ANALYSIS OF THE INFLUENCE OF WAVES IN THE OCCURRENCE OF ACCIDENTS IN THE PORTUGUESE COAST USING BAYESIAN BELIEF NETWORKS

WPLYW FAL NA WYSTĘPOWANIE WYPADKÓW W STREFIE BRZEGOWEJ PORTUGALII – ANALIZA Z WYKORZYSTANIEM SIECI BAYESOWSKICH

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Abstract: *Sea and weather conditions are the second most frequent cause of accidents in Portuguese waters accounting for 23% of the occurrences. However due to lack of information in the Portuguese maritime accident database it is difficult to assess what this cause consists specifically, i.e., fog, large wave heights or other events. In the present study significant wave height data was introduced in a Bayesian Belief Network (BBN) model in order to assess the correlation between their amplitude and certain accident typologies and related consequences (human injuries or fatalities). The results of different inferences of the BBN model show that through a simple modification of an accident model the influence of weather pattern can be assessed and specific risk factors can be identified.*

Keywords: *Bayesian Belief Networks, maritime accidents, significant wave height*

Streszczenie: *Stan morza i warunki atmosferyczne to druga z najczęściej występujących przyczyn wypadków na wodach terytorialnych Portugalii, odpowiedzialna za 23% zdarzeń. Ze względu na brak informacji w bazie danych o wypadkach morskich w Portugalii trudno jednak ocenić, co konkretnie stanowi o zaistnieniu wypadku: mgła, duża wysokość fal, czy też inne czynniki. W niniejszej pracy dokonano następującego zabiegu: do modelu opartego na sieci bayesowskiej (Bayesian Belief Network – BBN) wprowadzono dane o znaczącej wysokości fal, a to celem dokonania oceny korelacji między ich amplitudą, typologią wypadków określonego rodzaju, oraz wynikającymi konsekwencjami w postaci odniesionych przez ludzi obrażeń czy też wypadków śmiertelnych. Wyniki wnioskowania na bazie modelu BBN dowodzą, że dzięki prostej modyfikacji modelu wypadku można ocenić wpływ określonych warunków atmosferycznych na zaistnienie wypadku oraz zidentyfikować konkretne czynniki ryzyka.*

Słowa kluczowe: *sieci bayesowskie, wypadki morskie, znacząca wysokość fali*

1. Introduction

Accidents classified as a result of bad weather conditions are largely dependent on the accuracy of the information gathered after the occurrence, i.e., position of accident, significant wave height, existence of fog, etc., information which depends on the accident investigation procedure and subsequent data analysis. As reported in earlier studies, accidents identified *explicitly* as being related with bad weather conditions represent roughly 3% of the overall accidents (Guedes Soares *et al.*, 2001).

This low value of weather related occurrences can be related to poor or inadequate accident reporting schemes or due to the characteristics of the geographical areas where the accidents occurred. Portugal is no exception in both of these issues, i.e., the accident reporting scheme does not specify details concerning the influence of weather on the occurrences, and the Portuguese coast presents characteristics that lead to frequent occurrences due to the existence of rough seas.

These characteristics have been already identified in the work of Gouveia *et al.* (2007) where a statistical analysis of ship accidents in the Portuguese waters was performed. In that study the 857 records of the Portuguese Maritime Authority database were used to identify the main accident typologies. In it high frequency of some type of accidents as is the case of the 26 founderingings, 21 groundings or 5 collisions per year were identified. Similarly the main causes of the registered accidents were mainly material failure (25%), sea and weather (23%) and human error (18%).

Recently Bayesian Belief Networks (BBN) have been used in the maritime industry with the development of specific models to assess and identify risk factors associated to a given context (Eleye-Datubo *et al.*, 2006; Trucco *et al.*, 2006; Norrington *et al.*, 2008). In the present study a BBN model for maritime accidents developed by Antão *et al.* (2008) is used with the inclusion of wave data (significant wave heights) in order to assess the correlation between their amplitude and certain accident typologies and related consequences (human injuries or fatalities). In order to reduce the uncertainty only numerical data were used. For the real data the Portuguese Maritime Authority accident database mentioned above was used together with the HIPOCAS and NCEP/NOAA wave data were used.

2. BBN Model Including Wave Height Data

As mentioned, 23% of the causes of the accidents were *sea and weather* which is the second most frequent cause of occurrences. However, since no additional details are provided in the database, it is difficult to assess in

what consists specifically this cause, i.e., fog, high currents, large wave heights, wave steepness or other events. Earlier studies have shown that ship accidents reported as due to bad weather conditions occurred in areas also with highest expected significant wave height or highest mean wave steepness occurrence (Guedes Soares *et. al.*, 2001, Bitner-Gregersen and Guedes Soares, 2007).

