APPLICATION OF GIS AND MATHEMATICAL MODELING IN MARITIME CRISIS SITUATIONS

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Abstract

This paper aims to propose a decision support system for maritime crisis situation, due to fact that Croatia has decided to implement Directive 2002/59/EC to define places of refuge for ships in need of assistance off their coasts, or to develop techniques for providing assistance to such ships. In order to fulfill this Directive it is necessary to build an effective Decision Support System (DSS) based on GIS and mathematical modeling. The basic module of the proposed system is GIS, for all levels of DSS, that comprise information sub-systems about spatial and other data and serves the other modules with data and information. Starting points for analysis are shipping corridors, and 380 potential locations for places of refuge designated in the official navigational pilot book. Multicriteria analysis, with GIS-generated input data, has been used to establish "worthiness" of a place of refuge for each ship category, taking into account kinds of accident. Proposed mathematical models facilitate optimal usage of "available intervention resources".

Key words: *DSS, GIS, mathematical modelling, marine incidents, emergency management*

1. INTRODUCTION

When defining its future development, the Republic of Croatia has decided on a gradual approach to joining the European Union. In this respect, it has assumed a commitment to harmonize its legal system with the legislation of the European Union. As a result, it is necessary that, among other things, working procedures of the Ministry of the Sea, Tourism, Transport and Development and its respective services be harmonized with the provisions of certain directives of the European Community relating to the safety of maritime traffic. Therefore, Directive 2002/59/EC[1] is binding on all member states of the European Community to establish (and communicate to the European Community) the places of refuge for ships in need of assistance off their coasts, or to develop techniques for providing assistance to such ships. Consequently, the Ministry of the Sea, Tourism, Transport and Development (MMTPR) has initiated the procedure of harmonizing its working procedures and the respective executive organization to meet the requirements provided for in the Directive. In this context, a study has been initiated aiming to:

- examine the conditions of maritime traffic in the Adriatic, especially off its eastern coasts;
- show characteristics and assess the possibilities of action in case of maritime accidents or other emergencies or threats to the safety of ships or environment in the area within jurisdiction of the Republic of Croatia;
- develop working procedures for providing assistance to ships in distress in the area within jurisdiction of the Republic of Croatia;
- make preliminary selection of the places of refuge, in accordance with the experience and established working procedures in the European Community countries;
- create a DSS with GIS database of the relevant layers for the places of refuge.

First-year work on the project resulted in a study treating the issue of places of refuge (PoR) in a both scientific and professional manner. The study involves evaluation of natural, socio-economic and bio-ecological characteristics, maritime traffic situation and analysis of possible threats to the environment, and finally the principle of preliminary selection of places of refuge and their description. Relevant characteristics have been included in the GIS application called GIS ADRIA. An additional result achieved by this project is the drafting of the concept of a DSS for deciding on the requests for places of refuge, presented through the pilot project of three coastal counties. This concept is presented in this paper.

Two modules of DSS were conceived and built in the first stage of the project:

- GIS support with problem-oriented extensions, and over 30 thematic layers for subordinating characteristics of places of refuge;
- MCA (Multicriteria analysis) for valuation of each potential shelter according to the relevant criteria with direct interface towards GIS application.

2. BUILDING DSS FOR DEFINING THE PLACES OF REFUGE

The decision process is a generic process that can be applied on any kind of organized set of activities in order to meet objectives. Generally, there is no unique model of decision process, because it includes numerous variables, different levels of decisions (strategic, tactical, and operational), as well as different decision makers.

[1] Directive 2002/59/EC of the European Parliament and of the Council of 27 June 2002 establishing a Community vessel traffic monitoring and information system and repealing Council Directive 93/75/EEC

Generally, use of that knowledge and experience in the development of a Decision Support System (DSS) for emergency management system in case of maritime accidents logically leads to the implementation of a system that will support all decision levels (Mladineo et al., 2005). The organization of that system is generally hierarchic; at each level decisions are made in accordance with the political competences. Decision character is different at some levels and depends on the system organization; decision range at lower levels is in accordance with previously made strategic decisions. The DSS helps to structure and organize such a large quantity of information related to the emergency management system in case of maritime accidents, especially spatial data, in order to make it available to decision makers in a comprehensible and user-friendly way. A systematic approach throughout the DSS provides very simple and comprehensible integrated information regarding the technological changes and in accordance with different emergency policies and management methods.

