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Determinants of COVID-19 Infections on Sea-Going Ships and Their Socio-Economic Consequences for Seafarers and Shipowners in Terms of Modeling Ship Emergency Procedures

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Abstract: The COVID-19 pandemic has caused many negative socio-economic consequences for seafarers and shipowners of such importance that, on the one hand, it inspired and, on the other hand, it became an impulse to undertake research in this direction. It seems that avoiding at least some consequences would be possible if both shipowners and ship masters operated based on safety management procedures strictly adapted to the pandemic situation. Of course, many crisis management procedures have been developed in maritime practice so far. Still, they mainly relate to such events as maritime incidents, maritime accidents, maritime disasters, oil spills, terrorist attacks, or sea piracy. However, they do not consider the specificity of a crisis situation created for the safety of the ship's crew by the global pandemic. Its appearance made all maritime transport entities, especially shipowners, aware of the lack of preparation for such an eventuality. Based on the general recommendations of international organizations, such as the WHO (World Health Organization) or the IMO (International Maritime Organization), they began developing and implementing urgent procedures for handling ships under COVID-19 conditions. Since the recommendations were formulated generally and the pandemic spread very quickly, the prevention and response procedures for a ship found to be affected by COVID-19 were developed ad hoc and, therefore, were often flawed. Consequently, it was concluded that it is worth creating a universal model of the procedure for dealing with a sea-going ship in pandemic conditions and reducing the adverse socio-economic consequences for shipowners and seafarers. This became the primary goal of the research undertaken in this direction, and this goal was closely related to the adopted central research hypothesis. The substance of the matter comes down to the fact that knowledge of the factors causing coronavirus infections will allow the development and implementation of effective procedures for handling ships in pandemic conditions. It will also reduce the risk and consequences of coronavirus infections. COVID-19 infections can be caused by many factors that are beyond the control of the shipowner and the ship's captain. Still, there are also those factors that they can control and thus eliminate or at least reduce the risk of contracting the coronavirus by the crew. Thus, their correct identification, ranking their importance in terms of the risk of infection, and then focusing on the elimination of the most important of them is the basis for building a universal model, in the sense of the possibility of applying to any sea-going ship in pandemic conditions. The work includes RCA (Root Cause Analysis), stratification analysis, weighted Ishikawa diagram, and Lorenz-Pareto chart. The primary sources of information used in the research came from the literature review, the analysis of normative acts, the analysis of documentation and procedures on board ships in pandemic conditions, questionnaire research, direct and focus interviews, and participant observation.

Keywords: ship management; ship; captain; ship crisis management; COVID-19 pandemic in maritime transport; crisis management in maritime transport; determinants of infections in marine vessels; Ishikawa diagram; stratification analysis; Lorenzo curve in maritime transport



Citation: Kasińska, J.; Jendryczka, V. Determinants of COVID-19 Infections on Sea-Going Ships and Their Socio-Economic Consequences for Seafarers and Shipowners in Terms of Modeling Ship Emergency Procedures. *Sustainability* **2022**, *14*, 10882. <https://doi.org/10.3390/su141710882>

Academic Editors: Sebastian Saniuk, Tomasz Rokicki and Dariusz Milewski

Received: 31 July 2022

Accepted: 22 August 2022

Published: 31 August 2022

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1. Introduction

1.1. Pandemic as a Crisis Situation in Maritime Transport

The word “crisis” comes from the Greek “krino” and means a turning point, decisive moment, a qualitative change layout or crisis, shock, turn, choice, resolution. The verb “krinein” means to sift, split, choose, determine, and plant. It is, therefore, worth emphasizing that the Greek etymology does not indicate its pejorative character [1–4].

