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Safety and security of Baltic Sea area critical infrastructure networks - integrated management system

Keywords

critical infrastructure, network, inside-dependences, outside-dependences, operation impact, weather impact, safety, security, resilience, modelling, prediction, optimization, accident, consequences, mitigation, management

Abstract

The Baltic Sea basin is analyzed and Baltic Sea main geographical and climatological parameters are presented. The Baltic Sea environmental impacts of human activity and the ways of their consequences protection are discussed. The set of critical infrastructure networks at Baltic Sea and its seaside is identified and critical infrastructures and their operation environment methodology is introduced. The integrated management system of safety and security of Baltic Sea area critical infrastructure networks is proposed as a new research project continuing HAZAD project subjects and its core aims and description are presented. The project research team conception is created and partner cooperation added values are addressed. Seven main steps of project implementation are suggested. Moreover, the appropriate and wide references are given.

1. Baltic Sea basin

1.1. Baltic Sea geographical and climatological parameters

The Baltic Sea is a young, epi-continental, non-tidal and small sea on a global scale (it is about 1/900 part of world marine ecosystems) [4], [53]-[55], [58]-[61]. It consists of seven sub-basins, from the north: the Bothnian Bay, Bothnian Sea, Gulf of Finland, Gulf of Riga, Baltic Proper, the Sound and Belts, Kattegat (*Figure. 1a*). The whole area of the Baltic Sea is about 415 000 km². It contains 21,547 km^3 of brackish water. It is important that Baltic Sea has a narrow and shallow entrance (few kilometers in Danish Straits) thus, it can be compared to very big but not very deep lake. The Baltic Sea is the shallower sea in compared to the other world's ones (it is characteristic for epi-continental seas opposite to seas located between continents). It has an average depth of only 53 m while its deepest part is the Baltic Proper with approximately depth of 62 m and maximum depth of 459 m (Landsort Deep).

The water level in the Baltic Sea is higher than Atlantic Ocean because of the Sound and Belts and water cannot easily and quickly pass through these straits with mean depth of only 14 m. It also limits the exchange of water with Atlantic Ocean (there is needed about 33 years to exchange the whole water in the basin).

The drainage basin (also called catchment or watershed) of the Baltic Sea includes all the land areas from which water flows into the sea, either via rivers or as direct run-off. Accordingly, the Baltic Sea drainage basin consists of the whole or partial territories of 14 countries (*Figure 1b*). Nine of them: Poland, Lithuania, Latvia, Estonia, Russian Federation, Finland, Sweden, Denmark have direct access to the coast whereas Czech Republic, Slovakia, Ukraine, Belarus and Norway have not. In total, the Baltic Sea drainage basin covers an area of 1,745,000 km^2. It means that drainage basin is approximately four times larger than the sea. If the Baltic Sea area is added to its drainage basin, the total area is 2,250,000 km^2 – it is about 15% of all Europe.

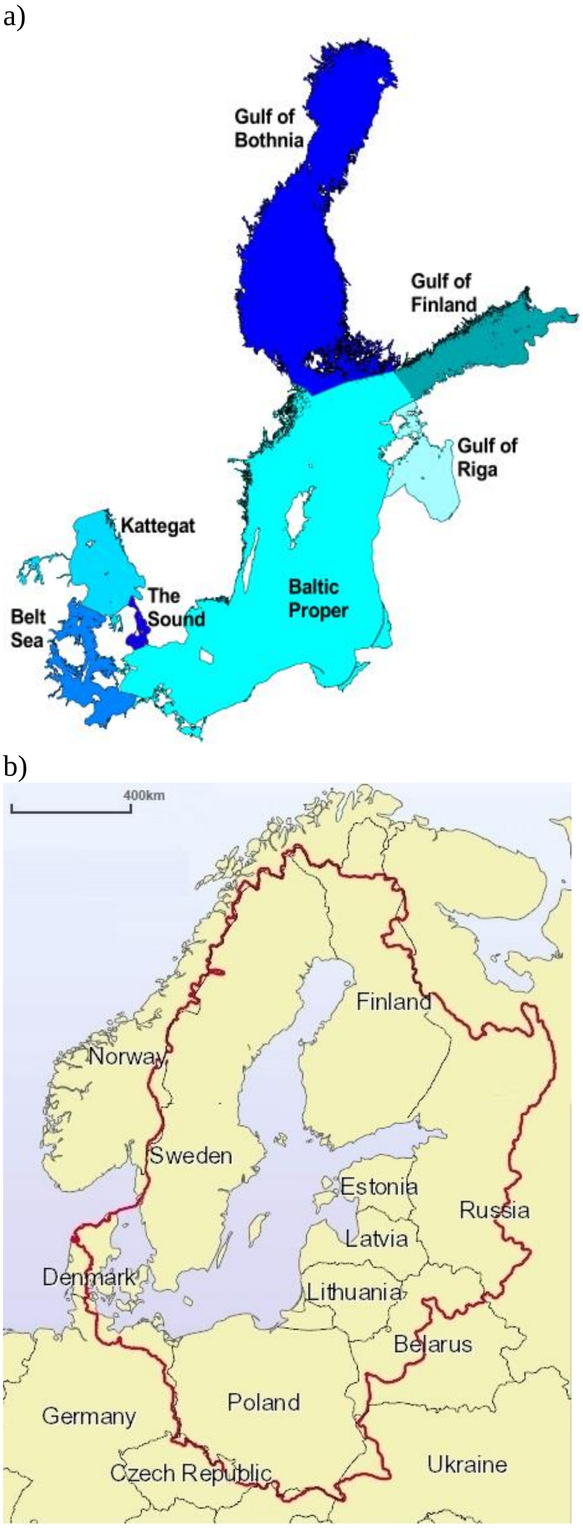

Figure 1. The Baltic Sea a) sub-basins [HELCOM, 2010], b) drainage basin
(source: http://maps.grida.no/baltic/)

There are 7 coastal types around the Baltic Sea. In the north rocky coasts are dominated, and in the south – sandy ones. The archipelagos prevail at Swedish and Finnish coastline. The archipelago between Sweden and Finland is the largest in the world and contains 25,000 islands. The cliff and klint coast are found in Estonia and on the west coast of Gotland, and lagoons in Gdansk Bay.

There are three abiotic important parameters of water that are fundamental for the Baltic Sea marine life: salinity, temperature and oxygen concentration.

The salinity of surface water varies from 1-2 PSU (PSU – practical salinity unit in average means parts per thousand) in Bothnian Bay, 2-4 PSU in Bothnian Sea to 20 PSU in Kattegat (compared to 35 PSU in common marine ecosystems). Near the mouth of large rivers, salinity falls close to 0 PSU. Moreover, deep water are more saline (10-12 PSU on average) than surface water (7-8 PSU on average). Thus, the rapid increase of saline at water depth of about 70-90 m (called halocline) is observed. The halocline limits the vertical mixing of water, consequently the bottom layer of water is much dense than surface one.

