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Risk assessment of the extraordinary pollution in the Adriatic Sea as an economically important area for the Republic of Croatia

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ABSTRACT

Risk assessment links the likelihood of adverse events occurring to their consequences. Such assessment is used in labour management and trade-off determination to identify the safety and impacts associated with a particular interest. In the maritime sector, it is mainly used to raise safety standards, prevent pollution, and maintain a healthy marine ecosystem. Risk control itself is traditionally focused on the relationships between individual actions and consequences, which are later considered in groups to assess their acceptability in accordance with safety requirements. Therefore, the risk assessment for the extraordinary pollution of the Adriatic Sea as an economically important area for the Republic of Croatia are described in this paper. First, the area of analysis is defined, and a meteorological description of the eastern Adriatic coast is provided. The risk assessment is carried out in three steps. The first step is a description of waterways, and the analysis of traffic density, regulations, and types of vessels in individual areas. The second step is a detailed analysis of statistical data on accidents in the Adriatic Sea. Finally, the most probable and the most undesirable extraordinary pollution events and their impact on the Croatian economy are analysed. In addition, examples and procedures for determining risk acceptability and its control in a part of the Croatian coast are presented.

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1 Introduction

Shipping is a mechanism for large deliveries of goods in world trade and plays a key role in human development. Billions of tonnes of raw materials and finished goods are transported daily from port to port in an economical, environmentally friendly, and safe manner. But maritime transport is also a high-risk area. Despite the modern high-precision satellite-era navigation, many accidents still occur [1,2].

Although the number of maritime accidents is attracting a lot of media attention, statistics show a slight but stable decrease over the last decade [3]. This is due to the harmonised and strict international rules and requirements issued by the International Maritime Organisation (IMO). But, despite the progress, maritime accidents remain a major problem for the industry as they have an extremely strong impact on human life, the environment, property, and various social activities. They range from minor injuries and damage to loss of life, complete loss of property, and irreversible damage to the environment.

Since different types of maritime accidents affect the environment differently, it is important to note that not only mechanical damage to the ship (collision, impact, or stranding of the ship) can result in environmental pollution, but also various crew errors, such as accidental discharge of oily water, fuel displacement accidents, poor waste management, etc. According to the National Response Corporation Environmental Service, just over one million tonnes of petroleum products end up in the sea due to industrial processes, natural phenomena, and accidental spills by humans. In addition, catastrophic accidents, such as the sinking of the Prestige tanker off the coast of Galicia in Spain and the explosion of the Deepwater Horizon oil rig in the Gulf of Mexico, still pose a threat to the sea and the marine ecosystem [4]. While the recent events are promising, new concerns about potential pollution arise from the need to exploit oil from increasingly demanding areas such as the Arctic and unexplored depths.

The impact of human error in routine work is a strictly regulated area. Every shipping company must have an approved safety management system including elaborated and detailed procedures. Using a checklist ensures that all the necessary actions are followed and helps reduce the likelihood of accidents.

The risk assessment of extraordinary pollution of the Adriatic Sea, which plays a huge role in the Croatian economy, is discussed in this paper. The goal is to analyse the extraordinary risks of pollution and their impact on the Croatian economy. Penalties and corrective actions always require more and more effort, and the damage can never be eliminated.

This paper is structured as follows: **Section 2** introduces the geographical area of the research. **Section 3** discusses the weather characteristics of the researched area and continues with the traffic conditions in the Adriatic Sea in **Section 4**. **Section 5** contains the risk analysis of the study with two scenarios, risk acceptance and control criteria, and examples from real life. **Section 6** explores the current practise of risk control in the Adriatic with a focus on the Croatian area and development. **Section 7** concludes on the implications of the discussed scenarios in accordance with current economic data on the Croatian coast.

In the first three sections, the descriptive method is used to establish the base and conditions of the study area. Since the meteorological, geographical, and traffic data condition the statistical data of the study, these factors are closely related to the nature of the risk and, as such, to accidents at sea.

Onwards, the development analysis of the most probable event and the most unfavourable event is used to establish two basic scenarios to define the risks. Statistical analyses of the data collected using the historical method was carried out to define the most likely accident. The data were collected from the official statistics of the Croatian Ministry of the Sea, Transport and Infrastructure [16] as this data is the most reliable.