The concept of crisis has a comprehensive meaning and is interpreted differently depending on its concerns. Therefore, for this study, the concept of crisis has been defined concerning maritime transport and the context of the pandemic. Therefore, a crisis is an event that is a broadly understood threat and a series of other events related to it that occur suddenly and unexpectedly. Such events have far-reaching effects (both negative and positive) and are difficult or even impossible to predict and estimate at the moment of this event. They are characterized by an element of surprise, deficit or excess of information, disorganization, delayed reaction, loss of control, interruption of normal decision-making processes, complex symptomatology, lack of panacea and quick solutions, necessity to make choices and make quick decisions, universality and idiosyncrasy, presence of both threats and opportunities, and sometimes panic. Moreover, this threat develops dynamically, and with time it covers the whole world. Counteracting the harmful effects of the crisis requires the involvement of forces and resources appropriate to its scale, nature, and range that exceed the capabilities of, for example, one economic entity, administrative unit, organization, or state [4–7].

The word “pandemic” comes from the Greek language, where “demos” means the people and “pan” means everyone. It means a disease of immense size [8], coinciding on all continents, i.e., on a global scale. The word “epidemic” is understood similarly, meaning the occurrence of disease cases at a specified time and area; previously unknown infectious diseases or other health-related phenomena occurring in a greater-than-expected number, much greater than in previous periods and much greater than average [9]. Compared to an epidemic, a pandemic has a larger global scale, while an epidemic has a local scope and occurs in one or more cities or one or several countries.

The appearance of both epidemics and pandemics worldwide is not a new phenomenon. In the 21st century alone, the following have already been announced: the SARS epidemic (2002–2003), the bird flu epidemic (2003–2006), the H1N1 swine flu pandemic (2009–2010), the Ebola virus epidemic (2013–2016 and 2018–2020), Zika virus (2015–2016), measles epidemic (2019–?) and the SARS-CoV-2 coronavirus pandemic (2020–?) [10–12].

Therefore, the question arises: Why was sea transport, despite previous experience, not prepared to fight the COVID-19 pandemic? The answer to this question is neither simple nor unambiguous. On the one hand, humanity has struggled with epidemics and pandemics since the dawn of history. Each pandemic had its specifics, but the dynamic development of medicine, which began at the turn of the 19th and 20th centuries, made it possible to fight the consequences of pandemic diseases [13]. Nowadays, an essential role in this aspect is played by the EU, WHO, and governments of individual countries. Taking into account the undertaken actions and the fundamental reasons for the unpreparedness of maritime transport (as well as other sectors) in the fight against COVID-19, some factors can be considered. Firstly, the response of the WHO to the developing pandemic was delayed (its state was announced only on 11 March 2020, while the Beijing authorities published information on pneumonia-of-unknown-cause cases on 31 December 2019). Secondly, the WHO repeated calls to the leaders of the Member States not to impose logistical restrictions on the movement of people and goods (i.e., from and to China, even after the announcement of the Public Health Emergency of International Concern, PHEIC), which delayed the restriction of air traffic and border closure. Thirdly, EU institutions initially presented an ambivalent approach to the spread of the coronavirus in China, Japan, and Korea (until March 2020, COVID-19 was not treated as a direct threat to the EU). We also observed a high level of split differences between social expectations and government actions between the WHO and some countries and significant differences in the level of

risk perception in individual countries, which introduced restrictions at various levels (in most cases, they were the so-called lockdowns) [14].

It should be emphasized that in maritime transport, as in other sectors, the COVID-19 pandemic, by its nature, is a specific type of crisis situation and has had a significant impact on the way maritime transport functions in the world. It has caused many economic and social consequences (including) for seafarers and shipowners and all other entities participating in it. Shipowners were and are prepared for crisis situations that are relatively well-known to them, such as marine incidents, accidents, and disasters, oil spills, pirate attacks, terrorist attacks, or the ship's entry into the area of hostilities. By way of explanation, the division into marine incidents, accidents, and disasters correspond to the severity of the events, and the main causes are collision or direct contact with another ship (rubbing against each other), a ship running aground, chafing or collision of the ship with port infrastructure elements, fire, explosion, hull damage, damage to watertight doors, damage to the ship or its equipment, dangerous list or capsizing, loss of position, and accident with rescue equipment. These causes may occur one after the other or in various combinations [15,16].