The oxygen concentration in the Baltic Sea is also different according to the depth. The surface water is generally well oxygenated (7-9 cm^3/dm^3) whereas the oxygen concentration immediately runs out at 60-70 m water depth, and finally the no oxygen concentration at 140 m water depth is observed (redox-cline). Additionally, the toxic hydrogen sulfide is produced beneath the redox-cline and in general there are no living organisms below 140 m depth in the Baltic Sea. The oxygen concentration has dramatically reduced for two last decades. The oxygen concentration below 3 cm^3/dm^3 causes stress for fish and animals living in the ecosystem.

Temperatures of the Baltic water ranges from -0.5 to +20°C. Moreover, the bottom water temperature is constant independently of the season (about 2-4°C) whereas the wind-mixed surface water temperature is variable according to the season. Thus, the layer between the seasonally changes of water temperature and deeper water with constant temperature at water depth of about 20-70 m (called thermocline) is observed.

The climate around the Baltic Sea is different in the north and south because of long north-south extension (about 3000 km) of the basin. The mean annual air temperature is 0°C in the north, whereas it is 8-12°C in the south. The surface air temperature has increased since 1871. The changes of temperature are resulting in changes in the season: the length of the warm season has increased, while the length of the cold season has decreased [59].

Both, the salinity and the air temperature have influence on the Baltic Sea annual ice occurrence. The ice impairs shipping as well as has influence on marine wildlife. The ice cover during normal and mild winters occupies 15-50% of the sea area in the north-eastern part of the basin, but may extended to the entire sea during infrequent severe winters. In general the Bothnian Bay is ice-covered every winter, while the Baltic Proper is usually ice-free. The latest winters with the Baltic Sea totally frozen were in 1941/1942 and probably also in 1946/1947 [58]. The first sea ice usually begins to form in November (in the beginning of October at earliest) in the shallow coastal areas in the northernmost Bothnian Bay. The maximum ice coverage is typically reached in February or March, but sometimes already in January, and finally sea ice remains in the Bothnian Sea usually until mild-May. In the Bothnian Bay, the ice thickness is commonly 65-80 cm, while 10-50 cm in coastal areas of Poland and Germany.

The Baltic is stormy sea (in average 3°B/year) and waves are short and steep. The highest waves are about 10 meters but typically they reach about 5 meters. Prevailing winds come from west, thus air pollutants are usually transported from west to east. On the other hand the Baltic surface water constantly and anti-clockwise circulates thus, the marine pollutants from the south can pass the east and the north coastal areas to return to the south. Moreover winds blowing at a speed of 15 m/s are strong enough to disrupt ferry and other ships, bring down electricity cables and other structural damages as well as whip up large waves at the coast to cause localized flooding. On the other hand strong winds and storms are essential for the ventilation and mixing of the stagnated waters and inflow indispensable salt and oxygen to the Baltic Sea from the North Sea and Atlantic Ocean.

The precipitation in the Baltic Sea region has varied between seasons and regions. The mean annual precipitation equals 750 mm/year for the entire Baltic Sea basin (including both land and sea). The largest precipitation amounts occur in Scandinavia and southern Poland mountain regions, while the lowest amounts occur in the northern and northeastern part of the basin as well as over the central Baltic Sea. Mean monthly precipitation is highest during July and August, with up to 80 mm in August, and lowest from February to April, with less than 45 mm on average.

For much of the Baltic Sea basin, in particular the eastern continental part and also much of the Baltic Sea itself, there is an annual cycle of clouds, with the largest cloud amounts during winter and the smallest ones during summer. However, little to nearly no annual cycle in clouds is observed in parts of the western and northern regions (in particular, mid- and northern Sweden and northern Finland). During summer months, few or no convective clouds form over the Baltic Sea, in contrast to the surrounding land areas.

1.2. Baltic Sea environmental impacts of human activities

Summing up, due to the Baltic Sea special geographical and climatological parameters (sheltered inland and shallowed sea with many coastal types, cold climate), the sea is highly sensitive to the environmental impacts of human activities. The Baltic Sea like other seas is an area where maritime transportation, trade, fishing and other industrial activities take place.

The Baltic is one of the most contaminated sea around the world because of living about 85 million people in 14 countries within the basin, multiple-using of coastal areas, intensive agriculture, building of a new cities, growing industry and other man activities in the surrounding drainage basin leading to the pollution dangerous for this region. This was the reason to create so-called HELCOM (Baltic Marine Environment Protection Commission - Helsinki Commission) for monitoring the pollution and other dangerous impacts of human activity on the Baltic Sea environment. The role of HELCOM is also the consolidation of international cooperation for the protection of the Baltic Sea environment, supervising and coordinating the implementation of the 1992 Baltic Sea Convention (so-called Helsinki Convention) [60] and binding decisions in order to further the objectives of the convention, giving recommendations on measures, defining pollution criteria and quality objectives and promoting researches.

Figure 2. HELCOM member states (source: https://en.wikipedia.org/wiki/HELCOM)

In *Figure 2*, the countries that are the HELCOM members are highlighted. The European Union (EU) is also HELCOM member and is strongly interested in Baltic Sea Region protection. According to the United Nations Convention on the Law of the Sea (UNCLOS 1982), the Baltic Sea was divided into the co-called exclusive economic zones (EEZ). The borders of EEZ at the Baltic Sea, claimed by each state are presented in *Figure 3*. In the EEZ each state has special rights regarding the exploration and use of marine resources, including energy production from water and wind. Moreover, each state is obliged to protection and preservation of its EEZ marine environment.

Figure 3. Exclusive economic zones at the Baltic Sea (source: http://maps.helcom.fi/)

A very important role in the Baltic Sea Region (BSR) protection plays the EU and EEZ states policy concerned with the safety and security of operating in this region so called critical infrastructures, critical infrastructure networks and interconnected and interacting complex networks of critical infrastructure networks. The strengthening the critical infrastructures resilience to climate and weather changes in this region also is one of the most important aspects of this EU and EEZ states policy.

2. Critical infrastructure networks at Baltic Sea and its seaside

2.1. Critical infrastructures and their operation environment methodology

Before the considerations on critical infrastructure installations at Baltic Sea Region, we refer to definitions of selected basic notions concerned with critical infrastructures and climate and weather impacts on their safety [7]-[16], [19]-[22], [33]-[34], [47]-[49], [67]-[70], [73]-[74], [86], [100]-[101].

We start with the notion of the complex system that is defined as a set or group of interacting, interrelated or interdependent elements or parts, that are organized and integrated to form a collective unity or an unified whole, to achieve a common objective.