Conceptualized DSS for tactical and operational level is divided in a number of segments (modules) that will be additionally built in the further phases. The basic module is GIS (Geographical Information System), for all levels of DSS, that comprise information sub-systems about spatial and other data and serves the other modules with data and information. The GIS module is divided into several thematic layers with basic information about places of refuges, climatological and maritime characteristics, hydrographic characteristics, ecological and biological characteristics, existing navigable waterways, maritime limits, boundaries of counties and cities, limits of territorial sea, continental shelf, military zones, topographic data, location emergency services, etc. (Mladineo, Knezic, 2005).

DSS is based on a combination of GIS analysis and a multicriteria method in order to enable effective emergency management (Jankowski 1995; Joerin, Musy, 2000; Marinoni 2005), namely it would be used to establish worthiness of a place of refuge for each ship category, taking into account different kinds of accidents. GIS is outlined as a powerful tool for the generation of aggregated information used in multicriteria analysis, as is the link between hierarchic decision levels in the proposed DSS (Bradaric et al., 2008; Grzetic et al., 2008).

3. CONCEPT OF DSS FOR PLACES OF REFUGE

Figure 1 show the conceptual scheme of DSS for the strategic level, namely DSS that support functions of Croatian’s Maritime Rescue Coordination Centre and supporting organizations of MMTPR, which are focused on support to the activities connected to:

- Segment A: planning and preparing for interventions at sea;
- Segment B: response;
- Segment C: relief and remediation planning.

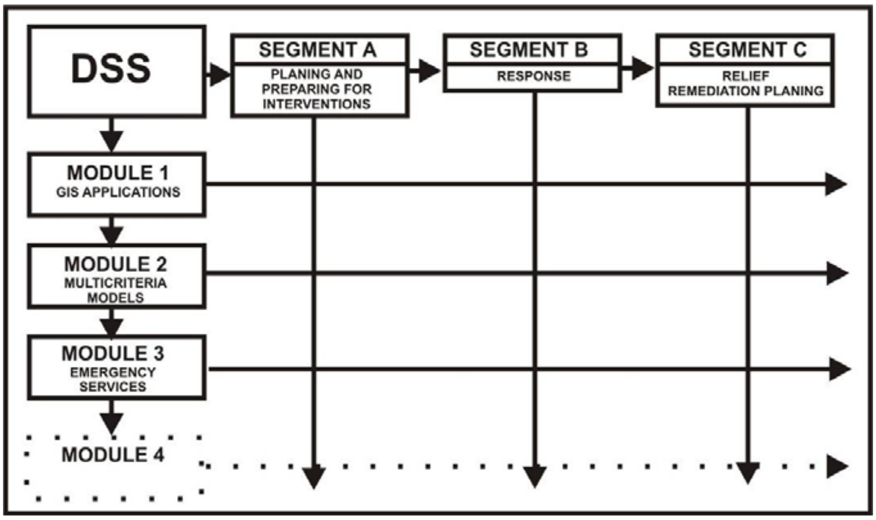

Figure 1: Basic DSS concept.

The function of Module 2 (multicriteria models) is the evaluation of the suitability of each of the 380 potential locations for places of refuge (PoR) designated in the official navigational pilot book for each category of vessel and each type of maritime accident. For the suitability valuation of each PoR, relevant criteria are defined as well as their ranges and weights that define the importance of criteria. There are a total of 14 criteria for assessing each potential place of refuge (Table 1).

Table 1: Criteria for Multicriteria Analysis

Criterion No.	**Criterion Description**	**Criterion Weight**
Cl	Swing room	9
C2	Navigational approach	8
C3	Bottom keeping	8
C4	Grounding suitability	7
C5	Booming ability	9
C6	Wind protected (preferential)	10
C7	Accessibility by road, train, and/or air	8
C8	Socio-economic acceptability	10
C9	Oil spill shoreline sensitivity	9
C10	Ecological sensitivity	10
C11	Repair facilities	6
C12	Tug response time	8
C13	Dispersants response time	8
C14	Tank barge response time	8

GIS analysis is a first step, with evaluation of relevant criteria presented as thematic layers. For criteria that cannot be spatially presented using GIS analysis, specific numerical values, as the input for multicriteria analysis, are evaluated by expert teams.