Returning to the main threat, the study, which resulted in the development of a weighted Ishikawa diagram determinant of infections of crew members on sea-going ships, focused on the search for an answer to the fundamental question: What causes, despite the management of the safety, operation, and crew of the ship at sea, any infection of their crews with the COVID-19 virus occurs at all? This is important because there are many provisions of international law or guidelines and recommendations formulated by the international maritime organizations and port procedures that are supposed to prevent them. In addition, there are many internal ship management procedures developed by the ship owner and/or operator, often in cooperation with powerful insurance institutions or banks (which, incidentally, can also act as ship owners), estimating the risks and their costs that may be associated with it.

We must notice that the pandemic surprised the shipowners. From their point of view, it immediately resulted in a significant increase in the importance of safety procedures in managing a sea-going vessel and its crew in entirely new conditions. The basis for developing effective procedures in this situation is the knowledge of the development of the pandemic situation in the world and related legislative changes, changes in the functioning of seaports, or the latest medical achievements in the aspect of coronavirus diagnostic tests and treatment. It is also imperative to know about the factors that cause infection when it occurs or in the event of suspicion of the possibility of contracting COVID-19. In terms of the previous considerations, the appearance of this threat is synonymous with the emergence of a crisis situation on the ship. In this context, the procedures of proceedings on-board sea-going vessels are of great importance in a pandemic. The development of a universal model for such a procedure has been recognized.

1.2. Research Problem

Respecting and implementing the provisions and guidelines of various international organizations concerning the safety of navigation (e.g., IMO, WHO), shipowners of sea-going ships develop on that basis internal management and conduct procedures on a sea-going vessel. These procedures take into account international standards (e.g., the MLC2006 convention) and national statutes and are in line with the regulations of the flag states. However, since these regulations are quite general, shipowners use them to create more detailed, internal procedures. Therefore, the procedures differ in terms of the country of registration of the shipping company, the country of registration of the ship, the requirements of the ports the ship enters, or the degree of detail contained therein, and in terms of the procedure to be followed on board in a pandemic situation. In this context, it is crucial to look for answers to the following question: What is the easiest and optimal way to act for the master of a sea-going vessel to minimize the risk of contamination of the crew members with the virus, and thus, in extreme cases, also a risk of death on board this vessel? Solving this problem, ultimately leading to the construction of appropriate procedures on

board, requires knowledge of the factors influencing the emergence of this threat. Therefore, identifying and assessing the importance of understanding factors influencing exposure risk of contamination of the ship's crew with the COVID-19 virus became the main subject of our research.

1.3. Objectives and Main Hypothesis

The literature review confirmed the author's initial assumption that the above concern, probably due to its topicality, has not yet been solved. This was a critical premise and justification for undertaking research. Their results could become the basis for developing a universal model of the procedure for dealing with a sea-going vessel in pandemic conditions.

Therefore, the main objective of the research [C_0] is to develop a universal model of the procedure for dealing with a sea-going vessel in pandemic conditions by identifying and assessing the significance of the determinants of COVID-19 virus infections of its crew members in terms of the risk of contracting the coronavirus. The primary research position [H_0] is the claim that thanks to the knowledge of these factors, it is possible to reduce the risk of future threats leading to the infection of crew members with the COVID-19 virus. Consequently, it is also possible to reduce the risk of occurrence of the negative socio-economic impact of the pandemic on seafarers and shipowners through the implementation of effective procedures for dealing with a sea-going ship in pandemic conditions.

The implementation of [C_0] and the verification of [H_0] required the achievement of subobjectives, such as:

- C_1 : Identification and description of the socio-economic impact of the pandemic on seafarers of sea-going ships and their shipowners;
- C_2 : Analysis of management procedures and handling on board a sea-going ship in a pandemic situation;
- C_3 : Identification, description, and ranking of the significance of the root causes and subcauses of the risk of contracting the COVID-19 virus by seafarers on board a sea-going ship.

