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Normalization of maritime accident data using AIS

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ABSTRACT

The Automatic Identification System (AIS), fitted on most ships today, is primarily used for real time ship monitoring. This paper illustrates how stored AIS data can be used to construct activity data that can be used to normalize accident statistics, to turn recorded numbers of accidents into accident rates. We show, by way of some examples, the potential in using AIS to construct different types of activity data, and discuss the advantage of combining measures based on different activity data when monitoring accident trends or trying to identify accident prone types of vessels. The analysis and discussion are based on a combination of the Norwegian database of maritime accidents and 6 years of recorded AIS data.

The paper addresses methodological issues regarding the construction and use of these activity measures, demonstrates how they can provide new knowledge both for researchers and authorities and outlines some directions for further research.

1. Introduction

Consider a case where a maritime regulator observes an increased number of groundings of a certain category of ships in their national waters. This increase can for example be caused by deteriorating safety standards on this ship type, or it may just be caused by the fact that there are more of these ships sailing in their national waters, or that the ships that are there are more active. The absolute number of accidents provides the regulator incomplete information and directed regulatory measures will be hard find. By using traffic data to normalize accident numbers, thus constructing accident rates, provides opportunities for a more nuanced understanding of risk than when employing only not-normalized accident statistics. However, reliable data that reflect activity have historically been scarce within shipping (see e.g. Ref. [1]).

As the Automatic Identification System (AIS) tracks ships and their movement, stored AIS data can be a useful resource for normalizing accident statistics. Normalization, in this context, essentially means combining the number of accidents with the activity levels (see e.g. Refs. [2–5]). It will be demonstrated in this paper how AIS can be used to construct measures for activity that are useful for normalization of accident numbers. When accident statistics are normalized the output is commonly denoted as *accident rates* (or causality rates) (see e.g. Refs. [6,7]). Such rates can again be used by different stakeholders in order to monitor accident trends or identify accident prone vessel categories or geographical areas, use it as input to quantitative risk analyses and develop and risk indicators (cf. [8]).

The motivation for this paper comes from our prolonged collaboration with Norwegian maritime authorities. The Norwegian Maritime Authority (NMA) has over the years developed a detailed database of ship accidents in Norwegian waters. As this only contains accidents, and does not have records of activity beyond that, the NMA encounter problems when using it to monitor the maritime risk level, and also for developing risk based regulative strategies (cf. [9]). AIS-based normalization may contribute to improving and expanding the knowledge base to these ends.

Every ship accident is unique with specific and complex causal chains (see e.g. [10,11]). The methods developed here are not intended for detailed studies of individual events. Rather, it is an exploration of ways of including AIS-based measures of activity in the statistical treatment of ship risk, primarily for regulatory purposes. As the theory section will show, such measures are more common in other sectors such as road and air transport.

AIS data have primarily been used for real-time traffic monitoring and collision avoidance and has rarely been aggregated and combined with accident statistics on a national level. The vast amount of data generated by AIS provides some new and possibly better alternatives in terms of analyzing and understanding maritime risk. Many of these opportunities are currently being explored in an emergent literature, some of which will be discussed in section 2.1. AIS data has been employed in

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different ways in studies of maritime accidents [3–5, 11–19]. Several of these and other applications of AIS have potential to improve the knowledge base both for operators and regulators to better manage ship safety. There is, to our knowledge, few publications that specifically address and discuss the use of activity data obtained from AIS for normalization. By way of some examples, various ways of using activity data to construct accident rates and how they may be interpreted and made useful from a regulatory perspective will be discussed. Importantly, there are also methodological pitfalls both in the construction and application of such normalized measures, that need to be discussed.

Due to space restrictions we will limit our exploration to two types of ship accidents: groundings and allisions (unwanted contact with immobile structures).[2] Further, the focus is on two main vessel categories – cargo and passenger vessels.

The problems to be investigated are:

- How can AIS data be used to normalize accident statistics?
- How can different measures of activity be used individually and collectively to broaden the basis for policy and risk based regulation?

Additionally, drawing on experiences from our analyses, some methodological advice on how to use AIS based activity data for normalization is outlined.

As this paper discusses attempts to utilize AIS for normalization purposes, the contribution is mainly a conceptual demonstration and methodological contribution. Hence, it includes discussion of some of the problems encountered and errors made in this first attempt. The latter is important as a cautionary note for further research. The opportunities provided by big data may be dazzling, promising the “end of theory”[3] and a more (big) data driven science, but the cases illustrate that the application of these data sets needs to be done with a keen eye of the practicalities and governance of maritime operations. AIS provides a vast array of possibilities to construct activity measures. Choosing those most suited for the purpose one is pursuing, rather than the most convenient one for statistical purposes, will be crucial.

2. Background and theory

This section first discusses how AIS data have been employed for the purposes of risk research and management in the maritime industry, before focusing on the issue of normalization, assessing the state of the art of normalization of accident data in the maritime industry and comparing it with other transport sectors.

2.1. AIS data as an emerging resource for research and management of maritime risk

AIS data is an information resource for different marine users [21], used for e.g. traffic forecasting, navigation safety assessment, empirical research, planning of infrastructure and policy making (see e.g. Ref. [20]). A comprehensive literature review of application areas of AIS has been conducted by Fournier et al. [22]. Based on 204 articles, they divide between 4 main areas of application that have been addressed. These areas are denoted as 1) maritime environment topics, 2) marine safety, 3) security, and 4) Technical issues (including e.g. technical equipment, data computing and data quality). In their literature review of the use of AIS within the domain of maritime safety, Lensu and Goerlandt [14] distinguish between articles focusing on operational use of AIS (maritime surveillance), responses (to prevent accidents and consequences), policy decision support, and fishery management. According to them, the earliest publications were exclusively about operational use. More recently, policy-oriented use has gained more attention.

AIS is an important tool supporting real time traffic surveillance, conducted by traffic controller of fairways and sea areas [23]. In addition to the visual representations of ship movements, and information regarding ship identity, position, track, speed, cargo also etc., models have been developed to identify hazardous behavior among individual ships (see e.g. [23–25]).

Judging by the number of publications, the use of AIS data as a basis and input into risk models, especially related to collision and groundings, has been the main area of research (see e.g. [17, 26–35]). According to Altan and Otay [36], based on their literature review, there are two factors that are widely used in the risk models. This is *obstacles on the rout* of the vessels and the *failure of maneuvering* (due to e.g. loss of maneuver control, human errors, weather conditions, mechanical failure etc.). Models for simulating traffic patterns and associated risk has been developed by e.g. [37–39].

AIS is has turned out to be an important tool in accident investigation due to the improve the information regarding contributing causes (see [40]). Explorative analysis of conditions associated with navigation accidents, based on aggregated information from several ship, has been conducted by several researchers (e.g. Refs. [4,5,11–19,41]). Some of these explorative studies have been conducted to support risk modelling. This also includes use of AIS data to obtain data to calculate different types of accident frequencies relative to the traffic volume, e.g. number of ship entries into sea areas [4] and sailed distance [18].

2.2. Normalization of absolute numbers and the selection of appropriate activity data

The literature on the use of aggregated activity data within the area of risk and safety studies is relatively scarce. Most is concerned with how to apply activity data to construct measures of risk (e.g. Lost Time Injuries, Fatal Accident Risk, etc.), describing the technical procedures rather than discussing the relevance or validity of the data. The selection of activity measures has predominately been determined by the *availability* of data, more so than their appropriateness (cf. [59,42]).

Normalization here refers to the adjustment of values measured in order to make them appropriate for comparisons. It is a way of controlling for specified conditions that are assumed to have an impact on the absolute numbers. When comparing numbers of accidents, it is reasonable to assume that the activity level is among those factors that influence the absolute numbers, and by controlling for activity, it is possible to identify differences that can be attributed to other factors. Based on the assumption that the selected activity is associated with accidents, activity is often referred to as *exposure*.[4] In order to normalize, it is necessary to have some sort of data that quantify the activity level. Technically, normalization implies a calculation of *accident rates* by using a simple equation where the absolute number of accidents is the numerator, and the activity data the denominator.

