Reconstruction of various navigational scenarios of the «Ever Given» ship, including grounding in the Suez Canal using the bridge simulator with up-to-date electronic navigation charts

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Abstract. The Suez Canal is the largest maritime shipping traffic thoroughfare in the world. The global cargo turnover accounts for 10-12%. The accident occurred on March 23, 2021 with the container ship "Ever Given", blocking the Suez Canal. It fully paralyzed shipping traffic in the region and caused enormous damage to the economy. Reconstruction of various navigational scenarios of the containership, including grounding based on the bridge simulator, allowed examination of navigation and developing recommendations to prevent similar accidents in the future. Within the limits of the research, the authors used electronic navigation charts S-57 with up-to-date information on the accident time, a similar model of containership and hydro-meteorologic conditions in the bridge simulator’s session. An assessment of the risk of grounding a container ship has been carried out using the method of Bayesian trust networks.

1. Introduction
The current situation in the global maritime transport business is dictated by the need to increase the size and speed of merchant vessels. At the same time, the statistics of the accident rate of the world fleet are far from the desired indicators. In this regard, the analysis of resonant accidents of large-tonnage sea vessels is now more relevant than ever.

In the article, the authors attempted to analyze the accident that occurred in the Suez Canal on March 23, 2021 using the capabilities of the NAVI-TRAINERPROFESSIONAL 5000 navigation simulator and the mathematical apparatus of Bayesian trust networks (Figure 1). The paper proposes to estimate the probability of stranding the container ship "EverGiven" according to several scenarios. The first situation concerns actual conditions corresponding to the accident. Situation 2 deals with the conditions corresponding to situation 1, but with the presence of a tow escort. Situation number 3 is referred to the conditions corresponding to situation 2, but with the presence of additional "garages" on both sides of the canal in the area of the accident.
2. Materials and methods
Due to the fact that the details of the accident on March 23, 2021 are known, it is proposed to describe the sequence of events and indicate the key factors that influenced the incident in accordance with the above scenarios. The following key factors are proposed for consideration: wind; speed; dimensions; time for making a decision; availability of tugs and "garages".

Using the method of Bayesian trust networks (BTN), in accordance with scenarios 1-3, we will build a probabilistic model of the management decision-making process before an accident and calculate the total probabilities of making correct decisions (MCD) and making incorrect decisions (MID) [1].

The experts were students of the training and retraining courses of the IPK of the Admiral F. F. Ushakov Maritime State University (captains, pilots). On average, the navigator's experience in the sea of experts was more than 10 years. The assessment (expert) was made on a scale (points) from 0 to 10.

Data for the calculation using the BTN method for scenario 1:
- wind –9 (points);
- speed – 5 (points);
- dimensions – 9 (points);
- time to make a decision – 8 (points);
- no tugs and garages – 10 (points).

| Table 1. “Ever Given” ship particulars |
|--------------------------------------|
| Name of parameter | Details         |
| IMO                  | 9811000         |
| Name                 | Ever Given      |
| Vessel type          | Container Ship  |
| Length               | 399.94 m        |
| Breadth              | 59 m            |
| Draught              | 16.0 m          |
| Main power           | 59300 kW        |

3. Results and discussion
The BTN method provides probabilistic estimates of MCD and MID and it provides a qualitative analysis of management decisions according to situation 1. This approach allows the authors to argue that the risk of stranding was too high, since the full probability of MID was unacceptably high [2]. The key factors for situation 1 were strong (squally wind). The speed of the vessel was higher than it is
allowed. The dimensions of the container ship are a large-tonnage vessel. Restrictions on the time of decision-making by boatmasters on the bridge include the ratio of the dimensions of the vessel and the characteristics of the channel. There is absence of deterrent factors, such as towing support, emergency mooring to the shore – "garage".

As a result of conducting simulation modeling on the navigation simulator “NAVI-TRAINER PROFESSIONAL 5000”, we obtained the following data, which are presented in Figures 2-11.

![Figure 2](image2.png)

**Figure 2.** Wind direction: a – true; b – relative.

![Figure 3](image3.png)

**Figure 3.** Wind speed: a – true; b – relative.
Figure 4. Wind power.

Figure 5. Roll angle.
Figure 6. Rate of turn (ROT).

Figure 7. Speed over ground (SOG).
Figure 8. Steering.