This definition lays emphasis on the interactions between the parts of a system and the external environment to perform a specific task or function in the context of an operational environment. This focus on interactions is to take a view on the expected or unexpected demands (inputs) that will be placed on the system and see whether necessary and sufficient resources are available to process the demands. These might take form of stresses. These stresses can be either expected, as part of normal operations, or unexpected, as part of unforeseen acts or conditions that produce beyond-normal (i.e., abnormal) conditions and behaviors. This definition of a system, therefore, includes not only the product or the process but also the influences that the surrounding environment (including human interactions) may have on the product's or process's safety performance.

The system operating environment is defined as the surroundings in which a system operates, including air, water, land, natural resources, flora, fauna, humans and their interrelations.

The system operating environment threat is an unnatural event that may cause the system damage and/or change its operation activity in the way unsafe for the system and its operating environment, for instance: another ship activity in the ship operating environment that can result in an accident with serious consequences for the ship and its operating environment, a human error or a terrorist attack changing the system operation process in an unsafe way.

The climate related hazard is a natural physical event coming out from climate change that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, and environmental resources.

The system inside dependencies are dependencies within a system itself i.e. relationship between components and subsystems in a system causing state changes of other components and subsystems and in a consequence resulting in changes of the system state.

The system outside dependencies are dependencies coming from the system operating environment (external factors), including changes of the system state caused by outside this system conditions e.g. climate changes, changes of its functionality, location, other objects, government and human decisions (regulations, economic, public policy).

Now, we can define the critical infrastructure as a complex system in its operating environment that significant features are inside-system dependencies and outside-system dependencies, that in the case of its degradation have significant destructive influence on the health, safety and security, economics and social conditions of large human communities and territory areas.

Further, we may define the country's critical infrastructure as a complex system and assets located in the country which is essential (vital) for the national security, governance, public health and safety, economy and public confidence of this country.

More general notion is the regional critical infrastructure defined as the network of interconnected and interdependent critical infrastructures located in the considered region that function collaboratively in order to ensure a continuous production flow of essentials, goods and services.

And particularly, the European critical infrastructure is the network of interconnected and interdependent critical infrastructures located in EU member states that function collaboratively in order to ensure a continuous production flow of essentials, goods and services.

To explain two last definitions, we need to be familiar with the following three notions, the critical infrastructure network which is a set of interconnected and interdependent critical infrastructures interacting directly and indirectly at various levels of their complexity and operating activity, the interconnected critical infrastructures that are critical infrastructures in mutually direct and indirect connections between themselves and the interdependent critical infrastructures that are critical infrastructures in mutually dependent relationships between themselves interacting at various levels of their complexity.

The critical infrastructure accident. An event that causes changing the critical infrastructure safety state into the safety state worse than the critical safety state that is dangerous for the critical infrastructure itself and its operating environment.

The critical infrastructure network cascading effects are called degrading effects occurring within acritical infrastructure and between critical infrastructures in their operating environment, including situations in which one critical infrastructure causes degradation of another ones, which again causes additional degradation in other critical infrastructures and in their operating environment.

The critical infrastructure threat is the occurrence of an unwanted circumstance or event, that may cause damage, functioning disruption or service interruption to critical infrastructures.

The resilience is the sufficient ability of an object to continue its operational objective in the conditions including harmful impacts and the ability to mitigate and/or to neutralize those harmful impacts.

The critical infrastructure resilience is the ability of a critical infrastructure to continue providing its essential services when threatened by a harmful event as well as its speed of recovery and ability to return to normal operation after the threat has receded.

The critical infrastructure vulnerability is the critical infrastructure feature that makes it easily influenced by some external threat and hazards coming from its operating environment.

The critical infrastructure exposure is the fact or the condition of being exposed to something (of being subjected to an action or an influence), for instance being exposed to severe weather.

To be able to consider fluently the climate change impacts on critical infrastructures behavior, we introduce definitions of some notions related to those interactions.

The climate is defined as dynamic interactions of several components including atmosphere, hydrosphere, cryosphere, land surface and biosphere.

The weather is a short-term dynamically changing the states of atmosphere characterized by the values of several parameters including temperature, pressure, humidity and direction and force of wind.

The climate change is defined as any changes in climate over time, either due to natural variability or as a result of human activity.

The extreme weather event is defined as meteorological conditions that are dangerous and happen at a particular place and time and can generate severe hazards.

The hazard caused by weather change is an event associated with extreme weather that may cause the loss of life or severe injury, property damage, social and economic disruption or environmental degradation. For instance: a dangerous chemical relise into the sea water as a result of ship accident cause by severe storm.

The critical infrastructure resilience to climate change is the ability of a critical infrastructure to continue providing its essential services when it is exposed to hazards associated with coming out from the climate change harmful events as well as its speed of recovery and ability to return to normal operation after those threats has receded.

A bit different definition to the above is the following one.

The critical infrastructure resilience to climate change is a critical infrastructure capacity being able to absorb and to recover from hazardous events appearing as a result of climate change.

The critical infrastructure strengthening to climate change is an increasing critical infrastructure capacity through its components and subsystems parameters improving and its operating environment parameters modification to achieve its characteristics stronger what allows its functioning in its operating environment to be able to absorb and to recover from hazardous events appearing as a result of climate change.

The critical infrastructure natural disaster resilience is a critical infrastructure capacity being able to absorb and to recover from hazardous events appearing as a result of natural disaster impacts.

The critical infrastructure adaptation to climate change is a modification of critical infrastructure structure, its components and subsystems parameters and its operating environment parameters to achieve its characteristics that allows its functioning in its operating environment changed by climate change impacts.

The critical infrastructure natural disaster impacts risk is defined as the possibility of occurrence over the specified time period and area of dangerous alterations in the critical infrastructure normal functioning due to hazardous events coming out as a result of natural disaster impacts and interacting with critical infrastructure, leading to its and its operating environment degradation.

The critical infrastructure natural disaster vulnerability is a critical infrastructure feature that makes it easily influenced by some external factors and hazards coming from its operating environment dangerous changes forced by natural disaster impacts.

The critical infrastructure natural disaster impacts reduction is defined as efforts and actions to reduce effects of potential hazards coming from natural disaster influence on critical infrastructure by the reduction of their occurrence frequency and intensity, changing their interactions with people and their support systems.

The critical infrastructure natural disaster impacts mitigation is defined as efforts and actions to prevent and reduce effects of potential hazards coming from natural disaster influence on critical infrastructure by their elimination or reduction of their occurrence frequency and intensity, changing their interactions with people and their support systems and making alters the way people live and the systems they create.

The critical infrastructure resilience to natural hazard is the critical infrastructure capacity being able to absorb and to recover from natural hazards.

The critical infrastructure preparedness to climate change is the critical infrastructure ability to ensure effective response to the impact of climate change related hazards, including the critical infrastructure operating organizational reactions to the issuance of timely and effective early warnings.

The strengthening critical infrastructure resilience is defined as efforts, like policies, procedures and actions, taken to prolong the proper and effective functioning of a critical infrastructure and providing its essential services when it is exposed to unnatural threats and natural hazards.