Activity data can be obtained from different sources. In some cases, there are “ready-made” activity data based on formalized reporting systems. The availability of databases containing directly reported activity data varies across industries. Especially within aviation, international standardized reporting systems for activity data have been

[2] AIS has great potential for monitoring risk of collisions, and real time surveillance of it. The methods will, however, be somewhat different than those discussed in this paper, e.g. using AIS to identify areas where traffic is dense (e.g. [36]). Normalization of work-related personal accidents (i.e. occupational accidents) is not included in the analysis, as the traffic data normally do not yield a good estimate of exposure during on board activities such as maintenance.

[3] See Ref. [90] for a discussion of this notion.

[4] For example, it is reasonable to assume that working hours is a good measure of exposure to work related accidents, or that distance travelled in a car is a good measure of the exposure to the risk of a car crash.

implemented (see section 2.3). A more common approach is to obtain activity data indirectly. In these cases, activity is constructed by the transformation of other types of available data, such as e.g. calculation of vehicle mileage by combining records regarding fuel consumption and expected consumption per mile [43]. The use of AIS data also represents an indirect approach, as data indented for real-time traffic monitoring are aggregated and repurposed for statistical purposes. However, in contrast to the aforementioned methods, AIS data directly represents the navigational behavior of each single vessel (see section 3.1).

The possible practical applications of activity data and accident rates are many. Hauer [44] see activity data as a mean to control for traffic volume in order to compare different locations, seeking to identify the most accident-prone. Related areas of application are to compare numbers of accidents associated with different categories of vessels, or specific characteristics of the vessels such as register state, classification society, shipping company, type of activity, vessel design. Controlling for activity level is also relevant when comparing numbers of accidents over time in order to determine trends in the safety level and if other factors may have influenced the accident rate across the specified time periods.

Other areas of application are quantitative risk analysis and risk modelling (See e.g. Refs. [45,46] for reviews of maritime risk models). For such investigations, activity data and accident rates are used to estimate the *probability* of a certain type of accident (see e.g. Ref. [47]), which combined with consequence measures constitute the notion of risk (see e.g. Ref. [58] for a comprehensive discussion of the concept of risk). Based on historical observations of absolute accident numbers combined with exposure of the related activity, relative accident frequencies are calculated and used as a probability measure. In risk modelling, accident frequencies are also used in the validation and/or calibration of the models.

As an extension of quantitative risk analysis it is also possible to use activity data and normalized accident rates as *lagging risk indicators*. The concept of a *risk indicator* represents measurable variables that correlate with risk, appropriate to use as a representation of (future) risk (e.g. Refs. [11,48–54]).

When quantifying risk based on accident statistics, the orientation has typically been on obtaining activity data that quantify situations (such as time, number of situations, distance sailed) in which there is a probability that a certain type of accident may occur (see Ref. [42]). This is reflected in the use of the term "exposure" to denote the activity data. Exposure then, is a quantitative measure of the activity during which an accident may occur [47], viz. situations where one is exposed to hazard. From a risk perspective exposure can statistically be seen as the number of stochastic "trials" and the number accidents as one of several possible outcomes. Thus, quantification of exposure and accidents, may be used to calculate the probability of an accident.

Within this paradigm, finding the most appropriate or "correct" exposure measures - related to a certain type of accident - is therefore important (see e.g. Ref. [47]). The premise for a perfect exposure measure is that the number of accidents is proportional with the exposure measure. If the exposure doubles the accident number doubles [55,47]. However, using historical data to estimate risk (i.e. conceptualized as a combination of the probability of future non-wanted events and the belonging consequences) when studying complex systems that may be considerably transformed over time, is rather problematic. It is questionable that one can assume that each measurement is a representation a stochastic "trial" which again can be used to estimate a true underlying probability.

In the literature, some correlations have been identified between e.g. traffic millage (road traffic) and accidents [43], but there are also studies indicating that there is not necessarily a linear relationship between exposure and number of accident accidents. Persaud and Musci [56] have shown that there could be certain factors that determine the relationship between the assumed exposure data and the numbers of accident, and that the calculated frequencies therefore could be misleading.

Bjelland [55] has conducted series of regression analyses between activity data and major accidents from Norwegian oil and gas industry, aviation, and road transportation, in order to explore their relationship. The study is conducted with reference to the context of probabilistic risk analysis and the assumption of a positive linear relationship. He includes a regression model with a negative relationship between events and number of offshore installations, and he concludes that there is no basis for asserting that there exists a positive linear relation between events and activity level. The analysis of the data from aviation and road transportation support the same conclusion. However, the data from the oil and gas industry shows that there has been a yearly decrease in number of accidents and an increase in the activity level measure. From an empirical perspective, conceiving activity data as a mean of normalization, the findings of Bjelland [55] could simply be interpreted as a decrease in accidents over a certain time period of time when controlling for activity. The assumption about a relationship between the number of historical and the number of future accidents has also been question been questioned by e.g. Rae [57] and Aven [58].

The difference between using activity data to estimate probabilities, and to identify accident-prone subjects by controlling for the activity, may be illustrated by using road transportation as a case. If one wants to use historical data for calculating a probability of an accident, it might be insufficient to use vehicle-kilometers travelled because the speed for different transport modes or types of drivers (e.g. age groups) will influence the probability [59]. In contrast, when the ambition is to compare and eventually rank accident-prone subjects, speed in this case becomes more a question of several potential explanations for the observed differences.

Using activity data to normalize numbers of accidents presupposes that the analysts employ their knowledge regarding the qualitative characteristics of the activity and the accidents they scrutinize. For instance, in commercial fixed wing aviation, the majority of the accident have typically occurred during take-off and landing [60,61]. Due to this, it is reasonable to claim that numbers take-off and landings is a more appropriate exposure measure when monitoring aviation accidents, compared to the other measures.

2.3. Activity data used within different transport industries

Table 1 gives an overview of the most common activity measures used within different transport industries. As the table shows, it has not been common to use sailed distance and time in operation within the shipping industry.

Data that reflect the activity level and the exposure to certain hazards have historically been difficult to obtain within shipping, compared to other transport industries. The lack of appropriate data, at least until the introduction of AIS, partly explains why no international standard has been developed for how to normalize accident data within the maritime sector. Despite the limited access to data that indicate activity level, researchers have tried to normalize maritime accident data by use of the scarce available sources. For instance, length (kilometres) of coastline in the defined areas has been used as activity measure (see e.g. Refs. [1,75]). It could be argued that coastline length could serve in some extent as an appropriate measure of activity when comparing geographic regions, but it is obviously inappropriate if the ambitions is to compare e.g. time periods, types of vessels, shipping companies, flag states etc.

The number of vessels is also used as an activity measure. In Great Britain, the Marine Accident Investigation Branch (MAIB) of the Department for Transportation has normalized fishing vessel accident data by dividing the total number of accidents by number of registered vessels [71]. In Norway, the Norwegian Maritime Authority (2016) has normalized the absolute numbers of ship accidents involving Norwegian vessels, by using number of vessels in Norwegian register as activity measure. However, this activity data is limited to Norwegian vessels, excluding all foreign vessels operating in Norwegian waters.

Within the scientific maritime accident research literature, numbers of vessels have also been used as activity measures to compare different

Table 1
Common activity data measures used within different transport industries.

	Shipping	Railway	Aviation	Road traffic
Activity frequency	- Numbers of port calls [3-5]	–	- Number of flights - Numbers of departures - Numbers of landings [61-63]	–
Time spent on activity	- Numbers of vessel days [64]	–	- Flight time (hours) [63]	–
Distance	- Nautical miles sailed [65]	- Train distance - Car distance [66-68]	- Flight distance - Flight distance per passenger [1,60,63]	- Vehicle mileage/km [43,47,59,69,70]
Number of subjects	- Number of vessels [2,18,65,71-73]	–	–	- Number of vehicles - Numbers of licensed drivers [59,74]
Extent of infrastructure	- Km coast line in a defined area [1,75]	- Km of railroad tracks in a defined area [1,8]	–	–

types of vessels (e.g. Refs. [2,18,73] and register states (e.g. Ref. [76]). A different example of normalization is the work of Kujala et al. [3]. They have estimated yearly number of accidents in Finnish territorial waters in proportion to port arrivals. Sormunen et al. [4] have also used number of port calls as activity data to normalize collision and grounding accidents, and numbers of ship crossings into the Gulf of Finland. Jin et al. [64] have been able to calculate yearly accident rates of fishing vessels operating in different geographical areas in North American waters by combining data regarding vessel activity from the Commercial Fisheries Database system and accident data from the Coast Guard. They have chosen to normalize the accident data by dividing the yearly number of accidents by vessel days.