Figure 9. Engine power.
As a result of the analysis of the key factors that influenced the accident, the most significant ones were selected according to the results of expert assessments [3]. To assess the risk of this accident, we have chosen the method of Bayesian trust networks, which, in accordance with GOST R 58771-2019, is included in the list of approved ones. Thus owing to the carried out calculations, we built a BSD, which allowed us to determine the full probability of making an erroneous decision by the navigators of the “EverGiven” when following the Suez Canal (Table 2).
Table 2. Bayesian networks calculations

| Wind velocity | Ship’s speed | Ship’s dimensions | Time for decision making | The absence of tug boats and docks | Condition probability | Total probability |
|--------------|-------------|------------------|--------------------------|-----------------------------------|---------------------|------------------|
| a1, a2       | b1, b2      | c1, c2           | d1, d2                   | e1, e2                            | g1, g2              | g1, g2           |

→ yes b1

| 0.5 | 0.9 | yes c1 | 0.9 | yes c1 | 0.9 |
|-----|-----|--------|-----|--------|-----|
|     |     | yes d1 |     | no e2  | 0.01 |
|     |     | 0.8    | yes e1 | 0.99 | 0.01 |
|     |     |        | yes e1 | 0.99 | 0.3176 |
|     |     |        | no e2  | 0.01 | 0.0029 |
|     |     |        | no e2  | 0.01 | 0.0032 |

→ no c2

| 0.1 | yes c1 | 0.9 | yes c1 | 0.9 |
|-----|--------|-----|--------|-----|
|     | yes d1 | 0.9 | yes e1 | 0.99 |
|     |        | 0.5 | yes e1 | 0.99 |
|     |        | 0.5 | no e2  | 0.01 |
|     |        | 0.4 | yes e1 | 0.99 |
|     |        | 0.6 | no e2  | 0.01 |
|     |        | 0.3 | yes e1 | 0.99 |
|     |        | 0.7 | no e2  | 0.01 |

→ yes b2

| 0.5 | yes c1 | 0.9 | yes c1 | 0.9 |
|-----|--------|-----|--------|-----|
|     | yes d1 | 0.9 | yes e1 | 0.99 |
|     |        | 0.5 | yes e1 | 0.99 |
|     |        | 0.5 | no e2  | 0.01 |
|     |        | 0.4 | yes e1 | 0.99 |
|     |        | 0.6 | no e2  | 0.01 |
|     |        | 0.3 | yes e1 | 0.99 |
|     |        | 0.7 | no e2  | 0.01 |

→ no c2

| 0.1 | yes c1 | 0.9 | yes c1 | 0.9 |
|-----|--------|-----|--------|-----|
|     | yes d1 | 0.9 | yes e1 | 0.99 |
|     |        | 0.5 | yes e1 | 0.99 |
|     |        | 0.5 | no e2  | 0.01 |
|     |        | 0.4 | yes e1 | 0.99 |
|     |        | 0.6 | no e2  | 0.01 |
|     |        | 0.3 | yes e1 | 0.99 |
|     |        | 0.7 | no e2  | 0.01 |

→ yes b1

| 0.5 | no c2 | 0.1 | no c2 | 0.1 |
|-----|------|-----|------|-----|
|     | yes d1 | 0.9 | yes e1 | 0.99 |
|     |        | 0.8 | yes e1 | 0.99 |
|     |        | 0.8 | no e2  | 0.01 |
|     |        | 0.8 | yes e1 | 0.99 |
|     |        | 0.6 | no e2  | 0.01 |
|     |        | 0.3 | yes e1 | 0.99 |
|     |        | 0.7 | no e2  | 0.01 |

→ no c2

| 0.2 | yes d2 | 0.2 | yes d2 | 0.2 |
|-----|--------|-----|--------|-----|
|     | yes e1 | 0.9 | yes e1 | 0.99 |
|     |        | 0.8 | yes e1 | 0.99 |
|     |        | 0.8 | no e2  | 0.01 |
|     |        | 0.8 | yes e1 | 0.99 |
|     |        | 0.6 | no e2  | 0.01 |
|     |        | 0.3 | yes e1 | 0.99 |
|     |        | 0.7 | no e2  | 0.01 |
The total probability of MID is 0.86. Therefore, running aground was almost inevitable. The a priori probabilities obtained by direct inference using the BTN method (Table 2) and the marginal probabilities (parent probabilities) proposed by the experts correspond to the a posteriori probabilities obtained by the reverse conclusion of the BTN. The calculation of the total MID probability for scenarios 2 and 3 is performed in a similar way [4].

4. Conclusion
Thus, the total probability of MID (0.86) obtained using the BTN method for the conditions in which the navigators of "Ever Given" were confirms the objectivity of the grounding of the vessel (situation 1). Moreover, the modeling by the simulator showed the same result with the help of dynamic visualization of both the vessel's movement conditions and the MID that eventually led to an accident with severe consequences for the world economy [5].

Further studies suggest the development of recommendations for navigators to ensure safety when following a large vessel in the Suez Canal, taking into account the impact of external factors (wind, current, visibility conditions, etc.).

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