The strengthening critical infrastructure resilience to climate change is an increasing the critical infrastructure capacity through its components and subsystems parameters improving and its operating environment parameters modification to achieve its characteristics stronger what allow its functioning in its operating environment to be able to absorb and to recover from hazardous events appearing as a result of climate change.

Finally, to be familiar to the notions concerned with the critical infrastructure water environment, we introduce definitions of selected terms related to this environment.

The basin is a lake or river and its drainage area [4].

The brackish is a water body that it is neither fresh water nor fully marine water, but with a salt concentration in between [4].

The bottom water (deep water) is the water beneath the thermocline [4].

The epi-continental sea is a sea situated on, rather than between, continents [4].

The exclusive economic zone (EEZ) is an exclusive part of the continental shelf, taken to be a band extending 200 miles from the country shore where this country exploration and exploitation of marine resources is allowed [102].

The halocline is a rapid increase in salinity that occurs at a water depth of about 70-90 m in the Baltic Sea [4].

The redox-cline is the oxygen gradient from water depth of about 60-7- m to about 140 m in the Baltic Sea [4].

The surface water is the water above the thermocline [4].

The thermocline is the temperature gradient between a water depth of 20 m and about 70 m in the Baltic Sea [4].

The water exchange is the time water stays in a given area, or the retention time; water exchange varies in time and space in any given coastal area [4].

2.2. Critical infrastructure installations at Baltic Sea region

Considering definitions of main notions from the above methodology concerned with critical infrastructures and their networks and the nature and features of the industrial installations at the Baltic Sea

Region, we are convinced to distinguish the following 8 main critical infrastructure networks operating in this region [7]-[10], [22], [47], [49]:

- port critical infrastructure network;
- shipping critical infrastructure network;
- oil rig critical infrastructure network;
- wind farm critical infrastructure network;
- electric cable critical infrastructure network;
- gas pipeline critical infrastructure network;
- oil pipeline critical infrastructure network;
- ship traffic and operation information critical infrastructure network.

We classify the above distinguished shipping critical infrastructure network to the class of so called dynamic installations and the remaining distinguished 7 critical infrastructures to the class of so called static installations.

Moreover, we suggest to call the network of all those distinguished 8 networks operating at Baltic Sea Region the Global Baltic Network of Critical Infrastructure Networks [33]-[34].

The elements of those critical infrastructures and their networks, on the one hand, may be vulnerable to damage caused by external factors (threats from) and on the other hand, they may pose actual or potential threats to other critical infrastructures and networks. The dangerous events coming from/to critical infrastructures located in the Baltic Sea area can be divided into:

- the threats associated with dynamic installations, like shipping and port operations,
- the threats associated with various static industrial installations, like listed above,
- the natural hazards associated with weather and climate change.

The model of area-picture of potential dangerous events coming from/to critical infrastructures in the Baltic Sea area is shown in *Figure 4.* This model can be used to construct a global network of interconnected and interdependent critical infrastructure networks existing in the Baltic Sea Region what is highly reasonable as usually the critical infrastructures are not isolated and they create a system of interconnected and interdependent critical infrastructures [85].

Often, one industrial sector activities concerned with one critical infrastructure may be in conflict of interest with the activities of a number of other critical infrastructures of other industrial sectors. Some sectors are quite stable while others are still changing, thus the global model of network on critical infrastructures needs to consider time-dependent behavior of critical infrastructures it is to be composed. The proposed approach, taking into account layers of “dynamic threats” (threats associated with dynamic installations), “static threats” (threats associated with static installations) and natural climatic hazards (hazards associated with climate/weather change), in a holistic and dynamic way, can help to indicate critical infrastructures which can be affected and can affect other critical infrastructures in fixed area of the Baltic Sea Region.

Similar ideas of schemes showing the connections and interdependencies between critical infrastructures have been presented in [92] and [27]. In [92], in *Figure 1*, individual infrastructure networks are represented on a single plane, whereas in *Figure 2*, the parallel lines represent individual sectors or sector subsets within the particular infrastructure. In this project, there are considered ties and dependencies existing within each infrastructure (internal dependencies) and between the different sectors (infrastructure interdependencies). A scheme showing the interconnection of critical infrastructures and their qualitative dependencies and interdependencies has been presented in the report prepared by Committee on the Peaceful Uses of Outer Space [27].

Among the “static threats” we can distinguish:

- the elements, which are merely obstacles and pose a threat such as shipwrecks and sunken chemical weapons,
- physical structures which are part of critical infrastructure and can have negative impact on other sectors or cannot co-exist in the same area (e.g. wind farms),
- and components of critical infrastructures, which constitute a threat to other sectors and at the same time they are themselves threatened with disturbances in their functioning.

The latter group of threats can include those coming from pipelines, electricity cables, oil rigs. For example failure of pipelines caused by anchors passing over the pipe, corrosion or breakage, can result in oil spills and affect both nature and many commercial sectors. The leakages can be also caused by operational spills and discharges or blowouts from oil wells [103].

Large scale wind farms may result in conflicts with other sectors such as shipping, laying of cables and pipelines and military activities, as they block specific areas. Furthermore, wind farms can potentially cause interference with hydrological processes of the sea by altering water currents or transportation of sediments [87].

The shipping sector is a critical infrastructure network which collides with other sectors, for example with wind energy sector. Wind farms occupy more and more areas and there is usually safety zone of 500 meters around wind farms, with restrictions for shipping, and a buffer zone of 500 meters around the cables, which prohibits anchoring of vessels [39].