The implementation of [C_1] was performed to indicate the specific socio-economic effects of the pandemic for shipowners and seafarers, and their scale and significance for both groups concerned. Achieving this goal has also become the basis for justifying the importance of undertaking the research in question. The implementation of [C_2] was closely related to the performance of [C_3]. In the case of [C_2], based on questionnaire surveys and the accompanying direct interviews, it was found that shipowners' procedures in a pandemic situation differ in terms of the scope of actions taken and the degree of their detail. The conclusions drawn in this way became the basis for the formulation of [C_3] and work on identifying the leading causes (and their subcauses) that affect coronavirus infection among ship crews, their description, and ranking their meanings. The achievement of [C_1] + [C_2] + [C_3] finally made it possible to implement [C_0] and thus, in short, to develop a universal model of the procedure for dealing with a sea-going vessel in pandemic conditions. Thus, [C_0] was verified.

1.4. Scope of the Research Subject

The survey covered representatives of 19 shipowners who have registered shipping activities in a country located in the Baltic Sea Region (except for former Russian shipowners), namely: PŻB Polferries, Unity Line, TT-Line, Northern Shipping Company, E-Line AS (Estline), Stena Line, Nordo Link, Destination Gotland, Rederi AB Lillgaard, Tallink Silja Line, Transfenica, Eckeroeline, Waseline, Finnlines, Viking Line, DFDS Lisco, DFDS Seaways, Scandlines, Fjordline. These entities have a total fleet of 130 sea-going vessels. Their area of operation is concentrated in the Baltic Sea Region (in the case of two shipowners, also outside it). This study also included representatives of maritime administration bodies and crews of sea-going ships. There were 43 people in total.

The choice was not accidental. Taking into account the main goal of the research, which was to develop a universal model of the procedure for dealing with a sea-going

ship in pandemic conditions, it was concluded that the needs of these shipowners coincide with the requirements of shipowners operating on a global scale. Especially, this model was supposed to be universal, so its implementation should be possible for all interested entities, and its effectiveness—similar.

The survey research was prepared and carried out by one of the authors (V.J.) and was multithreaded. In addition to the COVID-19 threat, it covered other areas related to shipping crisis situations. Only the part of the survey that directly related to COVID-19 was verified and used. The questions were addressed to 19 shipowners and 24 stakeholders from the maritime authorities and administration (for example, the authorizing officers and keepers of the ships), and crews of sea-going ships also. The authors found it necessary to conduct in-depth interviews in order to investigate the problem in more detail after conducting the survey. In-depth interviews were concluded personally by V.J. with eight stakeholders. The interviewers did not agree to disclosure of their employment or position on any other personal information. Therefore, the authors fully respect the request and kept the information as confidential.

Pilot research was carried out among members of two crews of large bulk carriers carrying out transports in and outside of the Baltic Sea area. Focus interviews were conducted with sea captains employed by the shipowners mentioned above, who, due to at least 20 years of professional experience, worked on ships also transporting loads around the world.

2. Materials and Methods

The following research methods and tools were used in the study: literature review, analysis of normative acts, documentation and procedures on sea-going vessels in pandemic conditions, participatory observation, direct interview, questionnaire research, RCA analysis (Root Cause Analysis), weighted Ishikawa diagram, stratification analysis, Lorenz–Pareto chart, UML language, and Visual Paradigm software.

