trips per day; while for outbound trips, the mean is 2.5 trips per day, and the median is 2.0 trips per day. In 12 days, there are more inbound trips than outbound trips; two types of trips are equal in 6 days; and in another 12 days, more outbound trips are seen.

Note that as reported in Table 1, there are about 28 vessels labeled as “Other/Not Specified” due to the data missing or error. We may have a few more big ships not counted.

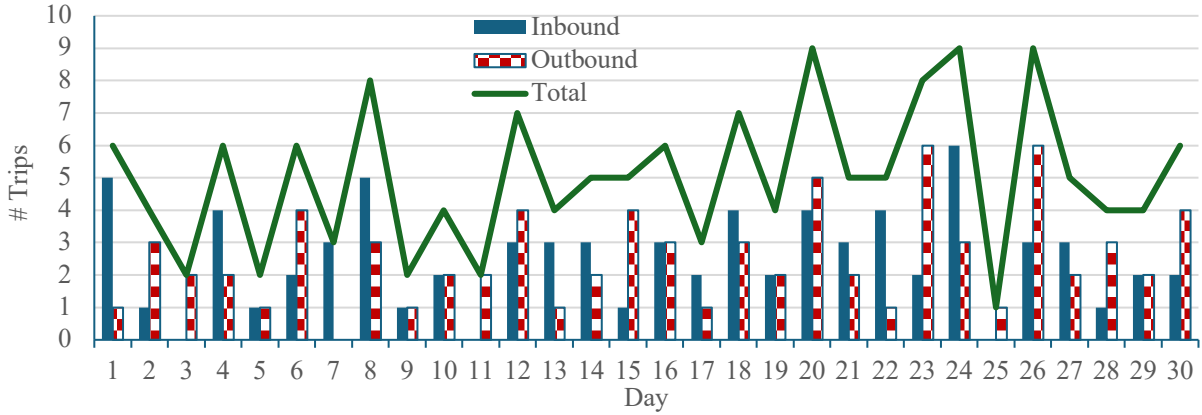


Figure 8 Number of trips made by cargo ships and tankers on each day of June 2025 in SNWW

As to the total number of trips, it is seen from Figure 8 that in three busiest days, there are 9 trips in total, and only one trip on the least busy day. Both mean and median number of trips are 5.0 per day.

As reported in Table 5, our algorithm identified 6560 or 7617 in-domain vessel conflicts with the circular or elliptical domain, respectively based on the AIS data of June 2025. Among them, most are crossing conflicts. That is, on average, there are 219 or 254 in-domain vessel conflicts per day with circular or elliptical domain, respectively. Note that here we only consider in-domain vessel conflicts for two reasons: (1) in-domain vessel conflicts imply direct vessel collision risk (one vessel already in the domain of another) compared with out-of-domain vessel conflicts, and (2) there are many more of in-domain conflicts (almost 10 times higher), as reported in Table 5. Then, using the average (or median) number of trips (i.e., 5 trips per day), it is estimated that on average 44 or 50 in-domain vessel conflicts may be caused by one ship during its navigation through the channel.

The capacity of channel can be estimated based on the accepted level of vessel conflicts in the channel. The larger the number of vessel conflicts is, the higher the risk of vessel collisions. The accepted maximum in-domain vessel-conflict number depends on a variety of factors, such as the channel characteristics, weather conditions, historical collision data, and travel demand. This maximum number is largely based on the judgement of the waterway navigation authorities and port authorities. Please note that in this study on the SNWW, if the largest number of accepted vessel conflicts is 100 per day, then the capacity can be roughly estimated to be 10 trips per day, given that the data shows 5 trips per vessel per day corresponding to averagely 50 in-domain vessel conflicts.

4. CONCLUSION

This study evaluated vessel-traffic characteristics, navigational conflict patterns, and channel capacity in the Sabine Neches Waterway (SNWW) using Automatic Identification System (AIS) data collected in June 2025. The analysis focused on moving vessels to reduce the possibility of incorrectly classifying stationary or berthed vessels as navigational conflicts. Vessels at least 50 m long were designated as reference vessels, while at least 20 m long vessels were considered surrounding vessels, and records with speeds below 0.5 knots were excluded. This approach emphasized interactions involving large commercial vessels while retaining smaller vessels that could potentially conflict with them.