The worst-case scenario was analysed using the generalisation and compilation methods, taking into account the collected historical information on traffic in the Adriatic Sea. The results of such a scenario should therefore be seen as an attempt at representation rather than a rule. The risk acceptance and real-life examples are based on the "as low as practicably possible (ALARP)" principle [26-27] and the examples on the compilation method IAEA-TECDOC-727 [28]. The ALARP principle categorises risks according to the probability of their occurrence and the severity of their consequences and the IAEA-TECDOC-727 method contests such predetermined probabilities of the occurrence of undesirable risk events in the work process. Finally, the impact of the identified risks on Croatian economy is presented on the basis of collected data from the Croatian Ministry of Tourism and Sport and the Ministry of Agriculture [35,37].

2 Geographical reach

The risk assessment of this paper applies to the entire Adriatic Sea area, but the analysis of the collected data focuses on the Croatian Adriatic coast.

Accordingly, the area of the Croatian economic zone is the most important subject of the analysis. It represents a complex and functionally interrelated structure of various subsystems, such as natural resources, transport, maritime activities, political relations, and security systems. All maritime assets are thus of interest to the Republic of Croatia and are therefore used under its terms. The economic zone is also called the exclusive economic zone, which indicates a harmonised and controlled use of public goods [5]. This means that in addition to the control of the exploitation of marine life, concessions and other such activities, a security system must be established and implemented. Thus, the economic zone in the Adriatic Sea is composed of two parts, starting from the centre line of the Adriatic towards the Croatian coast and from the centre line towards the Italian coast.

The sea coast extends from the mean low water line and comprises a land belt bounded by the line reached by the largest waves during storms, along the part of the land designated for some maritime activity, and which is at least six metres wide measured from the horizontal mean higher high waters line [6]. Geographically, the maritime good comprises sea waters of the territorial sea with their bottom and underground, as well as the part of the land that is designated for public maritime use. The enviable natural resources and geographically strategic position make the Croatian coast the crown jewel of the Republic of Croatia.

3 Meteorological and oceanographic characteristics of the Adriatic sea

Small seas like the Adriatic are generally characterised by local weather development, which is mainly influenced by the land distribution and its role in marine protection. Winds in the Adriatic generally depend on the barometric distribution of the wider area, while direction and strength are determined by the coastal masses. On the eastern side of the Adriatic, the climatic features and characteristics of the archipelago cause sudden contrasts in the weather.

Among other things, this leads to gusts and winds. The prevailing winds in the Adriatic are "bora" (NNE to ENE), "jugo" (ESE to SSE), "maestral" (WNW to NW) and westerly winds, which account for only a small part in the total number of days [7]. Winds of Beaufort force 6 or more blow up to 40 days a year, while the storm wind blows about 10 days a year and most commonly occur as bora. In general, the southern part of the Adriatic is dominated by jugo, and the north is affected by bora. The impact of these winds differs significantly in summer and winter [7].

Bora creates a relatively small leeward area as it blows from the mainland towards the sea. On the other hand, jugo can create big waves because of its long lee side. Important Adriatic winds are also lebić, which blows from the direction of SW and can be stormy, and maestral, which marks the summer season.

As the Adriatic is a semi-enclosed sea, the generation of waves is caused by the surface influence of the wind in its intense cyclonic activity. The most common wave formation in summer is caused by the maestral, and in winter by bora and jugo. The waves of the Adriatic Sea are characterised by repetition, 1.5 m height and, in stormy winds, by an average period of 4.6 seconds and height of up to 4 m. Waves up to 6 meters in height can only occur in the wider Kvarner area during SE jugo and in the Otran area during jugo [7].

The freshwater inflow from the northern Adriatic rivers, under the influence of the Coriolis force, creates a current along the Italian coast towards Otranto, causing the current to flow in the opposite direction. This cyclic flow caused by the difference in density describes the surface sea currents of the Adriatic. The average current speed is 0.5 knots and decreases drastically with depth. The difference in density in summer and winter, that is, the difference in temperature and salinity, creates the input NW current on the east coast and the SE output on the west coast of the Adriatic. In very strong gusts, the speed of the surface current can reach 3-4 knots, but even at a shallower depth it can reach a maximum of 1.5 knots [7].

The tides of the Adriatic are of a mixed nature in the transitional phases of the moon and substantially uneven in height. Only during syzygy, are they of the semidiurnal type, and during quadrants of diurnal type. During the syzygy, the rise of the tides is delayed counter-clockwise, while during the quadrants, the rise is uniform along the entire length of the Adriatic. The amplitudes increase from south to north, with a range of 0.22 to 0.60 metres [7].