Below, they are assigned to subsequent stages of this research [E_n], which covered:

- E₁: Literature studies, analysis of normative acts (in the field of Polish and international law), analysis of documentation and procedures of shipowners operating in the Baltic Sea in pandemic conditions, participatory observation, and direct interviews conducted with selected representatives of shipowners, member of the ship crews, and other employees of maritime administration bodies;
- E₂: A critical analysis of the detailed information collected in this way (primary and secondary), and on their basis to concretize and clarify the main research problem, the primary purpose of the research, and the leading research hypothesis;
- E₃: Development of the test procedure, the definition of their stages, formulation of specific objectives, as well as a selection of research methods and tools for their implementation and verification;
- E₄: Conducting surveys on the survio.com platform;
- E₅: RCA analysis of the root causes of COVID-19 virus infections of sea-going crews resulting from the lack of appropriate procedures on board a sea-going ship adapted to the pandemic situation;
- E₆: Classification of the causes mentioned above into root causes and their subcauses and ranking of their significance using a weighted Ishikawa diagram and stratification analysis;
- E₇: Presentation of the obtained results on the Lorenz–Pareto chart;
- E₈: Development of a model of the procedure for dealing with a sea-going ship in pandemic conditions using the UML language state and Visual Paradigm software;
- E₉: Presentation of the conclusions of the studies and formulation of recommendations for shipowners' enterprises and their officers.

The issue of survey research requires a broader explanation. The study aimed to find the opinions of all entities involved in creating, implementing, and enforcing procedures for dealing with ships at sea in a pandemic and on the process of their preparation, useful-

ness, effectiveness, the degree of detail, adaptation to reality, and possible problems with implementation in practice. These entities include representatives of:

- Maritime authorities providing general recommendations and guidelines for dealing with emergency situations;
- Shipowners managing sea-going ships, i.e., entities creating procedures for dealing with a pandemic situation;
- Crews of sea-going ships, including masters, deck officers, and engineer officers, i.e., persons directly managing the sea-going ship and its crew and responsible for their safety and health.

The questionnaire consisted of fifteen questions aimed at identifying the reasons for the occurrence of widely understood crisis situations on sea-going vessels. In this study, however, only those responses on situations related to COVID-19 infections was used.

Focus interviews were also conducted to identify the root causes of coronavirus infections among the crews of sea-going vessels (RCA). They included experts in implementing management procedures on vessels, recognized as masters of various sea-going vessels. They also often participate in the process of their creation. The main criterion for their selection was a minimum of 20 years of professional experience on sea-going vessels. Due to the specificity of this profession, which consists of the fact that the captain very often works for various shipowners during his professional life, it involves commanding units not only in the Baltic Sea but also around the world.

The sources of information and research methods, thanks to which the conclusions presented in Section 3.2 were drawn (more precisely: there are no footnotes in the text), also need to be supplemented. Namely:

- Conclusions concerning how seafarers perceive their work and spend their free time and the myth of freely exploring the world were drawn through the pilot study by one of the authors (J.K.) during her participation in two sea-going voyages on large bulk carriers. The study included participant observation and direct interviews with members of crews (including captain, officers, crew members, and cadets). As these observations and interviews lasted over four months in total, the conclusions result from the author's practical experience. They were supplemented with information obtained in the course of direct conversations already ashore with other people working for many years, before and during the pandemic, on various commercial sea vessels, with different shipowners, on different shipping lines, different positions (in this case, mainly with captains and officers), and with a crew of varying nationality. These conclusions also fully reflect the views of these people;
- Conclusions on the impact of quarantine duration on the seafarers' wages, their involuntary unemployment, the temporary maritime contracts proportion (working time at sea versus rest on land), and the consequences of these proportions (during the pandemic) for the breadwinners were drawn based on information obtained from additional (nonsurvey and not related to the author's (J.K.) sea-going voyages) direct interviews with prominent shipping masters transporting loads around the world (including, for example, China) on commercial sea-vessels during the pandemic, on different shipping lines, and with a nationally diverse crew.

The inductive method of the research procedure was adopted in this research.