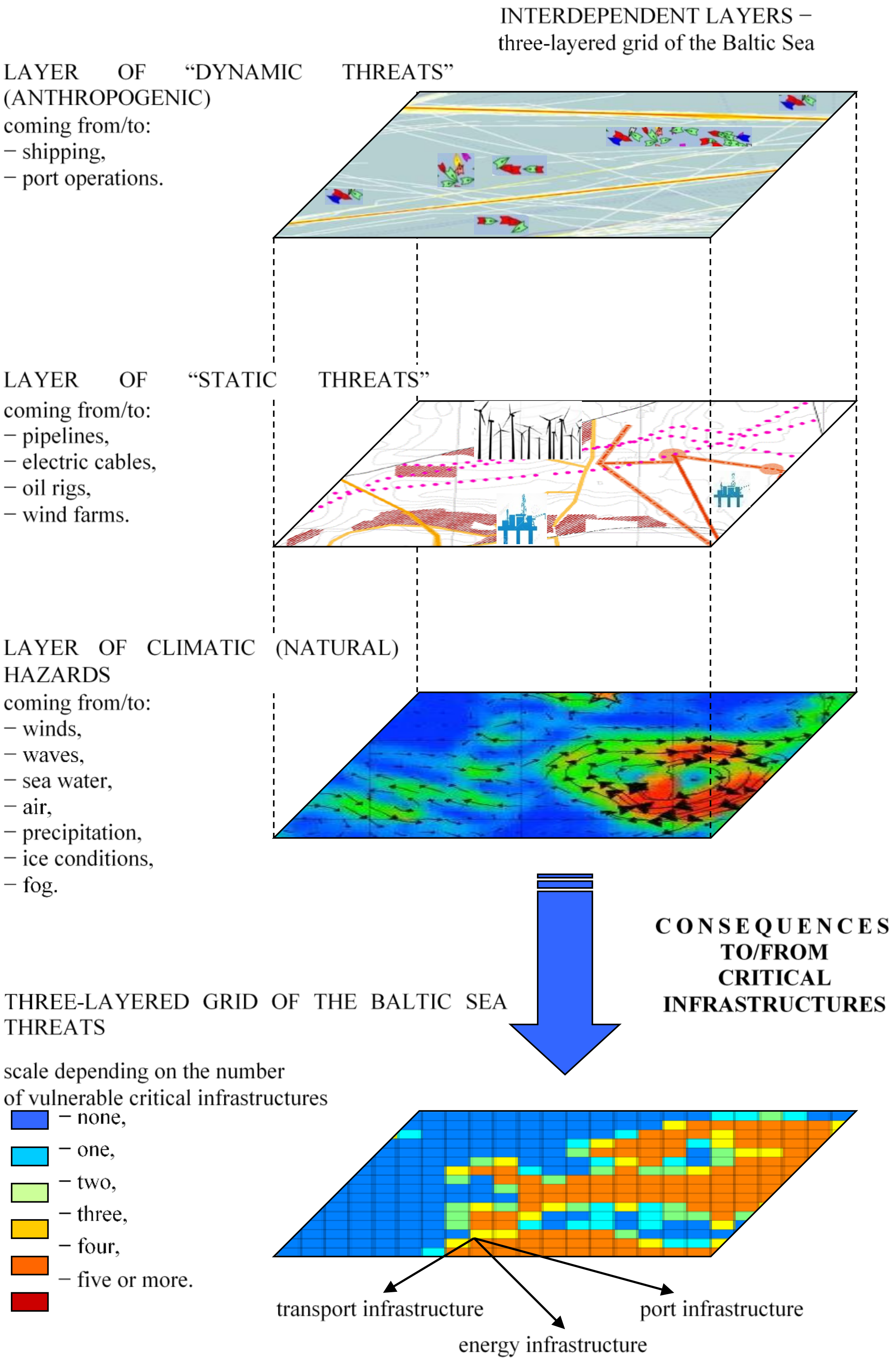

Figure 4. The model of area-picture of potential threats from/to critical infrastructures in the Baltic Sea Region.

Each month there are around 3,500 to 5,000 ships on the waters of the Baltic Sea; around 2,000 sizeable ships are normally at sea at any given moment, including large oil tankers, ships carrying dangerous and potentially polluting cargoes, as well as many large passenger ferries [28]. According to HELCOM, there has been an increase in both groundings and collisions during the last years. Many accidents result in oil spills. A large oil accident in the Baltic Sea would have serious ecological effects [104].

The main environmental effects of shipping and other activities at sea include air pollution, illegal deliberate and accidental discharges of oil, hazardous substances and other wastes, and the unintentional introduction of invasive alien organisms via ships' ballast water or hulls. Shipping adds to the problem of eutrophication of the Baltic Sea with its nutrient inputs from sewage discharges and nitrogen oxides (NOx) emissions [63]. In our opinion, those facts are sufficient and reasonable to consider the set of operating in the Baltic Sea area as a shipping critical infrastructure network what currently is not clearly acceptable in critical infrastructure safety analysis. Our suggestion is to accept our approach without any objections.

The Baltic Sea is facing an expansion in all sectors (*Figure 5*). This growth increase demand for the space and resources of the sea, and can consequently lead to conflicts within maritime sectors and between sectors. The Baltic Sea is already one of the most densely trafficked sea regions in the world. In addition to the pressures from place-based maritime activities, the already stressed Baltic Sea ecosystem is exposed to further pressures from diffuse sources like agricultural and industrial pollution and climate change [103].

In the layer of climatic hazards we can take into account wind, temperature, humidity, cloudiness, precipitation or solar radiation as well as occurrence extreme weather events – hurricanes, storms, etc. – and changes in weather patterns. Sea-surface height is an important indicator of climate variability and long-term change. According to [62], a compilation of mid-range and high-range sea-level rise scenarios projected respectively a 0.6 m and 1.1 m sea-level rise in the Baltic Sea over the 21st century.

The results of multi-media ensemble simulations of projected changes in sea-level extremes caused by changes in the regional wind field indicated that at the end of the 21st century the largest changes in mean sea-surface height will occur during spring, amounting to up to 20 cm in coastal areas of the Bothnian Bay.

The maximum change in the annual mean sea-surface height will be 10 cm. However, these results do not take into account large-scale sea-level rise or the land uplift in the Baltic Sea area. Another study that also took into account available global sea-level rise scenarios and simulated regional wind speed changes found that sea-level rise has a greater potential to increase storm surge levels in the Baltic Sea than does increased wind speed. This study projected large increases of storm surge levels at the entrance to the Baltic Sea, but the relative impact of changing wind speed on sea-level extremes may be even greater for areas in the eastern Baltic [62].

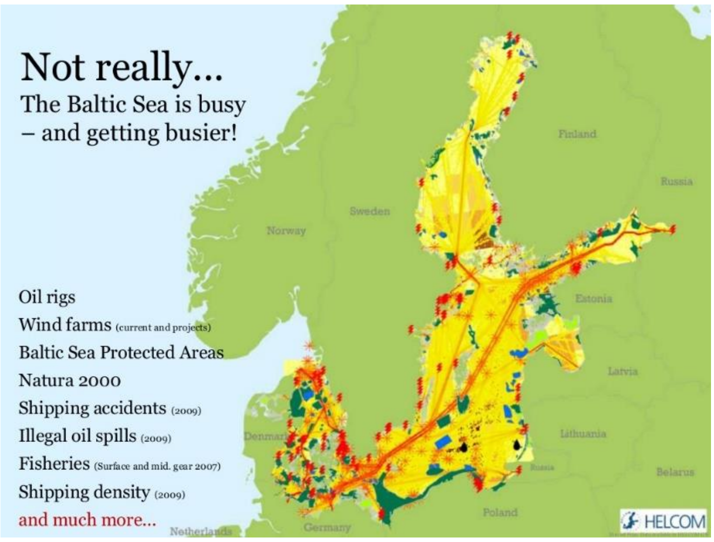

Figure 5. Components of spatial planning at BSR: critical infrastructures, obstructions, dangerous areas, protected areas, shipping accidents, traffic density, fisheries, oil spills and Natura 2000.