A mathematical programme of MCA adapted to the criteria values and connected to ADRIA GIS database performs selection or ranking of a certain number n of places of refuge within a pre-defined radius r around the position of a ship sending a request (Figure 2).

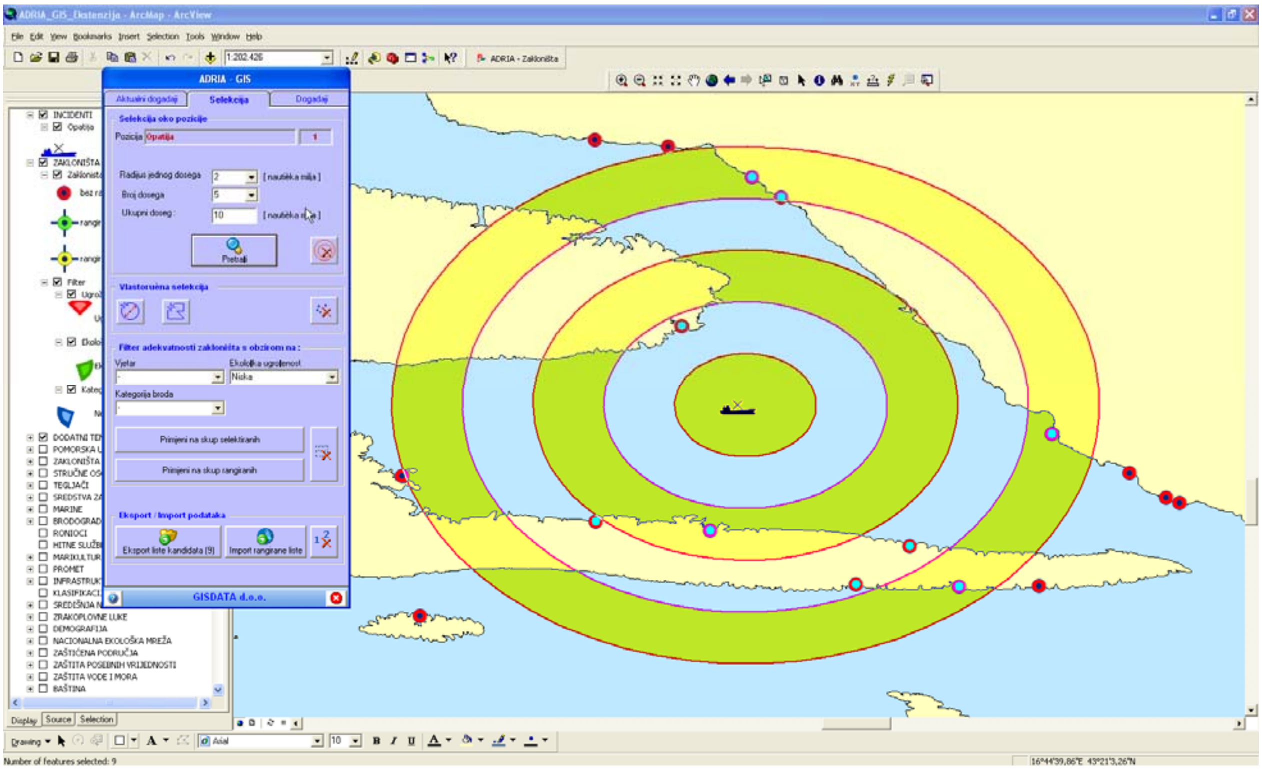

Figure 2: GIS + additional extension - Searching potential places of refuge according to defined radius.

The PROMETHEE I method ranks (Brans et al., 1984) actions (places of refuge) by a partial pre-order, with the following dominance flows:

$$\text{leaving flow}: \ \Phi^+(a) = \frac{1}{n-1}\sum_{x \in A} \pi(a, x), \qquad (1)$$

$$\text{entering flow}: \ \Phi^-(a) = \frac{1}{n-1}\sum_{x \in A} \pi(x, a). \qquad (2)$$

Where a denotes a set of actions (places of refuge), n is the number of actions and π is the aggregated preference index defined for each couple of actions. Finally, method PROMETHEE II ranks the actions by total pre-order:

$$\Phi(a) = \Phi^+(a) - \Phi^-(a) \qquad (3)$$

To facilitate and automate the process of decision making in an emergency, and consequently reduce the possibility of subjective error, the expert team develops "Scenario generator" matrix, as shown in Table 2, in which criteria weights are changed to adapt the decision-making process to the characteristics of a ship type or length, and an incident, e.g. ship damage.