The remainder of this paper will discuss different activity measures for comparison of accident rates (over time and between ship categories) in the context of shipping and some of their pros and cons for different purposes.

3. Methods and data

This section provides an overview of how different types of activity data has been obtained and constructed by the use of AIS messages, and how these measures have been used to normalize absolute numbers of accidents.

3.1. Constructing the activity data

The AIS is a radio transmitter placed on all ships over 300 gross tonnes, and several smaller ships. In 2000, the International Maritime Organization implemented a requirement for AIS, effective from 2004 [77]. The AIS reports the position of the ship, some data about the specific voyage (e.g. destination, cargo, estimated time of arrival) and an array of static data about the ship.[5] These standardized messages are received by other ships and land based stations (as well as a few satellites) at short intervals (seconds to minutes). The primary usage of AIS is collision avoidance and real-time tracking of ships. Anyone with a computer, a smart phone or a dedicated device can view them real-time. Vessel Traffic Centrals (VTS) and other ships use AIS to monitor traffic. The data is also stored in databases, in Norway managed by the Coastal Administration.

The AIS transmitters send both dynamic position messages and static messages (see e.g. Refs. [78,25]). The intervals between the different position messages vary with between 2 s and 3 min. The ship static messages are transmitted every 6 min. Since ship's static message includes information regarding the identity of the vessel by reporting the MMSI numbers, and the IMO number, it can then be used to harvest further information from international databases. Both the information about the ship's identity, and the position data have been used to construct the following activity data discussed in this paper: (1) Sailed distance (nautical miles), (2) Hours of operations, (3) Number of vessels and (4) Number of port calls.

Sailed distance (nautical miles) is obtained by measuring, for each unique vessel visible in AIS, the cumulative distances between each vessel position given in the AIS position reports. The data is then aggregated into the preferable ship categories and divided by defined geographical areas[6]. The short time intervals between each position report makes it fair to assume that the calculated distances are reasonably accurate. High speed and/or many bearing changes may, however, compromise this accuracy somewhat. As the tracks are linear interpolations between data points it is not unusual that some AIS tracks cross land in coastal areas, for example if a fast-moving boat turns a cape between two position registrations.

Hours of operations is constructed by summing, for each unique vessel identity, the hours that the AIS have been transmitting signals within a defined period of time. These data can then be aggregated into the preferable ship categories. This method is based on the assumption that an active AIS indicates that the vessel is in operation. The validity of this assumption may be questioned, due to an uncertainty whether the activation of AIS always reflects activity on board.

Number of vessels is constructed by counting the number of unique vessel identities transmitted by static AIS messages (IMO number, MMSI number) within a defined area (in our case vessels within the Norwegian baseline). Note that this number counts every vessel that has been in this area for the given year.

Number of port calls is calculated by an algorithm based on an assumption that every period of immobility of an individual vessel that lasts for more than a certain period within the Norwegian baseline and implies that the vessel is visiting a harbor [79]. The defined minimum time period that define a port call varies between different vessels types, due to differences in operations[7] (e.g. port time for ferries and HSC lasts only a few minutes, whereas e.g. tankers normally need more time). Based on the algorithm using the position reports, periods of relative immobility are reported as port calls. These are then automatically

[5] This includes: MMSI number and IMO number, name of the ship, type of ship, dimensions (length and width), draft, port of origin.

[6] The defined geographical area was Norwegian continental shelf and the Norwegian exclusive economic zone. This area was further divided into activities outside and inside the Norwegian baseline, as well as activities within different fjords. The activity data used in this present paper includes all activity within the Norwegian baseline.

[7] Due to the fact that data reduction is avoided, the parameters regarding speed and time may be modified.

checked for proximity against a list of coordinates of ISPS harbors.[8] Visits at ISPS harbors and visits at unknown harbors are counted for each individual vessel. The accuracy of the calls at unknown harbors is considered to be lower, especially for some ship categories such as e.g. fishing vessels. "Inactivity" among fishing boats may also reflect fishing operations. Furthermore, independent of vessel type, one may also assume that a grounding will be counted as a port call. However, we have validated the method manually, inspecting whether reported port calls are reasonable. And for the ship categories discussed here, the vast majority of counted port calls seem legitimate.

Common for all these four constructed activity data measures is that the quality can be compromised by 1) insufficient AIS coverage in some areas, 2) vessels without AIS transmitters, and 3) vessels with AIS that are sailing without transmitting.

While these weaknesses might be problematic while studying one single ship, they are insignificant when looking at larger data sets. The AIS coverage in Norwegian waters is generally good, and for the ship categories we have studied having an AIS installed and operational is legally required.

Our method of aggregation of data was flexible, preserving all data for individual ships (no data reduction), so that we could continuously refine categories and also develop new ones depending on the issue to be studied. This implies e.g. that ship taxonomies, defined geographical areas of activity, time criteria for assumed port call could be changed without the necessity of "re-obtaining" the AIS data. See Kleiven [79] for a technical note describing this process.

3.2. Obtaining accident data

The accident data is obtained from the MNA accident database [9], limited to Norwegian waters during the time period 2010–2015. The database contains all reported marine accidents involving all vessels sailing under Norwegian flag, and all foreign vessels operating in Norwegian waters. The marine accidents registered in the data base are categorized into 13 different accident types. In our project, we studied the following 5 major accident types; (1) collisions, (2) groundings, (3) fire and explosions, (4) allision and (5) capsizing.

In addition to information regarding type of accident, each event in the database contains information that can be divided into the following themes; vessel identity (vessel name, IMO number, MMSI number, call sign, shipping company, classification society and flag state), vessel description (type of vessel, gross tonnage, hull material, length, with, year of construction, etc.), geographical information (coordinates of the accident, port of departure, arrival port, type of water), accident description (data, time, damage on vessel), operational description (number of people on board, number of crew members, type of cargo, speed of vessel etc.), and weather conditions (visibility, wind directions, wave heights etc.).

All of these different types of information may be used to create categories that can be compared with regard to differences in accident rates. In this project the data was prepared especially for comparisons between *types of vessels, classification societies, flag states, age of the vessels, defined geographical areas along the Norwegian coast, seasons, months* and *years.*

The vessel taxonomy used in the official database (types of vessels) does not refer to any international standard. The taxonomy is complete (ensured by the use of several "other vessels" categories), and the categories are mutually exclusive, but there are apparently no consistent, unique classificatory principles in use. The latter conditions may be explained as a consequence of a pragmatic inclusion of new vessel categories during the years, when the present ones were considered as insufficient. This implies that the ship categories constitute a nomenclature, rather than a taxonomy (see e.g. Ref. [80] for an outline of classification principles). Because of these weaknesses – a new vessel taxonomy was developed as a part of the NSRM project, referred to as the NSRM taxonomy (Fig. 1, see Ref. [9] for details). We developed a three-level taxonomy using the activity of the vessels as the classificatory principle.[9] This was done by an adaptation of NMA taxonomy and the international StatCode5 ship coding system. A translation matrix was developed between these 3 different taxonomies. The use of StatCode 5 ship coding system was not considered as a viable option due to some rather questionable and non-documented structures in the hierarchy of subordinate categories.[10] However, due to the translation matrix and our method that ensured the preservation of raw data from each individual ship, it was possible to apply any of these 3 vessel taxonomies.

Repurposing AIS data (primarily intended for real-time surveillance) and accident data (primarily intended for national regulatory monitoring) into combined statistics introduces a need for harmonization of categories. The work of developing harmonized taxonomies to combine databases should not be underestimated when using big data for risk management (see Ref. [9]). As in the case with the NMA accident database, categories are the results of historical choices done for specific purposes. Categories are also influenced by politics: For example, in Norway it is highly relevant for regulators to develop separate categories that operate for the oil industry and the aquaculture industry, as these sectors sail under additional regulatory regimes, while this might be less important in other countries [9].

3.3. Combining activity data and accident data

The potential of combining AIS data with other data sources has been addressed by e.g. Tsou [21]. In the area of risk and safety research. Similar combination of AIS data with other dataset has been conducted by e.g. Lensu, & Goerlandt [14].