An AIS-based procedure was developed to address the frequency of conflict. The procedure identified surrounding vessels within the spatial and temporal search buffer, synchronized their navigational states at a common reference time through interpolation, and evaluated their relative positions and movements. Vessel conflicts were defined as encounters in which a surrounding vessel was already within, or was predicted to enter, the safety domain of a reference vessel. Specifically, two types of safety domain (or called ship domain), circular and elliptical ship domain were applied. Correspondingly, two models were developed to investigate three types of vessel conflicts: crossing, head-on, or overtaking encounters. Further, the revealed vessel conflict level was used to estimate the channel capacity.

The spatial analysis identified several persistent conflict-prone locations in the SNWW. The areas near the Port Neches turning basins, the channel northeast of Port Arthur near major intersections, and the Taylor Bayou Channel, were identified as hotspots with high frequency of crossing, head-on, or overtaking vessel conflicts. These locations are characterized by turning movements, intersecting traffic streams, narrow channel geometry, and near critical refineries facilities. The Taylor Bayou Channel and several nearby areas were also identified as vulnerable locations in previous studies based on the AIS data of 2012 (Wu et al., 2016), showing that certain locations have continued to experience navigational risk since 2012. Conflict frequencies were evaluated to distinguish heavily traveled locations from areas with highly risky navigational areas. The identified hotspots can be helpful in traffic monitoring, speed and scheduling controls, and infrastructure improvements.

Several limitations should be acknowledged. The analysis was based on one month of data and assumed that vessels maintained constant speeds and courses during the short prediction interval. It also did not consider weather, visibility, currents, vessel maneuverability, pilot decisions, or detailed traffic control activities. On the other hand, the estimate of channel capacity is based on

the revealed level of vessel conflicts, without considering other factors, such as the dock locations – different sections of channel may have different capacity.

Future work should focus on translating the proposed conflict-analysis framework into an operational decision-support tool for maritime agencies and port authorities. This would require validation using longer-term AIS data and historical incident/near-miss records, incorporation of environmental and operational factors such as weather, visibility, currents, vessel maneuverability, pilot actions, and traffic-control activities, and calibration of practical risk thresholds in consultation with the U.S. Coast Guard, port authorities, and other stakeholders. The proposed methods in this study could ultimately be integrated into a GIS-based or real-time decision-support system for monitoring conflict hotspots, traffic scheduling, speed management, and infrastructure planning.

Additionally, in the current study, the vessels traveling below 0.5 knots were excluded in the present study to avoid incorrectly identifying normally berthed or moored vessels as conflicts, an unexpected reduction in speed or stoppage within the navigation channel may indicate machinery failure, grounding, or another emergency and may pose a significant collision hazard to approaching vessels. Future methods could distinguish normal berth-related stops from abnormal in-channel stoppages using vessel location, navigational status, trajectory history, and proximity to docks or anchorages.

5. ACKNOWLEDGMENT

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6. DECLARATION OF GENERATIVE AI USE

During the preparation of this work the author(s) used ChatGPT to assist with language editing, paraphrasing, and grammar improvement of selected sentences. The author(s) reviewed and edited the content as needed and take full responsibility for the content of the published article.