3. Results

3.1. Economic and Social Impact of the COVID-19 Pandemic on Shipowners

The COVID-19 pandemic, as is already widely known, began on 17 November 2019, and on 11 March 2020, the World Health Organization (WHO) officially declared the state of the pandemic. Soon after, the borders were closed, and a ban on international flights and a mandatory quarantine for people coming to the country were introduced. From that moment, enormous problems for shipowners with the organization of substitutions for their crews on about 65 thousand sea-going ships sailing worldwide began. In anticipation of

the reaction and actions of governments, some of them temporarily froze the substitutions. Others tried to deal with the situation on their own (e.g., by renting buses which transferred seafarers to airports that had not yet been closed or ensuring that they were organized so that the date of arrival of the bus with seafarers to the port where the substitution was to take place was consistent with the date of entry of the ship, making it possible to replace the crew [17]). However, in most cases, the introduced restrictions on the movement of people between countries resulted in shipowners not starting new substitutions. They also did not allow seafarers to disembark and return home, although thousands had run out of contracts then. Some seafarers, who were caught on their way home or back, were quarantined, and thus practically trapped in hotel rooms worldwide. In many cases, as a result of restrictions, ships were also not allowed to enter or depart from certain seaports to change the crew in another port, and sometimes to both, which meant that the ship could neither moor in nor leave the port while remaining on the roadstead. Taking the above into account, many seafarers' stay on vessels was often significantly prolonged and exceeded the maximum duration of the seafarer's contract specified in the provisions of the Maritime Labour Convention, MLC 2006 [18]. This convention was adopted on 26 February 2006, entered into force on 20 August 2013, and is known as the Seafarer's Bill of Rights. It has established minimum labor standards and rights for seafarers, such as employment conditions, accommodation, recreational conditions, food, health and safety, medical care, and insurance. In extreme cases, the duration of the seafarer's contract, contrary to its provisions, was extended by up to 1.5 years. At that time, the International Chamber of Shipping and the International Maritime Employer Council provided data showing that in July 2021, this situation concerned about 250,000 seafarers awaiting replacement [19]. According to IMO statistics published in December 2020, their total number was estimated to be 400,000 [20]. It should be remembered that as many people were waiting for embarkation at the same time (so in total it was 800,000 people). For comparison, about 100,000 seafarers are swapped on ships every month under normal conditions. At the same time, considering that there are currently around 1,890,000 seafarers working on sea-going vessels in the world [21], the problem in question has affected the vast majority of them and their shipowners, demonstrating its scale and importance.

The increase in the duration of seafarers' contracts was equivalent to the fact that among their crews (physically and mentally fatigued from exhausting and long-lasting work), the risk of accidents at work increased accordingly. In a broader context, the risk of ship accidents also increased. In both cases, this always increases the cost of employing the crew (insurance costs, payments, and compensation for health disorders, etc.) and costs related to the ship (ship repair, ship loss, increase in insurance premium, costs associated to late execution of transport orders, etc.).

Another factor also influenced the extension of the duration of seafaring contracts. For example, restrictions were imposed on ships entering seaports, including a mandatory two-week quarantine of a vessel in the maritime zone. At the same time, the governments of some countries, for various reasons, including political ones, have extended the duration of customs clearance of goods, their loading/unloading, imposed huge duties, or introduced tedious and lengthy controls at seaports [22,23]. The duration of services provided by port services (e.g., pilotage) and port employees caused issues (in addition to loading/unloading the ship, they include, for example, operational and repair service of vessels). The problem emerged due to a limited number of hands to work, as the employees were in quarantine (suspected of contracting COVID-19) or during treatment. This also disrupted the operation of the ports themselves.