The key to the process of combining the accident data and the activity data is the IMO number and the MMSI number. This is information that are common both in the AIS data (static AIS report) and in the accident reports. The IMO and MMSI numbers obtained from the AIS data, are matched with the database of IHS Fairplay which gives us information about the vessel type according to the StatCode 5 taxonomy. The StatCode 5 categories are then translated into the categories used in both the NSRM and the NMA taxonomies, by the use of the translation matrix.

In addition, IHS Fairplay provides information that is also in the MNA accident database, such as *classification societies, flag states, gross tonnage* and *year of construction.* In order to distinguish between activities within different geographical regions, the information regarding the coordinates of the AIS position reports are matched with predefined geographical areas [9].

The information obtained from AIS and IHS Fairplay are used to constitute categories used for aggregating activity data from each individual ship in the total population of vessels in Norwegian waters. This aggregation is done without data reduction. This means that our combined data set, categorized for combining AIS-data with accident data, always contains the original categorizations of the ships and the full data sets about its sailing patterns and full records about the accidents. This makes it possible to alter existing or construct new aggregated categories used for comparison if this is deemed necessary later on.

[8] Ports covered by the IMO regulation of international port security called the "International Ship and Port Facility Security Code". This means all harbors allowed for international traffic.

[9] For example, a supply boat working for the petroleum industry will be categorized on the three levels as cargo vessels, offshore vessels, supply vessels.

[10] E.g. it was seen as incorrect for our purpose to consider a "well boat", an important category of cargo ships serving the aquaculture industry in Norway, to belong to the high-level category of "fishing vessels". These vessels do not conduct any fishing activities. They transport living fish for the aquaculture industry and, though they have fish on board, they have more in common with cargo ships in terms of activity patterns.

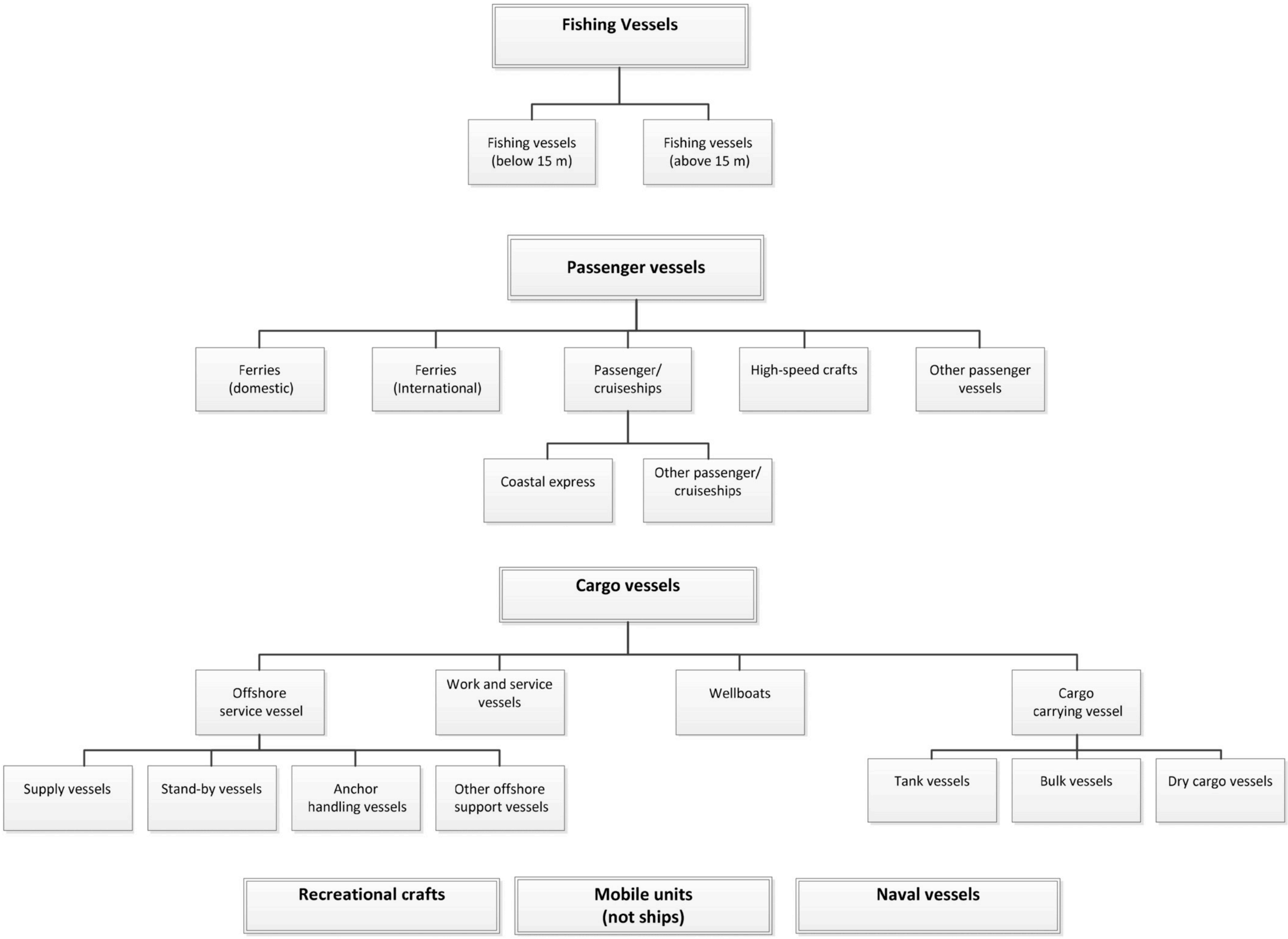

Fig. 1. NSRM vessel taxonomy.

Each accident registered in the NMA database is aggregated into the same ship categories as the activity data by the use of matching information and categories in the database, and the translation matrix between the 3 different vessel taxonomies. An overview of the combination of databases is given in Fig. 2.

As described in section 2.2, the calculation of accident rates associated with the different categories is rather straight forward, using the number of accidents as a numerator, and the activity data as denominator.

4. Results

In the following analyses, some rather simple examples are chosen, with high level categories of ships, and the most frequent types of accidents. This is done in order to focus here on the methodological and theoretical discussions primarily, to show the potential in these combinations of data, and how they can be interpreted and not primarily the calculated accident rates.

Two applications of normalization are discussed: how normalized data can contribute to monitoring of the development of the number of accidents over time and how normalized data can be used to make comparisons between ship types in terms accident rates.

4.1. Selected cases

To demonstrate the utility of AIS for normalization and implications of choices of different activity measures, a limited set of cases listed in Table 2 are pursued. The table includes a description of the reasons for the case selection.

4.2. Trending

4.2.1. Trending: groundings among cargo ships

Trends using absolute numbers (blue) and normalized results are shown in Fig. 3.

Fig. 3a)–d) displays the absolute numbers of groundings and the normalized frequencies by use of a) number of ships, b) hours in operation, c) nautical miles sailed, and d) number of port calls as denominator, each year in a six-year period. The numbers are for the total number of Norwegian (NOR[11]) ships in the cargo category. These curves illustrate how different forms of normalization affects the trend curve.

The general trends look quite similar when we compare the different normalized frequencies based on different measures of activity. Furthermore, the shape of trend lines of the different normalized frequencies is also quite similar to the trend of the absolute numbers.

One explanation for the similarities in shape between the non-normalized and the normalized curves is that there are only relatively small, slowly occurring changes in fleet composition, sailing distances etc., and consequently that the number of accidents dominates the equation from year to year. When monitoring the development over time, especially on aggregated categories like this, normalization does not lead to dramatic change in the overall trends.

There has been a decrease in the different normalized frequencies if

[11] NOR is the ordinary ship register of Norway, whereas NIS is an open register (with Norwegian flag), counted here as an international category.