7. REFERENCES

- Allianz Commercial (2026) *Safety and Shipping Review 2026*. Available at: <https://commercial.allianz.com/news-and-insights/reports/shipping-safety.html> (Accessed: 30 July 2026).
- Dinh, G.H. and Im, N. (2016) ‘The combination of analytical and statistical methods to define a polygonal ship domain and reflect human experiences in estimating dangerous areas’, *International Journal of e-Navigation and Maritime Economy*, 4, pp. 97–108. doi: 10.1016/j.enavi.2016.06.009.
- Du, L., Banda, O.V., Yamin, H., Goerlandt, F., Kujala, P. and Zhang, W. (2021) ‘An empirical ship domain based on evasive maneuvers and perceived collision risk’, *Reliability Engineering & System Safety*, 213, article 107752. doi: 10.1016/j.res.2021.107752.
- Fiskin, R., Nasiboglu, E. and Yardimci, M.O. (2020) ‘A knowledge-based framework for two-dimensional asymmetrical polygonal ship domains’, *Ocean Engineering*, 202, article 107187. doi: 10.1016/j.oceaneng.2020.107187.
- Fujii, Y. and Tanaka, K. (1971) ‘Traffic capacity’, *The Journal of Navigation*, 24(4), pp. 543–552. doi: 10.1017/S0373463300022384.
- Goerlandt, F. and Kujala, P. (2014) ‘On the reliability and validity of ship–ship collision risk analysis in light of different perspectives on risk’, *Safety Science*, 62, pp. 348–365. doi: 10.1016/j.ssci.2013.09.010.
- Goerlandt, F. and Montewka, J. (2015) ‘Maritime transportation risk analysis: Review and analysis in light of some foundational issues’, *Reliability Engineering & System Safety*, 138, pp. 115–134. doi: 10.1016/j.res.2015.01.025.
- Goerlandt, F., Montewka, J., Kuzmin, V. and Kujala, P. (2015) ‘A risk-informed ship collision alert system: Framework and application’, *Safety Science*, 77, pp. 182–204. doi: 10.1016/j.ssci.2015.03.015.
- Goodwin, E.M. (1975) ‘A statistical study of ship domains’, *The Journal of Navigation*, 28(3), pp. 328–344. doi: 10.1017/S0373463300041230.
- Hansen, M.G., Jensen, T.K., Lehn-Schiøler, T., Melchild, K., Rasmussen, F.M. and Ennemark, F. (2013) ‘Empirical ship domain based on AIS data’, *The Journal of Navigation*, 66(6), pp. 931–940. doi: 10.1017/S0373463313000489.
- Kundakçı, B., Nas, S. and Gucma, L. (2023) ‘Prediction of ship domain in coastal waters using AIS data’, *Ocean Engineering*, 273, article 113921. doi: 10.1016/j.oceaneng.2023.113921.
- Li, S., Qiang, M. and Qu, X. (2012) ‘An overview of maritime waterway quantitative risk assessment models’, *Risk Analysis*, 32(3), pp. 496–512. doi: 10.1111/j.1539-6924.2011.01697.x.
- Liu, K., Yuan, Z., Xin, X., Zhang, J. and Wang, W. (2021) ‘Conflict detection method based on a dynamic ship domain model for visualization of collision-risk hotspots’, *Ocean Engineering*, 242, article 110143. doi: 10.1016/j.oceaneng.2021.110143.
- Mou, J.M., van der Tak, C. and Ligteringen, H. (2010) ‘Study on collision avoidance in busy

- waterways by using AIS data', *Ocean Engineering*, 37(5–6), pp. 483–490. doi: 10.1016/j.oceaneng.2010.01.012.
- MundoMaritimo (2026) 'Nearly 3,000 maritime incidents reported worldwide in 2025'. Available at: <https://www.mundomaritimo.net/noticias/nearly-3000-maritime-incidents-reported-worldwide-in-2025> (Accessed: 7 July 2026).
- Paudel, S., Toosi, G., Wu, X. and Zaloom, V.A. (2024) 'Study on utilization of inland deep-draft waterway based on ship trajectories: Applied to Sabine–Neches Waterway', *Ocean Engineering*, 298, article 117038. doi: 10.1016/j.oceaneng.2024.117038.
- Pietrzykowski, Z. (2008) 'Ship's fuzzy domain—A criterion for navigational safety assessment in narrow fairways', *The Journal of Navigation*, 61(3), pp. 499–514. doi: 10.1017/S0373463308004682.
- Pietrzykowski, Z. and Magaj, J. (2017) 'Ship domain as a safety criterion in a precautionary area of a traffic separation scheme', *TransNav: International Journal on Marine Navigation and Safety of Sea Transportation*, 11(1), pp. 93–98. doi: 10.12716/1001.11.01.10.
- Rawson, A. and Brito, M. (2021) 'Developing contextually aware ship domains using machine learning', *The Journal of Navigation*, 74(3), pp. 515–532. doi: 10.1017/S0373463320001018.
- Rong, H., Teixeira, A.P. and Soares, C.G. (2024) 'A framework for ship abnormal behaviour detection and classification using AIS data', *Reliability Engineering & System Safety*, 247, article 110105. doi: 10.1016/j.ress.2024.110105.
- Sabine Neches Navigation District (2022) *Deepening project*. Available at: <https://navigationdistrict.org/deepening-project/> (Accessed: 16 October 2023).
- Smierzchalski, R. and Michalewicz, Z. (2000) 'Modeling of ship trajectory in collision situations by an evolutionary algorithm', *IEEE Transactions on Evolutionary Computation*, 4(3), pp. 227–241. doi: 10.1109/4235.873234.
- Szlapczynski, R. and Szlapczynska, J. (2017) 'Review of ship safety domains: Models and applications', *Ocean Engineering*, 145, pp. 277–289. doi: 10.1016/j.oceaneng.2017.09.020.
- Trucco, P., Cagno, E., Ruggeri, F. and Grande, O. (2008) 'A Bayesian belief network modelling of organisational factors in risk analysis: A case study in maritime transportation', *Reliability Engineering & System Safety*, 93(6), pp. 845–856. doi: 10.1016/j.ress.2007.03.035.
- Tu, E., Zhang, G., Rachmawati, L., Rajabally, E. and Huang, G.B. (2018) 'Exploiting AIS data for intelligent maritime navigation: A comprehensive survey from data to methodology', *IEEE Transactions on Intelligent Transportation Systems*, 19(5), pp. 1559–1582. doi: 10.1109/TITS.2017.2724551.
- U.S. Army Corps of Engineers (USACE) (2010) *Sabine–Neches Waterway Channel Improvement Project: Southeast Texas and Southwest Louisiana*. Available at: <http://www.usace.army.mil/Portals/2/docs/civilworks/CWRB/sabine/sabine.pdf> (Accessed: 30 July 2026).