There is a complex relationship between climate change and maritime infrastructure sectors. This relationship can be considered in terms of how climate change impacts on the maritime industry, e.g. extreme weather events, erosion of coastal infrastructure and opening of new sea routes.

The most serious and costly water-related impacts of climate change are likely to be coastal flooding. Low-lying port facilities, roads, rail lines, tunnels, pipelines, ventilation shafts, and power lines are potentially subject to flooding, depending on the extent of sea level rise and storm surges. Global climate change is likely to require reengineered freight facilities that are better able to withstand storm surges and flooding. For example, stronger, higher, corrosion- and scour-resistant bridges will be needed in areas subject to storm surges and salt water contamination. Lift-on/lift-off port facilities may replace roll-on/roll-off port facilities in harbors that experience unusually large tidal variations.

Critical infrastructure components can be also installations or objects that cause danger for vessels. Oil rigs and wind farms are the best examples of such obstructions.

3. Safety and security of Baltic Sea area critical infrastructure networks - integrated management system

3.1. Main project aims

The proposed project is aimed at proposing new methods and developing advanced tools capable to support effective modelling and decision making in the process of evaluating and controlling relevant risks in time including the safety and security aspects. The methods for analysis and assessment of relevant risks for different time horizons will be developed including long term conditions and consequences due to potential accidents and resulting pollution and environment degradation. Its main focus is on the creation and implementation of new techniques, procedures and strategies to improve and to reduce and control dynamic risks of real ports and maritime complex infrastructure systems, installations and processes related to the inside impacts (organisation structure, subsystems and components' interactions) and the outside impacts (coming from their operating environment threats and natural hazards).

The project will propose new methods ensuring and improving safety and security of critical infrastructure networks in various sectors with a special stress on their adoption to port and water of Baltic Sea area. With the created and adopted methods and tools, the project will improve and link conventional approaches within current methods and procedures of safety and security of critical infrastructure networks in various sectors, by providing an integrated package of solutions consisting of various packages of theoretical and practical tools. These methods and tools will allow to create an original and coherent theory of safety and security of critical infrastructure networks that will be ready for direct use by safety theoreticians and practitioners dealing with safety and security of port and maritime critical infrastructures and processes.

The main deliverable and impact of the project on the development of science will be the development and ordering safety and security knowledge and creating new coherent theory of critical infrastructure networks' safety and security and improving significantly the safety and security of human overall activity in port and maritime sectors by creating the Integrated Critical Infrastructure Safety and Security Management System (ICISSMS) placed at the newly created Internet Critical Infrastructure Safety and Security Management Centre (ICISSMC). The center ICISSMC will carry permanent education, dissemination and consultancy services to various port and maritime industry and administration sectors including seminars, conferences, training courses and fully operational interactive internet service as the main gate to all critical infrastructures safety and security related resources and knowledge. The results of the project will have an significant impact on the development of safety and security science and reducing negative influence of the risk of operating environment threats coming from human industrial activity and natural hazards coming from climate-weather change.

3.2. Project proposal description

Many transportation systems belong to the class of complex critical infrastructure systems as a result of the large number of interacting components and subsystems they are built of and their complicated operating processes having significant influence on their safety. This complexity and the inside and the outside of the port and maritime critical infrastructure dependencies and natural hazards cause that there is a need to develop new comprehensive approaches and general methods of analysis, identification, prediction, improvement and optimization for these complex port and maritime system safety and security in order to improve and to ensure high level of these systems operation and economy.

From the point of view of more precise analysis of the safety and effectiveness of port and maritime critical infrastructures, the developed methods will be based on a multistate approach to these complex systems safety analysis instead of normally used two-state approach. This will enable different port and maritime critical infrastructure inside and outside safety states to be distinguished, such that they ensure a demanded level of their operation effectiveness with accepted for the environment consequences of the dangerous accidents.

In most safety analyses, it is assumed that components of a system are independent. But in reality, especially in the case of port and maritime critical infrastructures, this assumption is not true, so that the dependencies among the critical infrastructure systems components and subsystems should be obligatory assumed and considered in the safety and security analysis and improvement. It is a natural assumption, that after decreasing the safety state by one of components in a subsystem, the inside interactions among the remaining components may cause further components safety states decrease. In reality, in the port and maritime critical infrastructures, it may even cause the whole system safety state dangerous degradation. In the project the new methods of the safety investigations of the multistate complex port and maritime systems with dependent components and subsystems will be significantly developed. The safety functions of the complex port and maritime critical systems with dependent components will be determined for as wide as possible class of complex port and maritime critical infrastructure networks. In the developed models, it will be assumed that the port and maritime systems components are dependent and have the piecewise exponential safety functions with interdependent departures rates from the subsets of the safety states. To tie the results of investigations of the port and maritime critical infrastructure networks inside-dependences together with the impacts coming from these critical infrastructures outside-dependencies, the semi-Markov models will be used. The linking of the inside and outside the port and maritime critical infrastructures dependencies and including other outside dangerous events and hazards coming from the operating environment threats and from natural hazards, under the assumed their changing in time and operation structures and their components multi-state ageing/degrading models, is the main idea of the project methodology. This join considering of all these elements is a main innovative aspect of this project and the basis for the formulation and development of the new solutions concerned with the modeling, identification, prediction, improvement and optimization of the safety of the port and maritime complex critical infrastructures related to their operation processes and their inside and outside interactions and impacts. Including into the project the analysis, modeling, identification, prediction, optimization and mitigation of port and maritime critical infrastructure accidents consequences also is of great added value.

Furthermore, generalizations and developments based on the methods concerned with effectiveness and cost efficient maintenance strategies, optimization methods and prognostic advanced methods for port and maritime critical infrastructure networks, will be performed in the project. In this aspect, the project is aimed on the entire elaboration of the methods of evaluation and improvement of safety and security of as wide as possible class of port and maritime complex multistate critical infrastructure networks composed of dependent components and related to their operation processes and other outside impacts. In the project, there will be pointed out the possibility of these methods practical applications to complex safety and security of port and maritime critical infrastructures and to analysis and optimization and mitigation of their accidents' consequences concerned with their operating environment pollution and degradation. The analytical methods proposed will be complemented with the statistical methods for operation, safety and security data processing that will include an innovative and original approach to the methods of safety and security evaluation and optimization on the basis of the existing rough and incomplete empirical data. Moreover, in the case of impossibility of analytical methods application, the Monte Carlo simulation method will be proposed. The Monte Carlo simulation method will also be proposed as a tool to control safety and security of critical infrastructure networks and their accidents consequence in real time to have information on their security and safety state and to predict the consequences of their accidents in the nearest future. Thus, these all approaches will fulfill a comprehensive solution of problems the project is concerned with. The activities also performed in the project will be research and technology development, innovation and demonstration, scientific experiments expanding knowledge, newly developed tools practical testing, education and training.