In many cases accidents associated with the occurrence of bad weather conditions are also linked with situations where crews present a low risk perception or a high risk acceptance, particularly in the cases of recreation and fishing activities respectively. In the latter, these risky behaviours are a consequence of social-economical factors, as there is a continuous effort to earn higher wages, which are proportional to the amount of fish captured (Antão *et. al.*, 2008). Therefore, in this study additional data of wave height will be introduced in a BBN model in order to assess the contribution that large waves had in the occurrence of certain accident typologies.

In order to fulfil this objective HIPOCAS wave database (Pilar *et al* 2008) and the NCEP/NOAA (National Centers for Environmental Prediction/National Oceanic and Atmospheric Administration) wave data were used. The need of using two sources of data was due to the fact that HIPOCAS only covered the period until 2001, whereas the NCEP/NOAA covered the remaining period of the accident sample (i.e., 2004-2006).

The HIPOCAS was an EU project aiming at producing a 40 years hindcast of wind, wave, sea level and current climatology for European waters (Guedes Soares 2008). The predictions were made with a typical horizontal resolution of 25-km and temporal resolution of 3 hours. The wave hindcasts were validated by comparisons with wave data buoy measurements when available.

In Fig. 1 shows the HIPOCAS grid with the location of the accidents. As one may see there are three different resolutions of the grid, where the finer one located near the Portuguese coast, Azores and Canary Isles is a grid of 0,25°; a second one is a grid resolution of 0,5° and a third one, located in longitudes above W33, is a grid of 1°. However, in many cases there was a mismatch between the accident location and the grid points. The option adopted in these cases was to use the nearest grid point data. Most of the accidents are located near coastal areas, and therefore, in the higher resolution grid (the exception is Madeira), what allowed to have a good match and an adequate input.

Fig. 1 Accidents location in HIPOCAS spatial grid

In the case of the NCEP/NOAA, the data is divided in a coverage (longitude, latitude) grid between 77°S-77°N of resolution 1.25°x1° degrees. This data, also presents a temporal resolution of 3 hours and ranges from 1999 until the present date. Due to the fact that the two sources present similar grids (in the higher resolutions) and use a comparable wave prediction model, it was possible to integrate both data within the model. Given these data sources, the specific significant wave heights on the ship accidents locations were identified.

For each accident the nearest position on the grids was chosen for each of the accident locations since very rarely the real position coincided with the grid one. Also, in case of equal distances between an accident position and two grid points, the preference to the grid points which present the nearest longitude to the accident one was given. This criterion was chosen in order to avoid potential influence of shallow water on H_s values in longitudes near to the coast. Waves generated by wind (wind waves) present primarily periods of 3 to 25 sec. and are a fundamental feature of coastal regions of the world (US Army Manuals, 2003).

If one considers the range of periods mentioned and the wave length given by:

$$L = \frac{gT^2}{2\pi} \quad (1)$$

where d is the water depth, L is the wave length and T is the wave period, from the criterion for deep water ($d > L/2$) it results that deep water starts at depth more or less of 500m (if one considers the upper limit of the wave period mentioned above). In fact if the results of Fig.2 are compared with the ones located at -8.75W, 37N, which is situated near the south Portuguese coast, a average difference of 30% on the significant wave height could be found, and a maximum of 55% of difference for the month of March.

These were expected results, although in both sites there are deep water conditions but the fundamental difference is that the second location is sheltered by the European coast while the other one is far in the open ocean where stronger winds can achieve great velocities on large distances generating waves higher than the ones measured near Europe.

Additionally the height of the locally generated wind waves is increased by the superposition of the swell coming from all directions, while the site near Western Europe coast has swell coming mainly just from western and southern part of the Atlantic Ocean.

Fig. 2 Wave height distribution for the year of 2004, location in -25W, 35N

Fig. 3 Density and cumulative distribution functions for the ϵ values of H_s in all the accident locations

As mentioned before, for each of the accidents, where the location was known (N=765), the estimated value was identified. Figure 3 presents respectively the density and cumulative distribution functions for the ϵ values in the accident locations, in which one may see a positive skewness as a result of the existence of large significant wave height (above 6 meters).

Fig. 4 shows the updated version of the BBN model presented in Antão *et al.* (2008) with the addition of the wave height node. The significant wave height is highly dependent on the hour and month nodes, as a result of alterations in the wave statistics with the season.

Fig. 4 BBN model with wave height node

3. Results and discussion

Based on the model of Fig. 4 a set of inferences were performed and are presented in this chapter. Although the above model can be considered as *simple* due to the number of nodes involved it should be mentioned that the number of states involved *per node* are large, ranging from 4 states, in the *fatalities* node, up to 31 states in the *Geo Position* and *Flag* ones. As mentioned above the Conditional Probability Tables (CPT) for each node is the result of real and numerical data with no expert opinion involved. In fact due to the substantial number of combinations in each node it wouldn't be possible to use expert opinion to populate the CPT's.