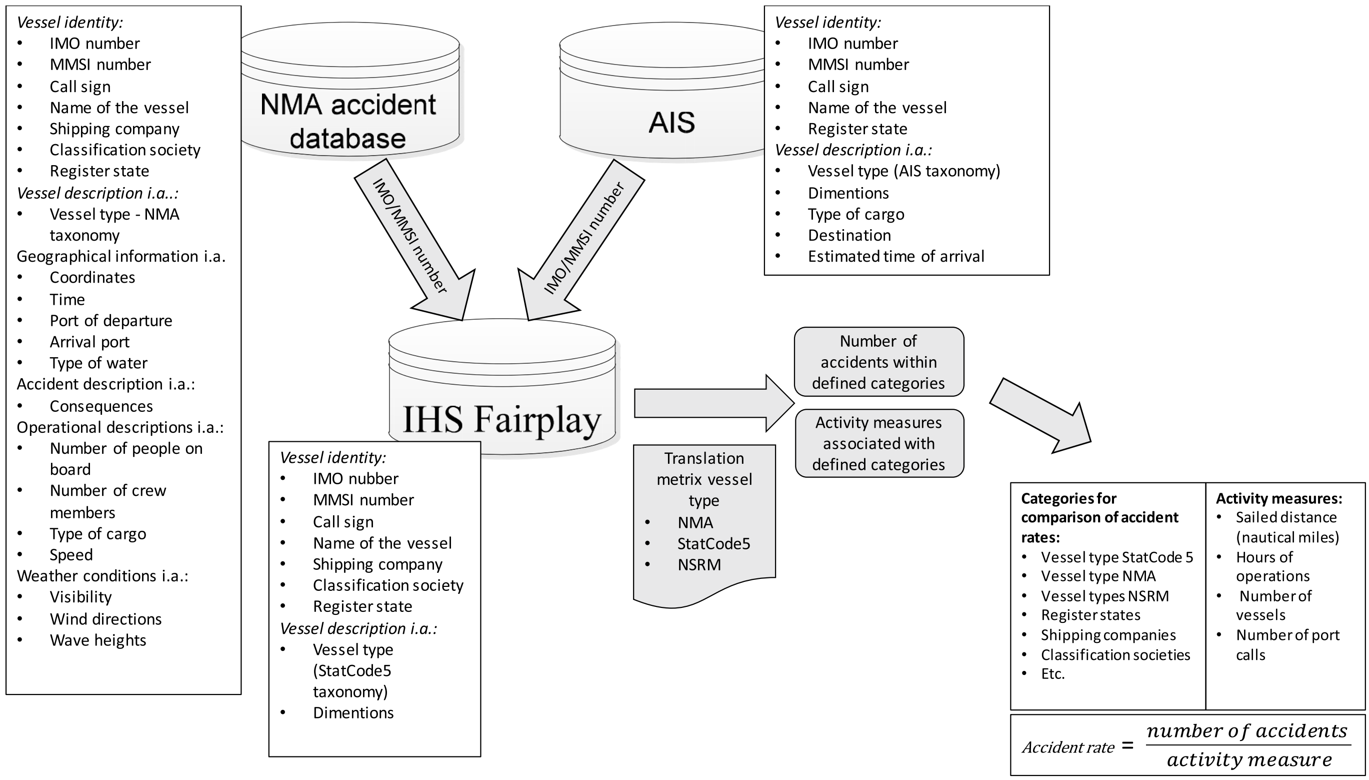

Fig. 2. Illustration of the combination of databases.

we compare 2010 with 2015, whereas the absolute number has had minor, insignificant, increase. When using the normalized frequencies to monitor grounding accidents, it is reasonable to interpret the results – in this specific example – as a reflection of a safety improvement, whereas when observing the absolute numbers, not controlling for activity, one would assume that such an improvement has not occurred during the period.

4.2.2. Groundings among passenger ships

Quite similar trends are also observed when comparing absolute numbers and different normalized frequencies using groundings among passenger ships as an example, Fig. 4a)–d). Still, the trends for this category show some differences that could be subject to further investigation. Most notably, the trend in curve d) is flat for the last three years while there is an increase in absolute numbers, suggesting that there is an association between port calls and groundings that could need further inspection. While the absolute numbers show a significant increase between 2013 and 2015 (27%), groundings per mill nautical miles, groundings per port call and per million hours in operations have decreased (respectively 1%, 26% and 28%). Groundings per 1000 ships has increased with 1%. These results imply that the number of port calls and hours in operations have increased considerably, compared to the numbers of groundings during this time period. Nautical miles sailed and number of vessels have increased at approximately the same magnitude as the increase in groundings. When trends for normalized results differ from the trend in absolute numbers (as with number of port calls and hours in operation here) this suggests, a fact one should be aware of, that the correlation is not always stable.

Table 2
Cases used in the present analysis.

Case	Motivation
1. Trending: Grounding, cargo ships. Number of groundings normalized against several measures of activity: Number of ships (in AIS database), Number of port calls. Sailed distance. Hours of operations. The trends for a 6 year period are studied.	Grounding is the most common incident and cargo ships the category with most ships. As such the n is high even for single years. We discuss how different forms of normalization affect the trends for the most common ship and incident category. The relevance for monitoring these incidents is also high since they are of the most common incidents.
2. Trending: Grounding for Passenger ships. Number of ships (in AIS database), Number of port calls. Sailed distance. Hours of operations	Here we expand the monitoring of case 1 with including another ship type.
3. Comparison: Norwegian vs Flags of convenience. -Number of ships -Sailed distance Comparison of 6 year aggregates	As above. Differently flagged ships have different working conditions and are regulated differently. A common concern in the public debate is that ships flying flags of convenience may have higher risk levels. We discuss how normalization of incident data can help us investigate that. This comparison is elaborated with discussions of patterns of activity and of reporting practices.
4. Comparison: Ferries and High-speed crafts. Allision Comparison of 6 year aggregates. All normalization factors.	These ship types have similar regulatory regimes and framework conditions. Their activity is also quite similar. This case is selected to illustrate how the comparison between ship classes are sensitive to which normalization factor is chosen (see Fig. 2).

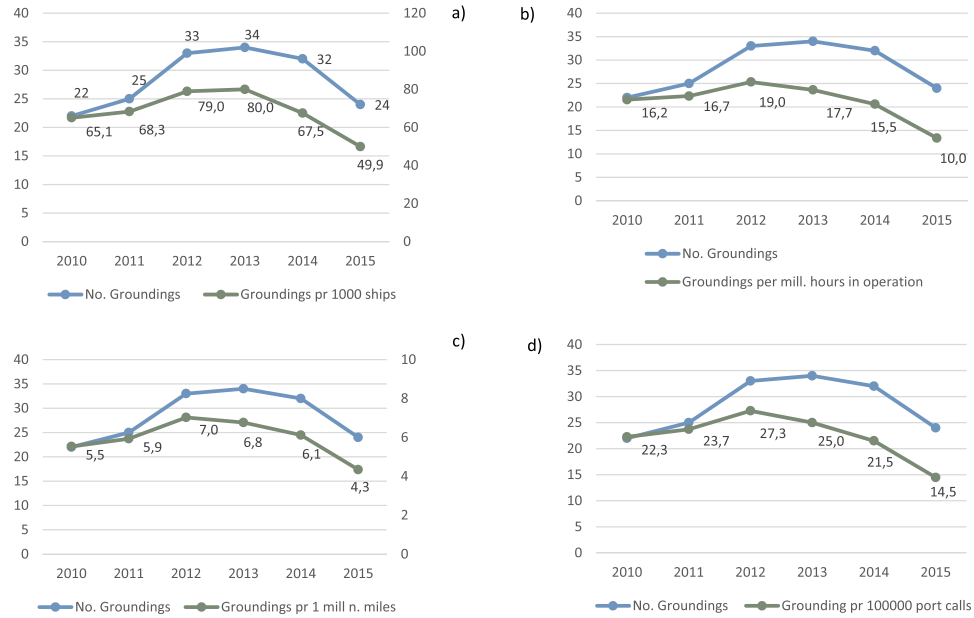

Fig. 3. Groundings for Norwegian cargo ships normalized against different measures of activity: a) per 1000 ships, b) per mill hours in operation c) per 1 mill nautical miles sailed, d) per 100.000 port calls.

4.3. Comparison

In the following section different ship types are compared using different measures of activity. While it appears that different measures applied to the same vessel category, as done above, do not yield dramatic differences in the sense that the overall trends are largely quite similar, this is not the case when using different normalization factors for comparing different ship types. Instead of trends, 6 year averages (2010–2015) are used here.

4.3.1. Comparing groundings among cargo ships and passenger ships

Fig. 5 is a comparison of a 6 years average for normalizations by the use of different activity data. The absolute number of groundings are approximately the same. The cargo vessels have considerably more groundings per port call and almost twice as many groundings per sailed distance. However, when using number of vessels and hours of operation as denominator, passenger ships have a higher grounding frequency.