Table 2: Example of "Scenario generator" matrix

SHIP CATEGORY / TYPE OF ACCIDENT	A - ship with length less than 30 m	B - ship with length between 30 and 80 m	C - passenger ship with length between 80 and 250 m	D - cargo ship with length between 80 and 200 m	E - cargo ship with length greater than 200 m	F - special ship with length greater than 250 m (LNG, Cruisers, Car-carriers, Container)
I. - drifting problems	S11	S12	S13	S14	S15	S16
II. - loss of hull strength	S21	S22	S23	S24	S25	S26
III. - stability problems	S31	S32	S33	S34	S35	S36
IV. - grounding	S41	S42	S43	S44	S45	S46
V. - collision of ships	S51	S52	S53	S54	S55	S56
VI. - fire or explosion on ship	S61	S62	S63	S64	S65	S66
VII. - other maritime accidents	S71	S72	S73	S74	S75	S76

The presented DSS, based on GIS in conjunction with multicriteria analysis, is found to be a powerful tool for spatial decision-making, because there is no such a tool (software) on the market (Figure 3).

Finally, Figure 4 shows calculated rank of potential places of refuge using MCA. The conceptualized DSS is divided in a number of segments (modules). One of the segments is 3D GIS used to simulate ship entering chosen place of refuge.

While developing the DSS it has been important to think about introduction of dynamic aspects of the system, such as wind which is very important during maritime accidents because it influences emergency management actions. DSS also supports a dynamic approach. For example, it is possible to input data about present wind and eliminate places of refuge which are exposed to the wind.