Fig. 5 shows the probability of a fatality for different ship and accident types, when the main cause of the occurrence was sea and weather and with small significant wave heights ($H_s=0$ to 2 m). In these conditions *capsize* is the occurrence that can lead to higher number of fatalities with *fishing* vessels.

This result could be surprising due to the fact that the height of the waves involved are small, however it is common practice to see fishing vessels operating near coastal areas and specifically in wave breaking zones, involved in *seabass* fishing, which lead to frequent accident of this nature.

Fig. 5 Probability of fatalities | type of accident= ϵ , type of vessel= ϵ , cause = sea and weather, $H_s=0-2$ m

Also *collision* presents high probability of leading to a single fatality. In the case *recreation* vessels, high consequences are mainly related to *shipwreck* and *collision* occurrences. Commercial vessels don't present so significant variation when compared with the previous two. This can be explained by the low number of accidents ($n=44$) with these types of vessels in the period of analysis.

When a comparison is performed between the two most representative ship types in two significant wave heights conditions (Fig. 6) one may see that variations are slightly more evident. In the case of *recreation* vessels when the significant wave heights are equal to 4-6 m, there is a decrease on the probability of no fatalities due to capsizes of 9% whereas the likelihood of a single fatality increases 5%.

Fig. 6 Probability of fatalities | type of accident= ε , type of vessel= ε , cause = sea and weather, $H_s = 0-2$ m and 4-6 m

The influence of these high waves in the case of fishing vessels is not so evident with small variations on the different accident types. These results can be explained by the fact that the operation with recreation vessels is seasonal and in many cases operated by inexperienced personnel leading to low risk perception in given situations, particularly in the presence of high significant wave heights.

Fig. 7 presents the probability of a given type of accident for different months and causes, with small significant wave heights. The fact that a particular accident cause was “coded” as a human factor or material failure doesn’t imply that sea and weather didn’t play a role in the occurrence.

Significant differences can be found particularly in the periods of May – July and November – December. If the first of these periods corresponds to a time with high levels of traffic and therefore with higher probability of occurrences (groundings and capsizes) mainly as a result of *material failures* causes (much associated with recreation vessels), in the second period one may see that the causes are mainly a result of *human errors*. In

this figure one may see also the low influence of weather patterns (sea and weather cause) in the occurrence.

Fig. 7 Probability of type of accident | month= ε , type of cause= ε , $H_s = 0-2$ m

However, when one compares the probabilities for capsizes with small and large significant wave heights (Fig. 8) considerable differences can be found. Similarly to the previous figure two periods can be identified where the impact of the large significant wave heights (4-6 m) leads to a higher probability of capsizing. These periods (February-March and September-November) present probabilities 3 to 13 times higher than the ones with small significant wave heights (0-2 m).

Fig. 8 Probability of type of cause | month= ε , type of accident = capsizing, $H_s = 0-2$ m and $H_s=4-6$ m

Fig. 9 Probability of authority involved in the rescue | fatalities = injuries = disappeared=0, type of accident = ε , Geographical position=Lisbon, Hs= 0-2 m

Similar analysis was performed to identify the authority involved in the rescue in case of an occurrence in different weather conditions (Fig. 9) and (Fig. 10). Typically the authorities involved in these operations are the Portuguese Navy Vessels (NRP), Maritime Police (PM), to the National Institute to Help Castaways (ISN), Fire-fighters or simple *none*.

Fig. 10 Probability of authority involved in the rescue | fatalities = injuries = disappeared=0, type of accident = ε , Geographical position=Lisbon, Hs= 0-2 m and Hs= 4-6m, Type of vessel= Fishing

It is interesting to notice that the probability that one of these authorities was involved in a rescue decreases with the increase of the significant wave heights, with few exceptions (the role of the PM increases in *shipwreck*

accidents) and a substantial increase of *none* authorities involved. These facts can lead to the conclusion that the means at the disposal of these authorities are limited and in some cases not located in areas with higher probabilities of being needed.

4. Conclusions

In the present study the significant wave height data was introduced in a BBN accident model in order to assess the correlation between their amplitude and certain accident typologies as well as related consequences (human injuries or fatalities). Results show that large significant wave heights are linked with the occurrence of specific accident types as well as with a higher probability of their occurrence in particular times of the year. Understanding these and other mechanisms associated with large waves will allow the reduction of the risk associated with operations in these weather conditions, by optimizing the implementation of mitigation measures (both proactive and reactive).

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