4 Direction of the Adriatic sea traffic

Waterways nowadays are conditioned by the location of ports, traffic, and hydrographic characteristics of an area. In the Adriatic, the ports in the extreme north-western part determine the waterways with their transhipment volume [8]. The main traffic route passes through the central part of the Adriatic between the Otranto Pass and the ports of the north-western part, respectively towards the ports of Venice, Trieste, Ravenna, Koper, and Rijeka. It is the shortest way to sail the Adriatic.

In addition to the main waterway, the Adriatic is also marked by other longitudinal waterways that are closer to the coast for better connections with smaller ports. Such waterways follow the coastline along the east and west sides. The longitudinal waterways on the eastern Adriatic coast (the coasts of Albania, Montenegro, and the part of Croatia extending to the Dubrovnik area) run in close proximity to the coast, within which inter-island waterways can be singled out as a special subgroup of nautical tourism waterways. They connect the nautical centres with the most attractive tourist destinations on the Adriatic coast.

In addition to the longitudinal waterways in the Adriatic, there are numerous transversal waterways that connect ports on the east and west coasts and ports with longitudinal waterways. On the east side, these are the ports of Rijeka, Zadar, Šibenik, Split, Ploče, Dubrovnik, and on the west side, the ports of Ravenna, Ancona, Pescara, Bari [9-10].

All facilities, infrastructures, and superstructures of international public transport are defined as public goods and their use is equal for all. The importance of this concept is reflected in the fact that Croatia's geo-traffic position is characterised by easy access to European maritime transport and is important for the general interest of the whole world [11].

5 Risk determination

Risk determination scenarios can be explored using two basic approaches to development analysis of the most probable event outcome and the most unfavourable event outcome. Risk assessment therefore amounts to a detailed and systematic evaluation of all actual and potential sources of danger, meaning it seeks to identify all foreseeable risks. The acceptability of a risk is very difficult to determine because it is linked to the consequences for human life [12].

Therefore, the final values are not easy to represent mathematically, and the analysis of the results should be seen as an attempt at representation rather than a rule.

Due to the fact that more severe consequences occur less frequently, and the probability of less severe consequences occurring is higher, the rule of inverse proportionality is applied. The consequence can thus be represented as the ratio between the sustained risk and the probability of its occurrence. However, statistical values from past events are used to determine these parameters. Due to the general progress of industry standards, the data are often outdated and cannot reliably show the risk probability but can serve as a point of reference.

5.1 Event with the highest probability of occurrence

In the risk assessment of the Adriatic Sea pollution, we consider the assessed risks in special circumstances, in which the first and the most important step is to analyse occurrences of the most probable adverse event.

Table 1 Historical overview of maritime accidents in the Adriatic [16].

	Stranding/ grounding and impact	Inability to navigate – failure	Sinking	Collision	Flooding	Fire	Total
2020	44	42	20	12	6	11	**139**
2019	67	56	23	15	18	8	**187**
2018	69	83	13	30	19	19	**233**
2017	61	59	12	19	13	18	**182**
2016	65	86	8	11	8	8	**186**
2015	47	48	11	11	8	9	**134**
2014	68	59	11	15	7	8	**168**
2013	45	60	17	8	11	12	**153**
2012	53	78	10	12	14	7	**174**
2011	49	64	9	7	11	7	**147**
2010	43	105	20	9	8	8	**193**
2009	59	104	8	3	10	8	**192**
2008	32	81	6	2	1	8	**130**
2007	72	92	7	10	8	8	**197**
2006	34	88	3	7	17	3	**152**
2005	43	61	12	15	15	7	**153**
2004	43	72	9	5	7	5	**141**
2003	37	70	9	0	6	6	**128**
2002	43	64	7	2	3	6	**125**
2001	28	72	3	1	5	3	**112**
2000	34	57	7	3	5	4	**110**
1999	17	52	3	0	4	11	**87**
Average	**48**	**71**	**10**	**9**	**9**	**8**	

Such an analysis boils down to the study of past events and, accordingly, the calculation of the forecast of the probability of occurrence. The disadvantage of this method is the unreliability of the data or their misrepresentation. Similarly, a maritime accident is caused by a series of events. Since some of these events are interrelated, conditional probabilities must also be determined [13-14].

Traffic in the Adriatic Sea is constantly increasing, and with it the probability of an accident. Especially during the tourist season, when a larger number of smaller vessels are underway, there is also an increased number of smaller accidents. Of course, such accidents are of a lesser extent of damage, but their number cannot be ignored. The impact of such accidents, apart from the consequences for human life, can pose a high risk of pollution. The reasons are usually traffic disruptions of larger ships, which can ultimately result in disaster.