Lengthening of the ship's anchorage (on the roadstead or in the port) is a waste of money for the shipowner. From an economic point of view, a ship that does not work is a ship that does not earn. On the contrary, it generates, in the most straightforward settlement, additional costs of fuel consumption or payments to the crew, but not only. It is estimated that the average cost of maintaining a ship in standard, in terms of non-COVID conditions, is several thousand USD per day. In addition, during the pandemic, the costs of

transport alone increased. The current price of transporting goods in containers (where, in terms of tonnage, 15% of cargo in world trade by sea is containerized cargo), including subsidies to the basic rate of sea freight in 2021, increased 4–5 times compared to their level 5 years before the pandemic, and sometimes even more (even nearly 7 times). The analysis of average freight values evidenced this. For example, using indicators: Drewry's World Container Index (calculated for eight major east–west shipping routes, DWCI), Shanghai Containerized Freight Index (calculated for 13 major connections starting in Shanghai), and Freight Baltic Index (calculated for 52 seaports in the world). In the case of the first of them, its average value in the last 5 years before the pandemic (2015–2019) increased from USD 1856/FEU (FEU is a unit equivalent to 40' container) to USD 9261/FEU in December 2021, while on 6 September 2021 it was USD 10,374.6/TEU (TEU is a unit equivalent to a 20' container), and on the route Shanghai–Rotterdam, as much as USD 14,287/TEU. The second indicator, on January 2, 2020, reached an average value of USD 1009.3/TEU; on December 11, 2020, it was already twice as high—USD 2311.7/TEU, and a year later, on December 10, 2021, four times higher—USD 4811/TEU. The value of the last of the discussed indicators in mid-December 2019 was USD 1431/FEU, in December 2020—USD 3004/FEU, and on 10 December 2021, as much as USD 9550/FEU. Special subsidies are not considered when calculating the value of these indicators. Such as, for example, the “Premium” service, which is a promise (but not a guarantee) of obtaining a slot, i.e., a place on the ship for a container, or FAK surcharges for “freight of all kinds” with promises of priority expedition. The most difficult moments of the period in question even caused a doubling of the basic rates. Figuratively speaking: for an importer importing several containers every month in 2019, e.g., from China to Poland, they were amounted to about USD 2000 per container, while in the third quarter of 2021, they were already USD 20,000 [24].

It should also be remembered that a large part of the global fleet of sea-going ships, operated by the most prominent participants in the transport market, is leased. In addition, the cost of chartering a medium-sized container ship (with a cargo capacity of 6500 TEU) transporting 20' containers (suitable for most of the transported cargo) in the first half of December 2021 was estimated (according to the Container Ship Time Charter Assessment Index—an index of charter rates on time; it considers the current day charter rates of six representative types of container ships; these are ships with capacities of 1100 and 1700 TEU chartered for a one year and with ships with capacities: 2500, 2700, 3500, and 4250 TEU chartered for two years [25]) at the level of USD 104,000. One year earlier, it was more than three times lower and amounted to USD 31.5 thousand [24].

In the broader context of the deliberations, the pandemic has also caused disruptions in demand and supply and in global supply chains, of which seaports are essential links. The market imbalance in early 2020 resulted in reduced demand for container transport and, therefore, a massive cancellation of shipping services by shipowners. At that time, manufacturers using container technology stopped production or severely reduced it, and in China, there was a labor shortage in transport connections. Accordingly, in January 2020, compared to January 2019, the number of ship entrances to the ports of Shanghai and Yangshang decreased by 17%. In February 2020, the number of entries to all ports in China decreased by almost 1/3 [26].

According to the ISC (International Chamber of Shipping—an organization representing national shipowners' associations and more than 80% of the world's tonnage in commercial shipping), due to unperformed voyages, shipowners' losses amounted to hundreds of millions of USD [27]. Deliveries were unpredictable, and the punctuality rate of the best shipowners, which before the pandemic was over 80%, decreased [24].

As a consequence, the number of tethered ships (i.e., ships standing idle in ports) has increased, accompanied by a gradual increase in the transport capacity of the global container fleet as a result of continued investments in new tonnage in 2019 (at the end of 2019, this capacity amounted to 23.23 million TEU, and in September 2020, to 24 million TEU). Ship deliveries followed it to shipowners (in 2019, a total of 178 ships with a total

capacity of 1.2 million TEU) and placing new orders, the portfolio of which in October 2020 included 282 ships with a total capacity of 1.6 million TEU [26].