Joint considering of the inside and outside of the port and maritime critical infrastructures dependencies and including other outside dangerous events and hazards coming from the environment and from other dangerous processes is an original approach to analysis of safety and security of complex port and maritime critical infrastructure networks. This joining is a main novel aspect of the project proposal allowing to develop significant and new results concerned with the modeling, identification, evaluation, prediction and optimization of the safety and security of the complex port and maritime critical infrastructures related to their operation processes and their inside and outside interactions and impacts. The analytical methods in systems' safety and security modeling, identification, evaluation, improvement and optimization proposed in the project will significantly extend the state of the art in this field by introducing new possibilities of investigation of the complex critical infrastructure networks s related to their inside dependences and outside dependencies and hazards, and in final effect, by the creation of an original and comprehensive theory of safety and security of port and maritime critical infrastructure networks.

The project models, methods, procedures and algorithms will be based on the achievements of the project partners established in theory of reliability and safety included in the monographs: "Reliability and Safety of Complex Technical Systems and Processes: Modeling-Identification-Prediction-Optimization" by Krzysztof Kołowrocki and Joanna Soszyńska-Budny, Springer 2011, "Reliability of Large and Complex Systems" by Krzysztof Kołowrocki, Elsevier 2014, "Consequences of Maritime Critical Infrastructure Accidents with Chemical Releases: Modelling – Identification – Prediction – Optimization – Mitigation" by Magdalena Bogalecka, Elsevier 2019 (to appear), "Reliability and Sensitivity Modelling and Optimization of Transportation Networks" (in

Polish) by Sambor Guze, Gdynia Maritime Press 2019 (to appear), “Reliability and Safety of Dependent Systems and Networks with Cascading Effects” by Agnieszka Blokus, Elsevier 2019 (to appear) and “Relibility and Safety of Critical Infrastructures: Reliability, Safety, Risk and Resilience Indicators” by Krzysztof Kołowrocki and Joanna Soszyńska-Budny, Elsevier (under completion) and in the recently published papers [23]-[24], [82]-[83], [100] that are the source of scientific inspirations for this project proposal. The proposed approach to the problems of safety and security of complex port and maritime critical infrastructure networks is an innovative and very important aspect of the project as in the word science there are no comprehensive and general solutions concerned with the safety of multistate complex industrial port and maritime complex critical infrastructure networks related to their operation processes and their inside and outside dependencies and impacts considered simultaneously. The scientific experiments (9 case studies) expanding the knowledge and primary practical applications of the created theory of safety and security developed methods to the real transport critical infrastructure networks and to their accidents’ consequences analysis, modelling, identification, prediction and mitigation, which are also an important reason for the realization of this project.

3.3. Project research team conception

To implement the project successfully and to achieve the results useful for the Baltic Sea region, it is supposed that the project consortium will be composed of the partners, the researchers and practitioners, from all 9 countries of the HELCOM member states (*Figure 2,* Section 1):
Partner 1. The Denmark’s Team;
Partner 2. The Estonia’s Team;
Partner 3. The Finland’s Team;
Partner 4. The Germany’s Team;
Partner 5. The Latvia’s Team;
Partner 6. The Lithuania’s Team;
Partner 7. The Poland’s Team involved in the project will include the following partners:
- Gdynia Maritime University (GMU),
- Gdynia Naval Academy (GNA),
- Gdańsk University of Technology (GUT),
- Polish Safety and Reliability Association (PSRA), the coordinator of the Poland’s Team,
- Maritime Search and Rescue Service (MSRS),
- Rzeszów University of Technology (RUT),
- System Research Institute (SRI);

Partner 8. The Russia’s Team;
Partner 9. The Sweden’s Team.

3.4. Partner cooperation added value

The project partners are convinced that the formation of the above is joint Project Research Team will lead to the development of high advanced research with serious impact on the development of the world science and knowledge in the field of safety and security with the wide possibilities of practical applications in the port and maritime sector.

The participants will widely discuss the sensibility and possibility of the creating the competitive international consortium in the field of safety and reliability of port and maritime installations and processes and applying successively for EU grant for this serious and viable project for the Baltic Sea region.

The project will be completed with the results dissemination and exploitation, including workshops, training courses, publications and practical demonstration of results.

The main deliverable and impact of the project on the development of science will be the development and ordering safety and security knowledge and creating new coherent theory of critical infrastructure networks’ safety and security published in 2 monographs-guidebooks (theoretical added value):
- Theory of safety and security of port and maritime critical infrastructure networks;
- Risk analysis of port and maritime critical infrastructure network accident consequences:

and improving significantly the safety and security of human overall activity in port and maritime sectors by creating (practical added value):
- The Integrated Critical Infrastructure Safety and Security Management System (ICISSMS);

to be implemented at created:
- The Internet Critical Infrastructure Safety and Security Management Centre (ICISSMC).

The project ambitious objectives and research activity are strategically very important to collaborating partners from social, economy, environmental and technological dimensions and will have a significant impact on reinforcing their competitiveness and excellence in overall safety and security research activity in general, and particularly in safety and security of port and maritime critical infrastructure networks scientific and technological advances and knowledge.

4. Main steps in project implementation

4.1. The first primary step of project activity

At the primary step of project activity, the analysis of industry installations and other systems placed within the Baltic Sea area, including their current status and prognosis of their future developments will be performed. Moreover, the specification of criteria determining particular installations and systems as critical infrastructures will be done.

After that, 8 Baltic Critical Infrastructure Networks (BCINs) for various existing in the Baltic Sea port and water areas industrial installations will be defined and analyzed. Moreover, an effort will be made in order to create a global network of all considered in this region critical infrastructures in the form of Baltic critical infrastructure network of networks called the Global Baltic Network of Critical Infrastructure Networks (GBNCIN).

4.2. The second step of project activity

The second step in the project research will be focused on the essential developing of tools concerned with modelling, identification and prediction of [34], [48], [70]-[75],[78]-[79]:

- the critical infrastructure operation process (CIOP);
- the weather change process (WCP) at the critical infrastructure operating area;
- the joint critical infrastructure operation and weather change process (CIOWP);

and their adaptations to 8 single Baltic Critical Infrastructure Networks (BSCINs) and to the Global Baltic Network of Critical Infrastructure Networks (GBNCIN).

At this research step, after modelling Critical Infrastructure Operation Process (CIOP) including Operating Environment Threats (OET) and modelling Weather Change Process (WCP) including Extreme Weather Hazards (EWH), the results will be join to construct the Critical Infrastructure Operation Process General Model (CIOPGM) related to Operating Environment Threats (OET) and Extreme Weather Hazards (EWH).

Similarly, after identification methods and procedures of Critical Infrastructure Operation Process (CIOP) including Operating Environment Threats (OET) and identification methods and procedures of Weather Change Process (WCP) including Extreme Weather Hazards (EWH), the results will be considered together in order to create the identification methods and procedures of unknown parameters of Critical Infrastructure Operation Process General Model (CIOPGM) related to Operating Environment Threats (OET) and Extreme Weather Hazards (EWH).