Of all ship types, oil and chemical tankers pose the greatest danger in terms of potential environmental damage and endangerment of human life. According to Maritime Transport and Possible Accidents in the Adriatic Sea data, tankers account for 20% of the traffic of the average number of merchant ships in the Adriatic. Traffic density is the highest on the main longitudinal waterway, i.e., in the central part of the open Adriatic Sea, where there are separate transport systems. The access nodes to the ports of Rijeka, Bakar, Zadar, Split, and Ploče, where there is no significant regulation of navigation, generally pose a problem [15].

As most smaller vessels in the Adriatic do not have an AIS system (Automatic Identification System), the existing AIS-based distributions of vessels on voyages are not complete and cannot be a reliable source for traffic analysis.

The total number of accidents on the Croatian Adriatic coast is shown in Table 1 below, in accordance with the records of the Croatian Ministry of Transport, Maritime Affairs and Infrastructure [16].

Table 1 shows that from 2000 to this day, stranding accidents and inability to navigate have predominated. The decrease in accidents in 2020 is the result of the Covid-19 pandemic.

According to the Search and Rescue statistics (SAR) of Ministry of the Sea, Transport and Infrastructure, up to 60% of accidents happened to vessels for entertainment during the tourist season. Research on such accidents has shown that the main reason for their occurrence is the lack of nautical experience and knowledge and inadequate equipment of boats and yachts [3].

According to the data above, on the distribution of accidents in the Adriatic, the port of Zadar records the highest number of accidents, 35%. The main reason for this is the previously mentioned predominance of traffic of small boats for entertainment, with unsatisfactory equipment and the operators' lack of nautical knowledge [3,16].

Therefore, the most probable adverse event is grounding and/or engine failure which leads to an inoperative vessel for entertainment and/or leisure in the coastal area of the major port nodes, with an emphasis on the Zadar area.

Furthermore, it is necessary to define the most probable pollution that could result from these accidents.

A grounding accident degrades the environment mechanically, but the extent of such degradation primarily depends on the location of the accident. In the case of a grounding accident on an underwater cliff, the pollution is limited to the contact surface of that cliff. Greater pollution would be caused by a puncture of the fuel tank and/or liquid cargo, in which case an oil spill would most likely occur.

On the other hand, a malfunction resulting in an inability to navigate could easily cause such a grounding, collision and impact or a combination of these. Thus, in the event of a collision, a liquid cargo spill and fire are a probable outcome for tankers. In the worst case, a vessel may sink, resulting in a complete spillage of fuel and/or cargo from the punctured tanks.

The greatest danger of collision for large ships is at the intersections of the main longitudinal waterway and the transverse waterways of the central Adriatic. Of course, the risk of collisions with smaller vessels is the greatest on the waterways along the coast and between the islands.

5.2 Event with the worst-possible consequences

The most unfavourable event in terms of pollution of the sea and marine environment is irreversible degradation of the marine environment, with the greatest efforts being made to eliminate the consequences. Such damage represents a permanent or temporary change to the affected area.

The advantage of such monitoring and risk analysis is the split process and sequence analysis, from which the most unfavourable event emerges. In this process, it is extremely important to understand the actions that cause the risk. On the other hand, it is important to know that such a sequence has a very low probability of occurrence and often unrealistically high damages.

The greatest danger to the environment is oil spills. As there are numerous oilrigs for the exploitation of crude oil and natural gas in the Adriatic, the collision of an oil tanker with an active platform could result in the most unfavourable event of pollution of the Adriatic Sea. The sizes of tankers sailing the Adriatic are generally Aframax and Suezmax. However, in determining the most undesirable event, it is interesting to consider the exploitation of a 330-m long VLCC tanker with a capacity of 300,000 tonnes. An example of this is the tanker Houston, such a VLCC, which sailed to port of Omišalj for transhipment in 2018.

According to the EU and the Croatian Institute of Oceanography and Fisheries, 70 million tonnes of oil and oil products are transported annually through the Adriatic Sea by tankers [17]. This amount of oil is about 100 times greater than the one spilled in the Gulf of Mexico disaster. Due to minor incidents, according to EU commission data, 100,000 tonnes of crude oil, oil products and other hydrocarbons are spilled into the Adriatic Sea every year.

Therefore, since the causes of the most probable adverse event are stranding, collision, and impact, it is necessary to analyse the worst-case scenario of such an accident.