- Wang, N. (2010) ‘An intelligent spatial collision risk based on the quaternion ship domain’, *The Journal of Navigation*, 63(4), pp. 733–749. doi: 10.1017/S0373463310000202.
- Wang, Y. and Chin, H.C. (2016) ‘An empirically calibrated ship domain as a safety criterion for navigation in confined waters’, *The Journal of Navigation*, 69(2), pp. 257–276. doi: 10.1017/S0373463315000533.
- Weng, J. and Yang, D. (2015) ‘Investigation of shipping accident injury severity and mortality’, *Accident Analysis & Prevention*, 76, pp. 92–101. doi: 10.1016/j.aap.2015.01.002.
- Weston, D. (2010) *Sabine–Neches Waterway Channel Improvement Project, Southeast Texas and Southwest Louisiana*. Civil Works Review Board briefing. Galveston, TX: U.S. Army Corps of Engineers, Galveston District. Available at: <https://planning.erdc.dren.mil/toolbox/library/ChiefReports/SabineNechesWaterway22Jul11.pdf> (Accessed: 30 July 2026)
- Wielgosz, M. and Pietrzykowski, Z. (2022) ‘The ship domain in navigational safety assessment’, *PLOS ONE*, 17(4), article e0265681. doi: 10.1371/journal.pone.0265681.
- Wu, X., Mehta, A.L., Zaloom, V.A. and Craig, B.N. (2016) ‘Analysis of waterway transportation in Southeast Texas waterways based on AIS data’, *Ocean Engineering*, 121, pp. 196–209. doi: 10.1016/j.oceaneng.2016.05.012.
- Zhang, W., Goerlandt, F., Kujala, P. and Wang, Y. (2016) ‘An advanced method for detecting possible near-miss ship collisions from AIS data’, *Ocean Engineering*, 124, pp. 141–156. doi: 10.1016/j.oceaneng.2016.07.059.
- Zhao, J., Wu, Z. and Wang, F. (1993) ‘Comments on ship domains’, *The Journal of Navigation*, 46(3), pp. 422–436. doi: 10.1017/S0373463300011875.
- Zhu, X., Xu, H. and Lin, J. (2001) ‘Domain and its model based on neural networks’, *The Journal of Navigation*, 54(1), pp. 97–103. doi: 10.1017/S0373463300001241.

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Xing Wu is a Professor of Civil and Environmental Engineering at Lamar University. In June 2011, he got his PhD at Northwestern University in the field of transportation engineering. After that, he worked as a postdoctoral researcher until May 2012 when he accepted the offer from Lamar University as Assistant Professor. During this time, he also worked in Oak Ridge National Laboratory as a visiting scholar. He was tenured and promoted to Associate Professor in Fall 2018 and promoted to Professor in Spring 2024. His research focuses on transportation modeling, geospatial data analysis and GIS applications. He has published about 50 papers in peer-reviewed journals in these fields with over 2400 citations. Especially since 2015, he has been working in waterway transportation, and more than 10 papers on maritime transportation were published by his research team. He was the Committee Member of Marine Safety and Human Factors (AW040) of the Transportation Research Board (TRB) from 2014 to 2024, and the associated editor of *Frontier in Future Transportation* since 2022. He also works as the Undergraduate Coordinator in the Department of Civil and Environmental Engineering at Lamar University.

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