Further, practical applications of the results of the above project activity will be done to modelling the particular BSCINs and the GBNCIN operation processes at the Baltic Sea area using the CIOPGM related to Operating Environment Threats (OET) and Extreme Weather Hazards (EWH) in this region and to evaluation of their unknown parameters.

Moreover, fixing the assets of single BSCINs and GBNCIN and identifying climate related hazards in their operating environment will be done.

4.3. The third step of project activity

This stage of the project activity will be focused on the essential developing of tools concerned with [71]:

- the critical infrastructures safety modelling;
- the critical infrastructures safety prediction;
- the critical infrastructures safety optimization;

and their applications to the single BSCINs and the GBNCIN.

At this stage of research activity, after modelling safety of multistate ageing systems with independent components and modelling safety of multistate ageing systems with dependent components and subsystems, the Integrated Model of Critical Infrastructure Safety (IMCIS) related to its operation process including operating environment threats (with other critical infrastructures influence, without climate-weather change influence) will be designed and the methods and procedures of identification of its unknown parameters will be proposed. Further, the adaptation of Integrated Model of Critical Infrastructure Safety (IMCIS) to critical infrastructure safety prediction will be done and the adaptation of Integrated Model of Critical Infrastructure Safety (IMCIS) to critical infrastructures network safety and “cascading effects” prediction (without climate-weather change influence) will be performed as well.

Practical applications of the results of the above activity will be performed to the particular 8 BSCINs and the GBNCIN (case studies 1-9) safety modelling, identification and prediction (without considering climate-weather change influence).

4.4. The fourth step of project activity

This step in project research will be focused on the essential developing of tools concerned with:

- the critical infrastructure operating environment threats and weather extreme hazards impacts assessment general model;
- the modelling critical infrastructure accident consequences;

and their adaptation to the chemical spill and other dangerous for the environment consequences generated by the accident of the single BSCINs and GBNCIN.

At this stage, the impact assessment model will be created starting with the integration of the Integrated Model of Critical Infrastructure Safety (IMCIS) and the Critical Infrastructure Operation Process General Model (CIOPGM) into the General Integrated Model of Critical Infrastructure Safety (GIMCIS) related to operating environment threads (OET) and climate-weather extreme hazards (EWH). Next, GIMCIS will be adapted to critical infrastructures network safety and "cascading effects" prediction related to climate-weather change influence and applied to the single BSCINs and GBNCIN safety modelling, identification and prediction (case studies 1-9).

The modelling critical infrastructure accident consequences will be done through designing the General Model of Critical Infrastructure Accident Consequences (GMCIAC) and the identification of its unknown parameters will be performed. Further, the GMCIAC adaptation to the prediction of critical infrastructure accident consequences will be done and its practical applications will be performed to the chemical spill and other events dangerous events for the environment consequences generated by the accident of one single BSCINs and GBNCIN operating at the Baltic Sea waters (case studies 1-9).

Additionally, at this stage, the inventory report of all impact models will be done.

4.5. The fifth step of project activity

The fifth step in project research will be focused on the essential developing of tools concerned with:

- the critical infrastructure resilience;
- the critical infrastructure business continuity under climate pressures;
- the critical infrastructure cost-effectiveness analysis;

and their adaptation to the single critical BSCINs and the GBNCIN.

The procedures of operation and safety optimization of critical infrastructure without and with considering WCP influence will be proposed to its resilience improving respectively by maximizing its lifetime in the set of safety states not worse than a critical safety state. Next, those procedures will be applied to optimization of operation and safety of the BSCINs and the GBNCIN without and with considering WCP influence (case studies 1-9).

Moreover, the method of critical infrastructure accident losses minimizing will be proposed and applied to the optimization BSCINs and the GBNCIN accident consequences.

Additionally, at this stage, the inventory report collecting and analyzing resilience indicators will be done.

4.6. The sixth step of project activity

At this stage of project activity, the research will be focused on practical adaptation and application of the tools developed in the project to the investigation of the hard meteorological conditions in Baltic Sea port influence on the BSCINs and the GBNCIN.

The results of earlier performed approaches to case studies 1-9 will be developed and applied to their final conduction and presentation to the invited stakeholders and critical infrastructure networks' administrative bodies during one-week seminar-meeting. The results of the following tools application to the BSCINs and the GBNCIN will be presented to the seminar audience for examination and evaluation:

- the Critical Infrastructure Operation Process General Model (CIOPGM) related to Operating Environment Threats (OET) and Extreme Weather Hazards (EWH) in this region;
- the methods of evaluation of unknown parameters of a port oil piping transportation system operation process related to Operating Environment Threats (OET) and Extreme Weather Hazards (EWH);
- the methods of identification of climate related hazards at the Baltic Sea area and their critical/extreme event parameters' exposure for port oil piping transportation critical infrastructure;
- the General Integrated Model of Critical Infrastructure Safety (GIMCIS);
- the methods of optimization of operation and safety without and with considering WCP influence through maximizing the lifetime in the set of safety states not worse than a critical safety state;
- the methods of optimization of operation and safety without and with considering WCP influence through minimizing the operation cost;
- the methods of optimization of operation and safety without and with considering WCP influence through maximizing lifetime in the set of safety states not worse than a critical safety state and minimizing operation cost;
- the inventory and comparison of the results concerned with safety;
- the new strategy assuring high safety and resilience;
- the General Model of Critical Infrastructure Accident Consequences (GMCIAC) to the chemical spill consequences generated by the accident;
- the methods of optimization of accident consequences through losses minimizing;
- the inventory and comparison of the results concerned with accident consequences;
- the new strategy assuring low consequences of accident concerned with chemical spills and other dangerous events;
- the new general strategy assuring high safety and resilience of critical infrastructure – operation process and safety parameters of critical infrastructure components/assets modification related to maximizing its safety characteristics and minimizing its operation

cost;

- the new strategy assuring low consequences of critical infrastructure accident – initiating events, environment threats and environment degradation processes modification related to minimizing critical infrastructure accident consequences.

4.7. The seventh final step of project activity

The final step of the project research activity will be completed with the reports on the project dissemination, communication and exploitation including workshops, training courses and publications.

The main deliverable and impact of the project on the development of science will be the development and ordering safety and security knowledge and creating new coherent theory of critical infrastructure networks' safety and security published in 2 monographs-guidebooks (theoretical added value):

- Theory of safety and security of port and maritime critical infrastructure networks;
- Risk analysis of port and maritime critical infrastructure network accident consequences:

and improving significantly the safety and security of human overall activity in port and maritime sectors by creating (practical added value):

- The Integrated Critical Infrastructure Safety and Security Management System (ICISSMS);

placed at new created:

- The Internet Critical Infrastructure Safety and Security Management Centre (ICISSMC).

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