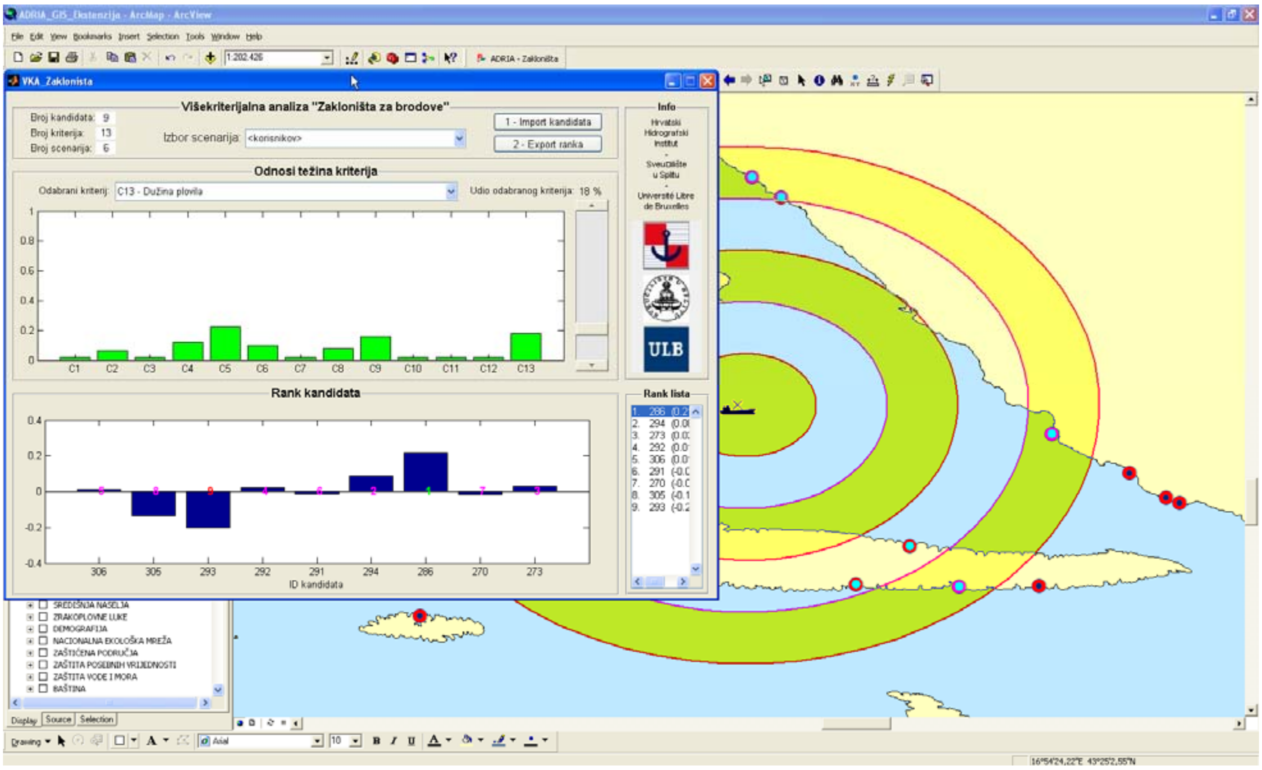

Figure 3: *MCA Software Support - Display of specific MCA scenario on selected PoR according to characteristics of incident (oil spill, fire, etc.).*

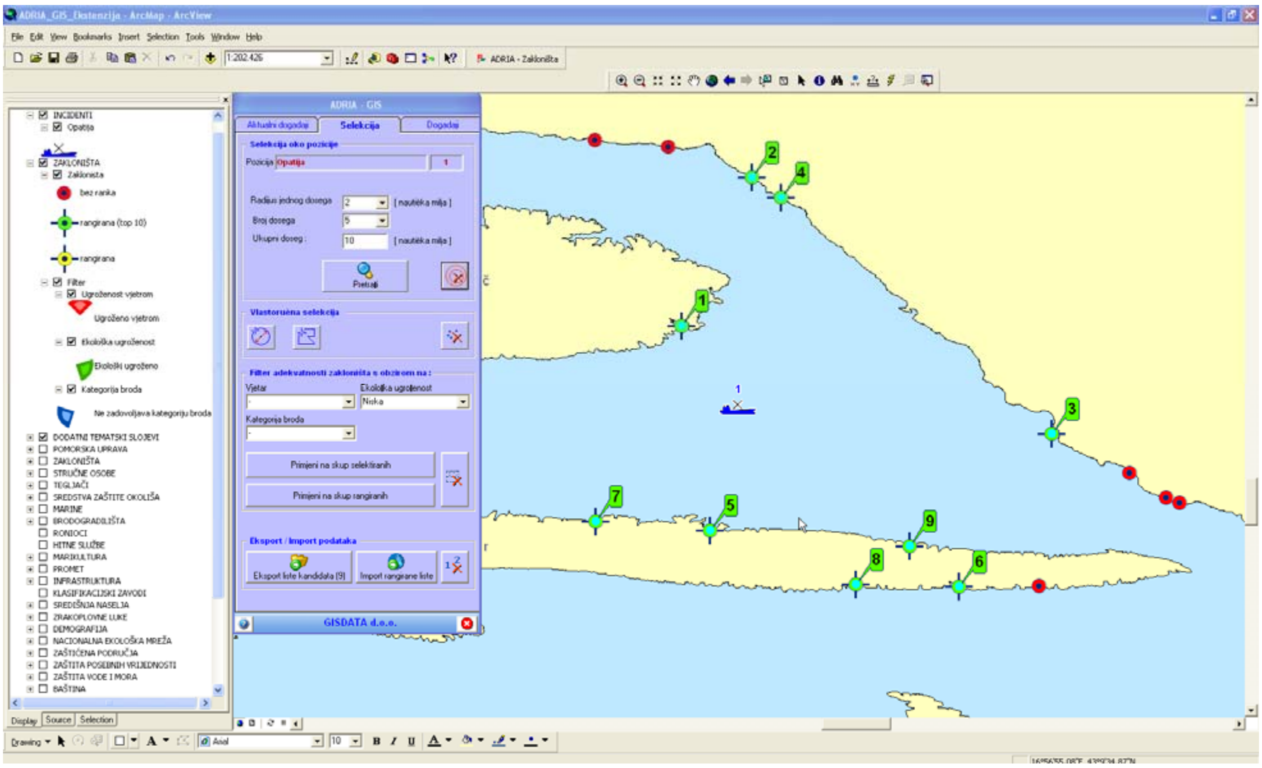

Figure 4: *GIS + additional extension: Display of calculated rank of potential places of refuge using MCA.*

