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An analysis of ship escort and convoy operations in ice conditions

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ABSTRACT

Winter navigation is a complex but common operation in the Northern Baltic Sea areas. In Finnish waters, the safety of the wintertime maritime transportation system is managed through the Finnish–Swedish winter navigation system. This system results in different operational modes of ship navigation, with vessels either navigating independently or under icebreaker assistance. A recent risk analysis indicates that during icebreaker assistance, convoys operations are among the most hazardous, with convoy collisions the most important risk events. While the accident likelihood per exposure time is rather low, accidents occur almost every winter. Even though these typically lead to less serious consequences, accidents leading to ship loss and oil pollution have occurred and may occur in the future. One aspect of ship convoy navigation in ice conditions is the distance kept between the icebreaker and the ships in the convoy, a form of the well-known ship domain concept. While operational experience naturally is a valuable source of information for decision making about the distance of navigation in convoys, systematic analyses are lacking. The aim of this paper is to investigate selected operational aspects of convoy navigation in ice conditions in the Finnish waters of the Gulf of Finland, based on data of the Automatic Identification System and sea ice hindcast data. Focus is on obtaining qualitative and quantitative knowledge concerning distances between vessels in escort and convoy operations and the respective transit speeds, conditional to ice conditions. Such empirical knowledge can support operational decision making, contributing to wintertime maritime safety.

1. Introduction

The Northern Baltic Sea area is a relatively busy area for maritime transportation, with maritime trade of vital economic importance several countries in the area. Simultaneously, this area is characterized by the presence of ice during the winter season. This leads to a harsh environment for ship navigation, which has important implications for managing the safety of the vessels operating in this area.

In Finland, winter navigation is organized by means of the Finnish–Swedish winter navigation system (FSWNS). This is a system which governs the implementation of ship transportation in winter conditions, ensuring the maritime accessibility and safety (FTA, 2014; Riska et al., 1997). It consists of five main components, which together ensure that the vessel design and operational environment is such that vessels navigating in Baltic ice conditions can proceed safely. The components are ice class regulations, additional requirements, ice services, traffic restrictions and icebreaker assistance; see TraFi (2010) for further details.

When vessels are authorized to proceed to their destination, they either navigate independently or are assisted by icebreakers. In icebreaker assistance, five practical operations are commonly distinguished (Rosenblad, 2007). In escorting, an icebreaker breaks a channel and a vessel follows the icebreaker at a certain distance. In breaking loose operations, an icebreaker passes a ship beset in ice to break the ice beside and in front of the assisted ship, releasing the ice pressure. Convoy operations are similar to escorting but with several ships following the icebreaker. In double convoy operations, one icebreaker travels slightly ahead of the other icebreaker, to assist a vessel with a larger breadth than the icebreakers. Finally, in towing operations, the assisted vessel is towed as it cannot follow the icebreaker because the ice pressure makes the channel close too quickly, or because the channel has too much slush ice. An icebreaker may have a vessel on tow, while simultaneously leading a convoy.

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As in open water conditions (Klanac et al., 2010; Kujala et al., 2009; Qu et al., 2012) and in Arctic navigation (Kum and Sahin, 2015), ship collisions are one of the most frequently occurring accidents in Finnish sea areas during winter (Valdez Banda et al., 2015a). Navigational accidents occur more frequently in ice conditions than in open water, but typically lead to less serious consequences. A recent risk analysis suggests that among accidents occurring during icebreaker operations, convoy operations are among the most hazardous situations in the wintertime conditions. Collisions between the following vessel and the icebreaker and vessels in a convoy are the most important related risk events (Valdez Banda et al., 2015b).

The icebreaker crew may advise the crew of assisted vessels, but the crews of vessels in convoy operations are responsible for arranging and maintaining a suitable distance between individual vessels. Simultaneously, a relatively high speed is typically maintained in the convoy to ensure efficient transport flows. The distance is important from a safety and operational perspective. If a ship shortens the distance to a preceding ship, a collision is more likely to occur. However, if a longer distance is maintained, the following ship may be hampered by the ice (slush in the channel and especially compressive ice) and get stuck in ice as a result.

In maritime safety research, it is known that vessel crews aim to keep a certain area around the vessel clear from other vessels, an area commonly known as the ship domain (Goodwin, 1975). Various analytical models have been proposed for ship domains (Pietrzykowski, 2008; Wang et al., 2009; Zhu et al., 2001) and empirical studies on the ship domain sizes have been made based on ship traffic data in open sea areas (Hansen et al., 2013; van Iperen, 2012, 2015) and port environments (Debnath and Chin, 2010; Rawson et al., 2014). Hsu (2014) has performed an empirical study on ship domains in overtaking situations using a ship handling simulator. Ship domains have also been used in studies on collision avoidance (Szlapczynski and Szlapczynska, 2015) and developing collision alert systems (Chin and Debnath, 2009; Goerlandt et al., 2015).