Again, the results illustrate the importance of the choice of activity data when monitoring accident statistics. While using absolute numbers might have given a regulator concerns about the navigation skills in the passenger ship category, other normalized frequencies would draw more attention to cargo ships.

In the theory section we noted that there has, historically, been a tendency to pragmatically use the activity data that are readily available for normalization. The results here illustrate the potential pitfalls in such a strategy. Choosing one normalization measure will skew the results

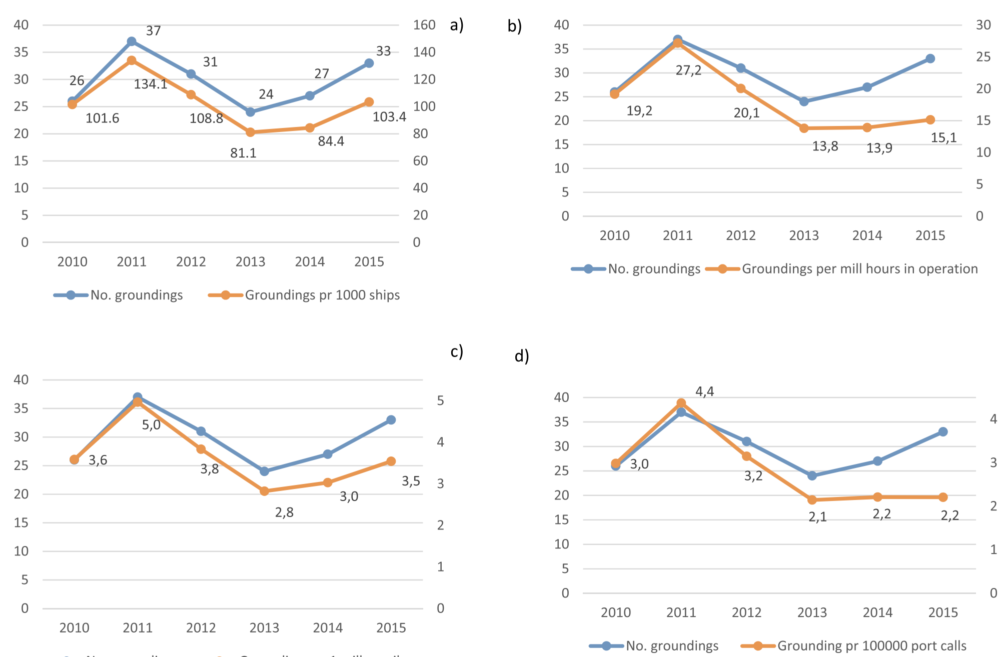

Fig. 4. Groundings for Norwegian passenger ships normalized against different measures of activity: a) per 1000 ships, b) per mill hours in operation c) per 1 mill nautical miles sailed, d) per 100.000 port calls.

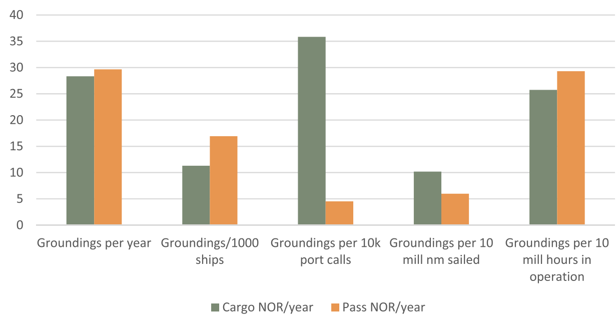

Fig. 5. Comparison of groundings for NOR registered cargo ships and passenger ships using 6 year averages.

when comparing categories of ships that have different activity patterns.

4.3.2. Comparing grounding among Norwegian and foreign ships

From the perspective of maritime authorities, the comparison of accident rates among ships belonging to different flag states is often regarded as important in terms of monitoring and regulating the vessel activities. The issue of flag and accident risk has also been a recurrent theme in the research literature (see e.g. Refs. [76,81–85]) and in public debate. Our example is a comparison of groundings among Norwegian and foreign vessels.

When looking at the aggregated number of accidents from 2010 through 2015 (Fig. 6), NOR vessels have more than twice as many groundings per year as foreign vessels in Norwegian waters. When normalized by sailed distance, the grounding frequency for Norwegian cargo vessels is twice the frequency of foreign vessels. By using hours in operation and number of port calls as denominator, the differences between the two groups becomes considerably less. The differences in the magnitude of the frequencies when using different normalization factors could partly be explained by differences in the fleet composition between Norwegian and foreign ships, as well as their activity pattern.

If we normalize these accident numbers by using number of ships, the grounding frequency for NOR ships is more than 15 times higher than the equivalent number for foreign ships. This has a technical explanation that requires some further elaboration before we go on to discuss the other factors. This large difference is at least partly explained by the fact that there are many more unique foreign vessels visiting Norwegian waters, than there are NOR ships operating along the coast. Most NOR ships operate all year along the coast while many foreign ships only pass through or enter Norwegian waters for a short visit. Our algorithm for constructing number of ships, counting all unique IDs registered by the AIS each year, skews this comparison as it generates an artificially high number of foreign ships. It will count the activity contribution of a foreign ship visiting for one day on equal terms with a NOR ship operating every day for a full year in Norwegian waters. To correct this, we recommend that the number of ships is calculated in other ways for these purposes. A new algorithm will be proposed in section 5.3.1.

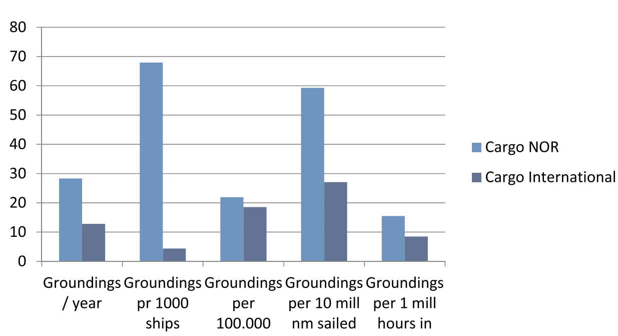

Fig. 6. Comparison of averages of accident rates for NOR and foreign cargo ships from 2010 to 2015 in Norwegian waters. Note that numbers for grounding per 1000 ships are based on an error that will be discussed further.

The grounding frequency is approximately twice as high for NOR ship when sailed distance is used in order to calculate a frequency. The difference is lower when hours of operations are used. This may reflect that the Norwegian vessels in average holds a higher speed when they are in operation (operations hours include time at ports). When using number of port calls as denominator, the relative difference in grounding frequency is even lower. This may reflect that the foreign vessels in average have longer sea passages than Norwegian vessels. Based on this comparison of the different types of normalized frequencies, the number of ships, as calculated by our algorithm, is clearly not an appropriate activity measure when comparing vessels categories that move in and out of our selected geographical area of analysis.

Still in our example, independent of which exposure data in use, foreign vessels seem to be less accident-prone when we evaluate grounding frequencies. An obvious interpretation is that foreign vessels are less prone to groundings than Norwegian vessels. However, the observed difference may also be attributed to other conditions. The frequencies are for example not controlled for differences in the fleet composition, in the sense that the high level category of cargo ships for Norwegian and foreign vessels contains quite different types of more specified vessel types accompanied by different operational patterns.[12]

Differences in reporting practices and regulatory control may also be a factor. The NOR ships sail in the waters controlled by their own regulators whereas the internationally flagged ships, according to international law, are subject to their own flag state regulators, meaning that these ships are subject to different regulatory and inspectorial regimes (see e.g. Refs. [81,86]). Thus the observed differences in the grounding frequencies between these categories may be attributed to different degrees of underreporting among respectively Norwegian and foreign vessels. Underreporting accidents is in general a rather widespread phenomenon within shipping [11,87,88] and it is reasonable to assume that foreign vessels have less incentives to report accident to Norwegian authorities, compared to Norwegian ships, that are more closely monitored by their regulators. As long as an accident occurs in areas without traffic surveillance (e.g. VTS centres[13]), and it is not necessary to call for external assistance to handle the situation, the information about the occurrence is entirely dependent on reports from the vessels. Traces from accidents may be detected during e.g. port state controls (e.g. damages on hull), but these inspections (for each individual foreign vessel) occur seldomly, at best every 5th month. Further, there are several vessels conducting innocent passages through Norwegian waters, from Russia to Europe.