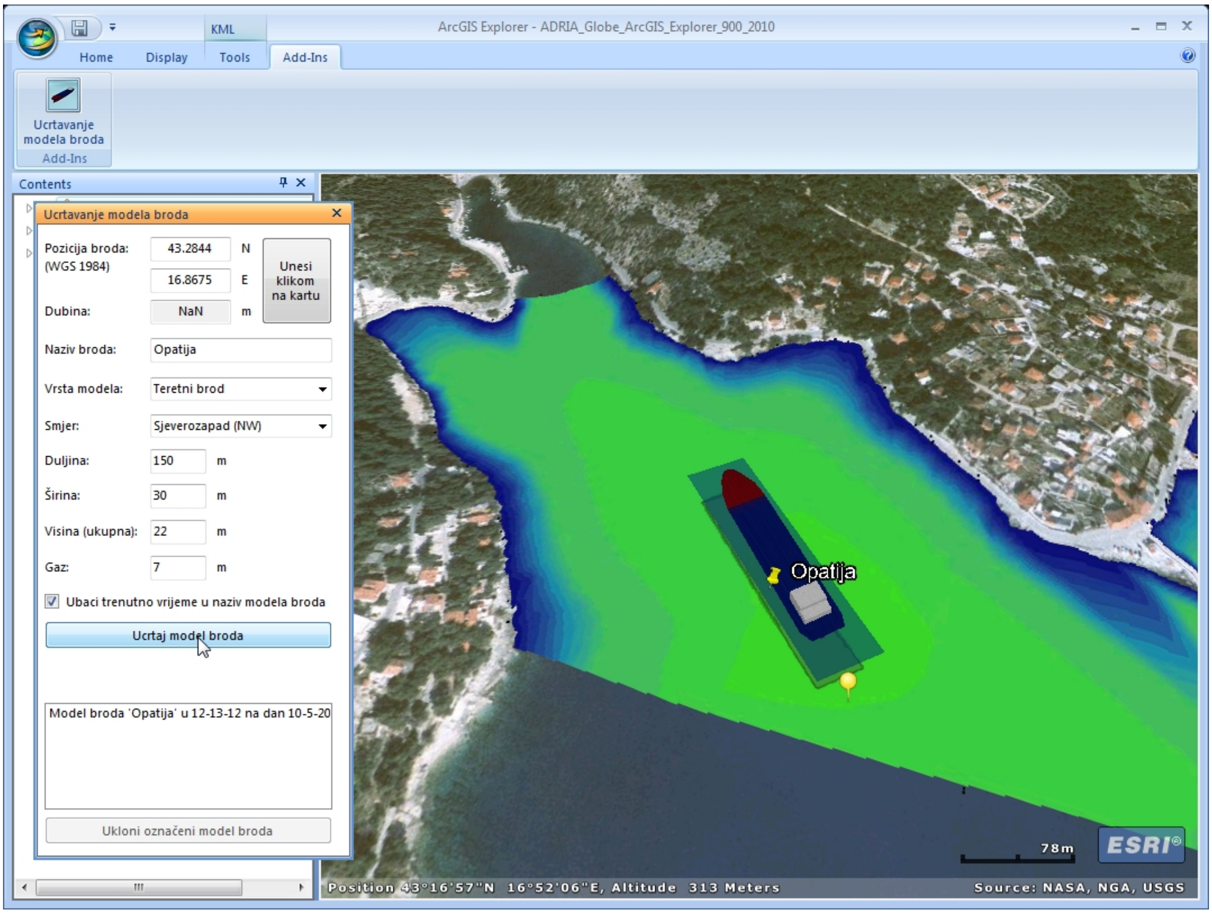

Figure 5: 3D model simulation of ship entering chosen place of refuge.

4. CONCLUSION

Supporting complex and sensitive decision-making processes such as selection of places of refuge for ships in distress cannot be achieved without mathematical modelling of specialised DSS to connect appropriate methods and data. The Decision Support System presented in this paper is a unique system for the safety of navigation at sea conceptualized as a conjunction of operational models and GIS spatial functions. Applied to the pilot counties it shows a potential to be used as an effective decision support tool. This paper proposes the basic concept of the DSS which helps to establish efficient emergency management using GIS and its spatial analysis tools. However, additional mathematical modelling is needed to expand and automate the choice of scenario for specific type of accident and ship category.

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