When it comes to VLCC tankers, according to the general calculations of stability in damaged condition, the worst possible event from the pollution point of view would follow the penetration of the two largest tanks (usually in the middle of the ship – tanks No. 3 and 4). Since oils have a lower density than the sea, they float on the surface. Therefore, the worst-case scenario would be the penetration of these tanks at the top, near the main deck, and the complete sinking of the ship. In the event of sinking, all the cargo in these tanks would float to the surface of the sea. The largest tanks can usually hold 10% of the total payload, which in our case of the VLCC would mean about 58,800 tonnes of oil. A possible explosion and fire could cause more tanks to rupture and a larger amount of oil to spill.

As the sea currents on the eastern side of the Adriatic move from south to north, the most adverse location of oil spill for the Croatian coast would be in the south-eastern part of the Adriatic [18-22].

As another example, we can consider the LNG terminal on the island of Krk. The liquefied gas is transformed into a cold vapour cloud during uncontrolled release into the environment. Such a cloud is called an aerosol and is heavier than air. When it warms up, this cloud mixes with the surrounding air and equalises its density. Furthermore, droplets of liquefied gas that have not completely evaporated can form smaller pools that evaporate at the surface.

A methane concentration in a mixture with air of 5-15% and contact with an ignition source would result in ignition. The form of ignition can be a fire-jet from a pipeline, combustion of vapour over a pool of liquefied gas, and the most undesirable scenario, a sudden ignition of a cloud of vapor, or in other words, an explosion. A gas explosion in the terminal area is unlikely but possible and can be divided into detonation or deflagration. Detonation is extremely aggressive and produces a shock wave faster than the speed of sound (1500 m/s). Since natural gas is not reactive enough for this type of explosion, a shock wave slower than the speed of sound (about 250 m/s) is more likely, in which case the explosion is described as a deflagration [23].

Also, since steel becomes brittle at -45 °C and liquefied natural gas is transported at -162 °C, it can be assumed that droplets of liquefied gas that suddenly come into contact with a metal surface (unprotected by water shower curtains) could easily cause a major structural damage to the ship.

The damage caused by such an event could in the worst case, apart from the loss of human life, result in the complete loss of the ship, loss of all cargo at the terminal and loss of terminal infrastructure, consequently resulting in the irreversible environmental degradation of the area.

5.3 Risk acceptance and risk control

An acceptable risk is one for which all the consequences are known and can be controlled by a series of preliminary measures. Such preliminaries constitute several barriers to prevent their occurrence. Risk and uncertainty are characterised by situations where the actual outcome for a particular event or activity has more than one possible value, leading us to the question of acceptability.

Risk acceptance can be qualitative or quantitative in terms of categorisation and evaluation. The comparison itself can be made without and in relation to other risks within an action.

The development of an acceptable model depends primarily on the availability of appropriate traffic data for the area under assessment, the satisfactory technical conditions available and the rules and regulations governing the navigation safety. An acceptable risk is one for which all the consequences are known and controlled by a series of preliminary measures that have multiple barriers to prevent their occurrence [23-25].

Since the consequences of accidents in the environment depend primarily on the type of vessel and other maritime facilities involved in the accident, the best way to present the pollution risk assessment is in a table. Since the risk is defined as the result of the probability of occurrence and the severity of the consequence, both elements are assessed separately.

The following categorisation is based on the "as low as practicably possible (ALARP)" principle, i.e., the categorisation of risks according to the probability of occurrence and the severity of the consequence [26-27].

The risk is then placed in the table by characterising the severity of the consequence in columns (C1 to C5) and the likelihood of occurrence on a scale (L1 to L5).

In this way, the values of the risk are presented in three categories:

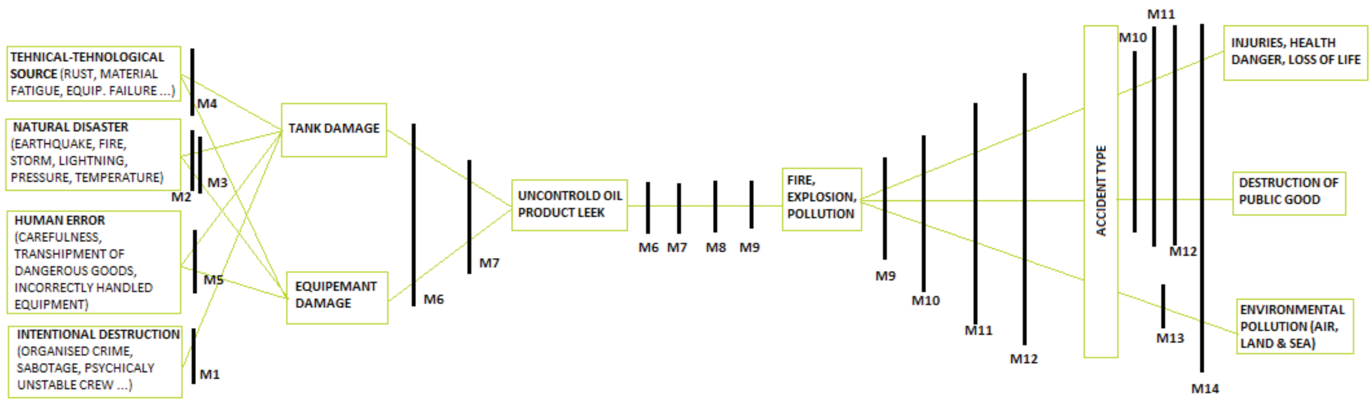
- Low risk (green) – Acceptable risk.
- Medium risk (yellow) – Tolerating the risk with additional safety measures that reduce the likelihood of its occurrence, thus placing it in the green acceptable range.
- High risk (red) – Unacceptable and intolerable risk that requires immediate corrective action. Such action cannot be carried out until the likelihood of such a risk has been reduced to an acceptable level.

As visible in the table, risks whose occurrence is unlikely, both because of their nature and because of the measures that prevent their occurrence, can be accepted. Similarly, small risks that have a high probability of occurrence are only accepted if the consequences are insignificant.

Risk mitigation and control are carried out in cases where their occurrence is unacceptable. If the analysed risks are included in the yellow zone, i.e., tolerable, it is up to us to choose whether to take any preliminary measures

Table 2 Overview of risk categorisation in the safety impact assessment [Author].

	CONSEQUENCES FOR				LIKELIHOOD OF OCCURRENCE				
	SEA	COAST	ECOSYSTEM	SEABED	VERY SMALL	SMALL	MEDIUM	HIGH	VERY HIGH
C1	NO POLLUTION	NO DEGRADATION	NO IMPACT	NO POLLUTION	1	2	3	4	5
C2	NEGLIGIBLE POLLUTION	NEGLIGIBLE DEGRADATION	NEGLIGIBLE IMPACT	NEGLIGIBLE POLLUTION	2	3	4	5	6
C3	LOW POLLUTION	LOW DEGRADATION	LOW IMPACT	LOW POLLUTION	3	4	5	6	7
C4	MEDIUM POLLUTION	MEDIUM DEGRADATION	MEDIUM IMPACT	MEDIUM POLLUTION	4	5	6	7	8
C5	HIGH POLLUTION	HIGH DEGRADATION	HIGH IMPACT	HIGH POLLUTION	5	6	7	8	9
					L1	L2	L3	L4	L5



Scheme 1 Overview of risk control at the Federation d.o.o oil terminal [29].

to reduce either the probability of their occurrence or/and its consequences. However, if the analysed risk is in the red zone, additional preliminary measures to reduce the likelihood of its occurrence and/or consequences are mandatory. This means that we would take additional steps to try to eliminate or reduce the consequences or minimize the probability of their occurrence so that they would be in the acceptable zone.

Risk mitigation is carried out according to the hierarchy: elimination, replacement, technical control (machinery), implementation of signs/warnings, administrative control (checklists), and personal protective equipment. In addition, it is extremely important that all participants are well-acquainted with the identified risks and the purpose of protective measures. Therefore, before starting any work, a meeting must be held to discuss the safety measures.

As a real-life example of risk control and acceptance of the risk of extraordinary pollution events, let us consider the Oil Storage Federation BIH Ltd. in the port of Ploče. The assessment of the probability of occurrence of a risk is based on the IAEA-TECDOC-727 method [28], which goes through predefined probabilities of undesirable risk events occurring in the work process. The initial data on the area were collected from various historical sources and compared with the statistics of similar plants. Thus, the cause of the danger is considered to be a disturbance in the process that can cause a harmful substance to enter the environment uncontrollably (tank leakage, mechanical damage to the pipeline and/or tank, etc.).

For each foreseeable disturbance scenario, the quantity of hazardous substances released and the possible consequences are assumed. In *Scheme 1,* we see the predicted sequence of events.

Between each event, protection measures are set, i.e., prevention and control of the risk that may cause the next undesirable event in the series.

For example, for the technical and technological cause of tank contamination, prevention measures include regular inspection and measurement of the wall thickness of the tank, while maintaining corrosion protection. Furthermore, for early detection of uncontrolled discharge, protection measures are regular inspection rounds and regular measurement of the liquid level in the tank. Fire and explosion prevention is also ensured through regular inspection rounds, early detection of a potential source of ignition, a tank inerting system, and a fire alarm system.