To investigate potential underreporting as a source of this difference, we supplemented our analysis with an investigation of the relative frequencies for accidents of different severities. For all groundings, the frequency of foreign and NIS vessels combined are 54% lower than the frequency for NOR vessels. If we only use those grounding accidents rated with high consequences in the accident database, i.e.

[12] The high-level vessel category of "cargo vessels" consist of various types of vessels, including e.g. dry cargo carriers, container ships, bulk carriers, tankers, coasters, offshore support vessels and small work support vessels. It is reasonable to assume that the Norwegian and the foreign fleet has a different composition and, due to this, a different activity pattern. Also, it is reasonable to assume e.g. that foreign ships would have a relatively higher proportion of vessels involved in deep sea international traffic, compared to the Norwegian cargo fleet. Norwegian vessels categorized as of cargo vessels includes e.g. relatively more offshore supply vessels, fish farming support vessels and other smaller work vessels. Foreign vessels are dominated by tankers, bulk, container and dry cargo vessels.

[13] There are relatively large sea areas in Norway without surveillance from Vessel Traffic Service centres. There is e.g. no surveillance between the Lofoten island and the fjords close to Bergen. This represents a distance of about 500 nautical miles.

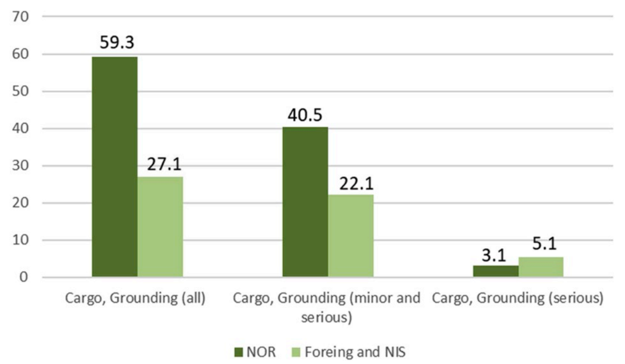

Fig. 7. Grounding per 10 mill nm sailed divided by severity of the groundings.

accidents that are serious enough that Norwegian authorities have been involved (e.g. rescue operations) the relative difference between NOR and foreign and NIS vessels declines. In the case of minor and serious groundings, the frequency of NOR vessels are 45% higher than foreign and NIS vessels. If only serious groundings are taken into account, foreign and NIS vessels have a frequency that are 40% higher.

Fig. 7 shows different normalized grounding frequencies for Norwegian and foreign cargo vessels with all groundings, only groundings with serious and minor consequences[14] and only groundings with serious consequences are used as nominator (and sailed distance as denominator).

It shows that the grounding frequency is lower for foreign ships than for Norwegian ships when using all groundings as nominator and serious and minor consequences, but becomes lower when only the most serious ones are counted. Although this could imply that grounding accidents among foreign vessels are relatively more often associated with serious damages, compared with grounded NOR vessels, a more plausible interpretation - with reference to the research on underreporting [87,88] - is that foreign ships have a higher degree of underreporting to the (Norwegian) costal state authorities, than NOR ships sailing in their own home waters, when confronted with less serious groundings.

The results illustrate that one should be careful to compare ship types with different activity patterns and different incentives to report incidents. This example shows how differences in the fleet composition and/or the activity pattern, as well as reporting practices, between vessels belonging to different categories may influence, respectively, the normalization factors and the reported number of accidents. This underlines the necessity of a thorough assessment of the comparability between the different categories compared. One solution is to strive for more specific and comparable categories (with regard to the type of vessel and activity). However, a more fine-grained categorization will result in a smaller number of accidents (nominator), which could contribute to compromise the validity of the comparison.

4.3.3. Comparing allision among ferries and high-speed passenger vessels

The results in the previous section illustrate that one should be careful to compare ship types with radically different activity patterns and different incentives to report incidents. In this section we have chosen to compare two vessel types whose activities are more and who sail under quite similar regulatory regimes (and thus would be expected to have roughly the same reporting practices). Both ferries and high-speed passenger vessels report relatively many allisions, mainly “contact damages” on the vessel or the ferry dock.

When we compare the average number of allisions from 2010 until 2015, ferries have more than 5 times as many as HSCs (see Fig. 8). When using hours in operations as activity data, the relative difference is smaller, and the allision rate becomes almost twice as high for ferries compared to high speed passenger vessels. When sailed distance is used as the activity measure, the relative difference becomes higher. These differences between normalizations with different activity measures is probably caused by the fact that we are comparing slow moving ferries with high-speed crafts covering longer distances. When we use the number of port calls, the allision rates almost equalize.

When we know that the hazards associated with these accidents predominately are associated with port calls, it is rather obvious that the number of port calls is the most adequate activity data. When used to calculate allision rates, this gives us information that alter the image we had when just inspecting the non-normalized numbers of allisions within these two vessel categories, or when using other normalization factors.

5. Discussion

Monitoring of changes in accident rates and identifying accident prone subjects is vital for decisions regarding allocation of scarce preventive resources. This holds for the maritime industry, for other transport industries and policy makers and regulators. Historical accident data is an important source of information to this end, and these statistics are also prominent in official reports. To make such data comparable over time and between categories of ships, some form of normalization is needed. Records of previous accidents must be turned into rates. We have demonstrated an approach for harvesting activity data from the AIS system that can be used for normalization purposes, and where several different normalization factors can be chosen.

AIS data makes it possible to gather information about vessels and traffic that is not easily obtained by other sources. This is especially relevant when monitoring the operation of vessels in international waters or within the territorial waters of another state, and when vessels are not making a port call and are not obliged to report their activity to the state authorities (e.g. in the case of innocent passage). As noted by Almklov and Lamvik ([81]:181) international ships sail under a “veil of obscurity” seen from the stance of coast state authorities. Systematic use of AIS data is one of the ways through which more knowledge about their activities and the risk they pose can be understood.

This paper has demonstrated the potential but also some of the pitfalls when utilizing AIS data. Normalization is a task that cannot be left to algorithms or experts in statistics. It is necessary to include maritime expertise in the process, as each evaluation must be done with a keen eye on the operational conditions in the maritime sector, and to what purpose one wants to use the statistics. It might be tempting to, for example, use sailed distance as a standard normalizing factor for all categories of maritime transport. Intuitively this will be a good benchmark for the industry as a whole.

However, this choice will skew attention towards certain categories (those sailing short distances along in coastal waters for example) as risk objects, while others (sailing longer stretches off the coast) will receive less attention. In the theory section we discussed the tendency in earlier research to work with what you got, to use the activity data that are at hand with little explicit reflection on the relationship the activity measure and accident type. With the manifold of opportunities provided by AIS in terms of normalization, such choices can now be made more purposefully.

5.1. Discussion of the normalization factors

Four different normalizations factors based on AIS data, number of ships, hours in operations, nautical miles sailed and number of port calls, have been employed in this discussion. These were used to analyze trends and compare different categories of ships. In some instances, when monitoring trends, the different normalization factors give quite different results in terms of the magnitude of the change in the frequencies, while the results are strikingly similar across different activity measures in other cases. Such differences can be attributed to the

[14] Serious consequences are groundings causing severe damage on the vessel (e.g. hull, propulsion), environmental spills, severe damage on properties of external parties, and/or injuries among the crew members. Minor consequences are groundings causing minor damages on the vessels, without reducing the integrity of the hull or the propulsion.

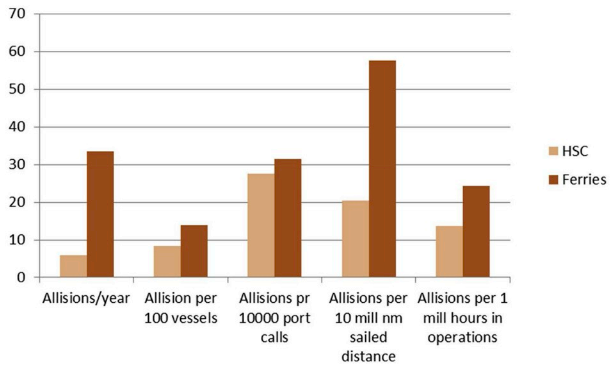

Fig. 8. Allision rates compared for high-speed crafts and ferries.

relationships between the accidents and different forms of activity, to what degree they represent exposure. This underscores two important points: The users of accident rates should have a good understanding of maritime activities, so that they can make sound evaluations of whether measures of activity represent exposure. Secondly, this understanding should also be employed when finding the normalization factor that best represents the activity one wants to control for when normalizing.