For independent navigation in ice, some methods have been proposed to determine the safe speed (ENFOTEC et al., 1996; Tunik, 2000). For convoy operations, mathematical models have been proposed to model the ship dynamics (Tsoy, 1983). However, empirical research on the operational characteristics and ship domains in convoy operations in Baltic sea ice conditions have not been performed. According to navigators and icebreaker crew, establishing such systematic knowledge would be beneficial for safety-related decision making, especially to substantiate experience-based rules of thumb (Rosenblad, 2007).

Considering the above, this paper presents an empirical analysis of ship convoy operations based on data of the Automatic Information System (AIS) and sea ice hindcast data. In particular, the ship domain concept is investigated in ice escort and convoy operations. Insight is sought especially about the distance between vessels in convoys and the convoy transit speed. The influence of ice conditions on these convoy characteristics is investigated.

The remainder of this paper is organized as follows. Section 2 presents the data applied in this study. In Section 3, the method of data processing and analysis is outlined, with results shown in Section 4. A discussion is given in Section 5, whereas Section 6 concludes.

2. Data

2.1. Maritime traffic data

The 2002 IMO SOLAS Agreement included a mandate that required most vessels over 300GT on international voyages to fit a Class A type AIS transceiver. The data transmitted by this Automatic Identification System is commonly known as AIS data. As an information exchange platform between vessels and shore organizations, AIS contains, amongst other, time-dependent data about the location, speed, course and navigational status of vessels. While AIS data quality has been mediocre in its early implementation years (Graveson, 2004), the quality has improved significantly in recent years (Felski and Jaskolski, 2013; Felski et al., 2015), and further improvements are possible with proper antenna installation (Last et al., 2015).

The original purpose of AIS was solely collision avoidance but many other applications have since developed. In the scientific literature, following uses have been identified: ship surveillance, tracking and security (Cairns, 2005; Ou and Zhu, 2008), collision avoidance and decision support (Mazaheri et al., 2012; Mou et al., 2010), discovery of traffic patterns (Meng et al., 2014; Pallotta et al., 2013; Silveira et al., 2013; Xiao et al., 2015), traffic simulation (Miyake et al., 2015; Rong et al., 2015), ship routing development (Chen et al., 2015), near miss detection (van Iperen, 2015; Zhang et al., 2015), risk analysis (Goerlandt and Montewka, 2015; Mulyadi et al., 2014; Qu et al., 2011; Wang et al., 2014), emission estimation (De Meyer et al., 2008; Jalkanen et al., 2014), impact on marine ecology of shipping traffic (Merchant et al., 2012), accident investigation (Mazaheri et al., 2014; Wang et al., 2013), maritime spatial planning (Shelmerdine, 2015) and ship performance estimation (Montewka et al., 2015; Mou et al., 2013).

For the present study, data from the period 19 February 2011 to 18 March 2011 has been used, with data fields as shown in Table 1. The selected period corresponds to severe winter conditions in the studied area. Since the main interest is in the convoy operations, which are carried out by icebreakers, the traffic data is organized per assisting icebreaker. Relevant icebreakers were identified using ice charts (SMHI, 2015). Charts of ice patterns and icebreaker locations were viewed for the considered time period and a list of Finnish icebreakers present in the Gulf of Finland was compiled. These icebreakers are listed in Table 2 with their main characteristics.

2.2. Sea ice data

The ice data was obtained from the hindcasts performed with the HELMI multicategory sea-ice model. The model is described in detail in Haapala et al. (2005) and Mårtensson et al. (2012). Therefore, only fundamentals relevant to the scope of this paper, are provided in this section.

For the purpose of analyzing escort and convoy operations, the following ice related parameters are retrieved from HELMI model: level ice concentration, level ice thickness, ridged ice concentration, ridged ice thickness, rafted ice concentration, rafted ice thickness, direction of ice compression, ice compression magnitude, ice drift velocity, direction of wind, wind speed, air temperature and sea water temperature.

Table 1
AIS data fields available for the presented model.

Data field	Unit	Explanation
MMSI number	–	A 9-digit code uniquely identifying a vessel
Time stamp	s	Time at which the message is recorded [YYYY]-[MM]-[DD] [hh]:[mm]:[ss]
Position		Longitude and latitude of transmitted message, in WGS-84 coordinate system
Ship type	–	A 2-digit code identifying the type of vessel, see USCG (2012)
Ship length and width	m	Dimensions from bow to stern and side to side, see USCG (2012)
Ship speed	kn	Speed over ground
Ship course	°	Course over ground, relative to true north
Ship heading	°	Direction in which the ship is pointing, relative to true north