If ignition occurs, there are fire extinguishing systems, systems to prevent fire from spreading, a tank boundary cooling system, along with the means to prevent and stop pollution [29].

As far as the control on board is concerned, according to the International Safety Management Code (ISM), every carrier is obliged to ensure satisfactory working conditions for its seafarers and all personnel on board, applying both risk assessment and the possibility of reducing it. Therefore, "each crew member on the ship must inform the supervisors or other competent person, and they have to inform the owner, if there is a significant risk to human life, ship or environmental safety, and a violation of working conditions and working procedures". The working principles must aim to improve the safety of their employees at work and protect against the risks that exist when executing particular work. As an example of risk control, International Safety Guide for Tankers and Terminals (ISGOT) recommendations and the approved checklists for routine on-board operations are carried out on crude oil and oil product tankers. Such checklists are usually divided into groups according to the type of work. We therefore have work at height, work with machinery, work below the waterline, enclosed space entry, contingencies (contingency planning – fire, stranding, failures, etc.), and others.

6 Risk control in case of extraordinary pollution in the Republic of Croatia

With the continuous increase in traffic and the proportional increase in accidents, it is necessary to strengthen preventive measures. From the above-presented risk analysis, we see that the greatest attention should be paid to larger cargo ships carrying dangerous goods. Thus, as of July 1st, 2003, the use of the ATS (Adriatic Traffic System) reporting system has been mandatory for participation in Adriatic traffic. It applies to tankers over 150 GT and to other ships above 300 GT carrying dangerous and/or environmentally harmful goods. In addition, maritime traffic management supervision by the Vessel Traffic Service (VTS) Croatia and navigation supervision based on the AIS device have been established at the access to the port of Rijeka [7].

Also, laws banning navigation and restrictive measures in sensitive areas, such as the Pelješac and Koločep Channels, the Murter Sea and the Žirjan Channel, were adopted, as well as a partially declared economic zone for countries outside Europe. In addition to the ban on navigation of ships transporting dangerous goods older than 25 years, the Law on the Coast Guard and the Rules on Places of Refuge were adopted.

Protection of the sea and maritime features in Croatia derives from the Barcelona Convention and the National Contingency Plan for Intervention.

Furthermore, Croatia has about 650 shelters on the Adriatic, of which 380 are natural shelters and 270 are ports [30-31]. Such shelters are extremely important in preventing major pollution. The risk of pollution from a ship, or the pollution itself, is much easier to control in a shelter. An oil spill in the open sea is almost impossible to stop from spreading, which can potentially endanger a large area, while in a port with a calmer sea surface and floating fences, such oil spills can be controlled. Also, pollution control in ports is possible even if a vessel sinks to a depth of up to 15 m.

In addition to the above-mentioned measures, the new measures on traffic directing, focusing on the northern Adriatic, should be pointed out.

Sudden marine pollution is the subject of an international plan for "Intervention for prevention, preparedness and response". Accordingly, on September 16th, 1993, the Government of the Republic of Croatia adopted the "Contingency Plan for Sudden Marine Pollution in the Republic of Croatia", which was renewed in 2008 on the basis of Article 50, paragraph 4 of the Environmental Protection Act (OG 110/07) and Article 63, paragraph 2 of the Maritime Code (OG 181/04 and 76/07). Procedures and measures for the implementation, prevention, mitigation, and preparedness for sudden marine pollution, in addition to extraordinary natural events at sea for the purpose of protecting the marine environment, are defined in the plan. The plan is implemented by the Croatian Headquarters, the MRCC Rijeka and the County Operations Centres (Županijski operativni centri – ŽOC). Also, the plan is incorporated into the regional intervention plan for pollution prevention, preparedness, and response of the Adriatic in agreement with Italy and Slovenia. Sudden pollution of the marine environment is considered to be of a quantity greater than 2000 m^3.

On October 3rd, 2003, the Republic of Croatia declared an ecological-fishing zone for the purpose of environmental protection and the use of living resources.

As already mentioned in the paper, the greatest danger to the navigation safety is posed by substandard and old vessels with unqualified management. Therefore, additional efforts were made during the tourist season regarding inspections on compliance with regulations and documentation. Under the development plan for the entire maritime system in the Republic of Croatia, the e-Maritime and e-Navigation system are being developed, with which the regulation of documents would be much more effective. The application of such "network-connected system" eliminates the possibility of falsification and misrepresentation, which drastically speeds up the control system and the verification of the vessel's fitness [31-34].