When *comparing* between different categories of vessels it is important to evaluate the comparability of the categories. Our analysis shows how differences in the fleet composition and/or operational patterns can influence the normalization factors (denominators) and by this the validity of the comparison. The opportunity to interpret different forms of normalization in combination not only helps choosing the one that is most "fair" for comparison, but also holds potential for a deeper investigation of which activities that are associated with the specific accident type. This is for example seen in our comparison of cargo and passenger ships, where differences between normalization by sailed distance and port calls indicates that there are differences in terms of operational patterns that skews the comparison.

There are some general issues of validity to be consider. For example, the metric "hours of operation" has some potential weaknesses as a measure for activity, as AIS transmitters might be turned off or signals may be lost even if there is activity going on. There are also some validity issues related to the number of port calls, as some false port calls may be produced by the algorithm (see section 3.1). Still, as constructs, they have a strong face validity.

Moreover, differences in reporting practices between the categories that are compared may contribute compromise the raw accident data and hence the comparability of the calculated frequencies.

5.2. What can AIS–based normalization be used for?

As addressed in section 2.2, the combination accident data and activity data may have different areas of applications. First, it is used to control for a defined activity when monitoring trends over time. This is done determine to what degree a trend in accident numbers represents change in the safety level or if it is caused by changes in exposure. Secondly, it is used to control for a defined activity when comparing numbers of accidents associated with different categories of vessels, or specific characteristics of the vessels (such as register state, classification society, shipping company, type of activity, vessel design etc.). This is primarily done to identify accident-prone subjects, geographical locations or specific characteristics of the vessels. Thirdly, activity data and accident frequencies are used to estimate probabilities of *future* accidents and applied in estimation of risk. In this paper the attention has been directed towards the first two applications.

It is part of the maritime authorities' mandate to seek to understand causes for changes in absolute number of accidents. For them, monitoring normalized numbers such as groundings per sailed distance, will be more adequate than raw numbers, and it will also allow for more "fair" comparisons between ship categories if appropriate measures of activity are chosen.[15] Both for authorities and researchers different forms of normalization will be suitable based on the question one seeks answer to.

In our examples, trends seen in the normalized longitudinal monitoring versus the development in actual numbers have been relatively similar as the changes in the denominator are small from year to year when the fleet is relatively stable. However, in some examples the normalized accident frequencies show a different trend compared to the absolute numbers. These differences illustrate that the conclusions drawn from monitoring absolute numbers and different normalized frequencies respectively may lead to quite different conclusions.

However, though this paper illustrates the potential in using AIS for normalization, our examples also illustrate pitfalls that must be considered when applying them:

1) By applying activity measures that do not match the exposure. For example, sailed distance, which is arguably is a good measure for many purposes, is a poor measure for the exposure to allision which is better covered by port calls.
2) By using common activity measures that skews the comparison between vessel types with different operational patterns.

Also, normalized measures, though potentially more precise than raw numbers, may be harder to interpret, as they require some understanding of how the measures of activity are developed. While no normalization factor is perfect, the opportunity to choose from several possible factors, and even using them in combination, is an improvement from the current situation. Having access to different activity data for normalizing the same phenomenon has a potential in terms of triangulation that may strengthen the validity of the interpretations of the frequencies. If different activity data gives frequencies that shows somewhat similar trends, it is reasonable to say that they support common conclusions. Cases of discrepancy, however, call for a more thorough interpretation process, and may be highly informative in themselves. More measures of activity to choose from expands the toolkit for interpretation, but also requires competence to understand their weaknesses.

5.3. Recommendations for further research and development

It is possible to develop algorithms that are better indicators of activity than those used for this paper. It is also possible to identify activity data related to different types of vessel operations (e.g. fishing, anchor handling, cable laying etc.), and types of sea passage (e.g. innocent passages, freight areas) based on the movement pattern of different vessels (see e.g. Refs [89,12]). This will help to secure activity data that is more closely associated with certain types of hazards and accidents (cf. [47]).

This paper has focused on the combination of activity data with the Norwegian accident database. There are however also applications of the activity data themselves, beyond risk management. For example, one can easily construct measures, combining activity data *without* including accidents, such as sailed distance per port call. These can then be compared between different ship categories (thus better understanding differences in operational patterns) or monitored over time to study changes in these patterns. For example, when doing such simple calculations, we observe a 17% decrease in sailed distance per port call from 2010 to 2015 for cargo ships, suggesting that ships in average sail shorter passages in 2015. Such applications, though not the scope of this paper illustrate the potential for use of aggregated AIS data for traffic analysis.

This geographical area in this analysis has been fixed. A very

[15] For authorities with responsibility of e.g. emergency management, environmental damages and rescue operations, monitoring the actual numbers of accident in different areas will typically be the most important numbers to watch, since this is what they need to know to dimension their emergency response capacities.

interesting extension of this study is to compare different areas, either within the area that has been discussed here or to compare Norwegian waters to other areas or national waters. To preserve a high N, and as our paper is mainly illustrative, we have worked mainly with high level categories here. However, particularly if one employs this method for areas with more ships and more accidents, it will be highly useful to conduct more detailed analyses using sub-categories of ships - such as specific flags or ship types.

Based on the discussion in section 3, we recommend that data reduction is avoided when constructing joint databases of accident data and activity data, since explorative analyses might necessitate adjustment of categories.

5.3.1. How to count the number of ships?

The measure for number of ships requires some further attention in future research. Prior to our project the NMA's normalization factor was the number of registered ships subsumed under its inspection regime. This was a purely administrative number, only counting Norwegian ships, and not reflecting the actual fleet sailing in Norwegian waters. In our analysis using AIS for normalization we counted the number of ships that had been registered in the Norwegian AIS database, that is, all ships that have been in Norwegian waters the year in question. This also proved to be problematic, particularly in the comparison of Norwegian and foreign vessels. While the majority of NOR flagged vessels can be expected to stay in Norwegian waters for most of the time, an international vessel often visits Norwegian waters only briefly but will still be counted as one vessel for the year in question. This generates an artificially high denominator in the normalization equation where the number of accidents involving foreign ships in a year is divided by the number of foreign ships in Norwegian waters that year.

This difference between Norwegian and foreign ships can be compensated for by adjusting the algorithm generating the activity measure. It will be more appropriate to generate an average of how many ships of each category are in Norwegian waters every given day. Thus the adjusted algorithm will be:

1. Count number of international and NOR ships registered each day for an entire year.
2. For each category, summarize these and divide them with 365 to obtain a yearly average of the daily fleet composition.

Thus, one can still employ our counting algorithm, but by reducing the time interval to a day and averaging these over a year, we greatly reduce the error caused by the fact that counting the number of unique identities for a year creates an impression that there is more activity by foreign ships in Norwegian waters than there actually is.

Such problems, in hindsight one can even call them errors, illustrate some of the pitfalls when extracting big data for these purposes. There might be systematic tendencies in the activity data that will lead to errors if they are aggregated by algorithms without the necessary quality control.

6. Conclusions

AIS provides new opportunities for obtaining activity data. AIS data make it possible, as we have shown, to construct new measures of activity. These can, in turn, be used to normalize accident data into frequencies or accident rates parallel to those used in other transport industries. This paper has illustrated that such rates can be used to compare categories of ships and to monitor accident statistics over time. As our examples have shown, however, it is necessary to have a thorough understanding of ship types and their activities to select appropriate activity measures. A wider range of measures for activity on which to normalize accident data makes it possible to construct more sophisticated and fit-for-purpose accident rates. There is no “best” normalization factor for all purposes. Rather, the choice of factor depends on the questions one is seeking answers to. As such, this contribution, by exploring a wider variety of normalization factors, increases the number of questions that may be answered. Also, by means of triangulation, combined analysis of the results using different forms of normalization, it can provide an improved statistical understanding of the causes of incidents.

This paper presents our methodological approach and some examples of how AIS data can provide a stronger basis for risk monitoring and management in the maritime industries. The potential for further exploration of this is great.

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