7 Impact on tourism and the economy

Assessing the damage of the most unfavourable event is very difficult. This is mainly because its unknown severity, total costs, and corrective efforts do not follow any regularity.

Since the caterers' annual earnings during the tourist season, along with the values of marine biomass and annual earnings from sales are known, the total value represents the worst damage rate for a certain area.

Thus, the consequences of pollution on the Croatian Adriatic coast are reflected in the economic damage. According to the Central Bureau of Statistics, Croatia had 1.3 million visitors in 2019. Of these, 87% visited the coastal area, which amounted to revenues of 1.1 billion euros [35].

According to the Directorate of Fisheries of the Ministry of Agriculture, the Croatian fleet consists of over 200 vessels that catch over 60,000 tonnes of small pelagic fish a year, which accounts for 90% of the total fish catch in Croatia and 56% of the total catch. The catch of 350 trawlers makes up about 6% of the total catch and about 25% of the total catch value of 60 million euros [36-37].

The analysis of the development of infrastructure of nautical tourism shows that the development in different counties is uneven. Primorsko-Goranska County is recording a decline in the number of ports, while the Šibensko-Kninska, Zadarska, and Splitsko-Dalmatinska counties are experiencing a continuous growth. The main reason for this is the orientation of the port of Rijeka towards freight traffic. Furthermore, the Port of Rijeka saw a record number of large cruise ships in 2019, the development of which was unfortunately interrupted by the pandemic. It is also important to note that in the last few years, the port of Rijeka has invested the most funds in the developing infrastructure to accommodate this type of vessels.

The income from berth renting in nautical tourism has annually brought around 69.3 million euros to Croatia in the last ten years. In addition, Croatia generates around 106.6 million euro in revenue from transit vessels with other catering services, with a constant annual increase of around 5% [38].

Ultimately, cleaning costs are subject to large value fluctuations. They depend largely on the technology used for cleaning, so it is impossible to estimate them in advance. According to a well-known historical example of the Exxon Valdez tanker spill, the total cost of cleaning up the 38,800 m^3 oil-spill was roughly 2.1 billion US dollars [39].

Hence, the total possible damage is the sum of losses from tourism, fish sales and breeding, imports that replace goods (quality) for the time needed for recovery and clean-up costs (efforts – human labour, equipment, and means spent). It is also necessary to mention the violation of social value and coastal infrastructure.

8 Conclusion

The analysis in this paper shows that oil pollution prevention plays a vital role for the Croatian economy. If the most unfavourable case analysed in the paper occurs, from the point of view of the economy and welfare, the impact would be catastrophic in all parts of Croatia. Due to the varied classifications and risk perceptions of individuals making the assessment, the process is arguably very subjective. As so, it is important that the risk assessment is carried out by a team of professionals at regular intervals. Re-analysis of the same process by the group will give us higher chances to determine all the associated risks and hopefully establish all the prevention barriers.

One of the greatest dangers in risk management is the illusion of security and it is certain that silencing and neglecting the risks lead projects to ruin. Project risk management depends primarily on the level of risk tolerance of those responsible. According to some authors, risk perception is even considered one of the main areas for improvement in the development of risk management practices.

Knowing the characteristics of certain jobs and having information about similar ones, it is possible to predict what risks the project may be exposed to and what the consequences may be if these risky events occur. Better project management results are achieved by determining how to counter these risks as quickly as possible and by implementing measures early, because it is always more efficient and significantly cheaper than repairing the damage from the consequences of the risk later. Today, strong organizations set high standards for safety at sea. But with all the demands, there is always room for progress and new goals.

Criteria for determining acceptable risks are nowadays created through systematic elimination and risk assessment. An accident is never the result of one wrongdoing and there are always several barriers on board to prevent an accident from occurring. Hence, with the omission of one of the barriers, we encounter the term avoided accident or "a near-miss".

The acceptable risk is difficult to describe objectively because it depends primarily on the perception of the consequences. However, with the application of risk control systems and their analysis, the industry standard is constantly raised to a higher level and the management of identified risks becomes routine.

Risk control is the most important measure in accident prevention and thus the prevention of marine pollution. Further research should focus on the control of compliance in structural and technical requirements of smaller vessels for entertainment and the regulation of the operators' qualifications. The fact is that such vessels cause the most accidents in the eastern part of the Adriatic and can potentially cause extraordinary pollution with catastrophic consequences for the Croatian economy.

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