Therefore, the scrapping of ships also increased, more significantly than usual, even those that have not yet reached the age of economic maturity, i.e., the end of the ship's depreciation period, which usually covers 20–25 years. This was since before the pandemic, the shipowner maintained a ship without temporary employment at the expense of several thousand dollars a day, but it was a ship that was waiting for further transport orders. It was practically certain that this downtime period was temporary, and soon there would be employment for it. During the pandemic, this expectation has lost its economic sense, becoming one of the main reasons for the reduction of fleets by shipowners [28].

There was also a temporary shortage of places for containers on a board of container ships during increased demand. Ordered in Asia before the pandemic outbreak in the first quarter of 2020 and transported by sea, goods were still delivered to recipients from Europe or America. Later, due to the introduced restrictions and the closure of economies, there was a lack of new supplies from China (in maritime transport, there was also a temporary lack of access to containers, which were temporarily excluded and used in China as warehouses for storing cargo). Subsequently, due to government-implemented protection programs, purchasing goods for days made by consumers trapped in their homes, investing free financial resources in various tangible goods, and buying goods for the stock by importers, there was an accumulation of demand (under normal market conditions, that huge demand would be spread over the entire calendar year). Conversely, there were too many places on ships, so shipowners could not fully use the transport power of their fleets. According to the analytical company Sea Intelligence, in August 2021, this concerned as many as 12.5% of container ships' loading potential (i.e., over 3 million TEU). The loss of sufficient production capacity in seaports to handle sea-going vessels (as already mentioned in the context of increased ship standstill) has caused serious delays in maritime transport. Delays affected the export side, bottlenecks in unloading, and receipt of supplies on the import side, leading to further disruptions in the supply chain. According to Sea Intelligence, in mid-November 2021, current problems with loading ships occurred in more than 3/4 of container ports worldwide, where about 300 ships a day were waiting to enter, which is nearly 5.5% of the world's fleet [24,27].

To conclude the pandemic's effects on shipowners, it should be mentioned that although they were generally negative, one should notice bunker fuel prices (after their temporary increase). The improvement in terms of freight rates has nevertheless led shipowners to record profits in this difficult and unusual situation [26].

3.2. Economic and Social Impact of the COVID-19 Pandemic on Seafarers

As already mentioned, during the pandemic there were massive issues with the replacement of crews caused by the pandemic. These included: lack of air connections, inability to transit through some countries and difficulties in obtaining visas or transit permits, expiry of many important and necessary documents on the way from/to the ship and to work on it, performing tests for the presence of the coronavirus, the obligation to undergo quarantine before leaving the ship, before boarding it, and after arriving in the country, etc. In many cases, they caused the seafarer to be recruited or imprisoned for up to a month and longer, extending the start or duration of their contracts and thus increasing the number of negative consequences for seafarers.

The first obvious consequence of this state of affairs was their physical overload with work and the appearance of mental health challenges or impacts, such as increasing stress and accompanying psychosomatic symptoms, anxiety, depression, self-harm, or even suicide among seafarers. Reports carried out by Yale University, for example, showed that one in five seafarers took them into account [29].

The authors met with an important view in this trend of reflection, expressing a particular belief prevailing among the society that a seafarer is a profession that requires not only hard physical work but, above all, high mental resistance to isolation on a ship.

Following this line of thinking, a seafarer should therefore be more resistant to a more extended stay at sea than another average person who has nothing to do working at the seas and oceans. This is also accompanied by the belief that working at sea is conducive to strengthening interpersonal ties among crew members or exploring the world. Nothing could be further from the truth. Nowadays, even apart from the pandemic, seafarers spend most of their time off from working at sea locked in their cabins, watching movies on laptops, or browsing social media. Some of them permanently have webcams turned on, which allows them to receive a substitute for family life. This is not conducive to the integration of the crew, as it was in the times when the passage through the equator was accompanied, for example, by sea baptism, and the crew spent their free time in the ship's common room watching TV together, playing chess, cards, or other games. For this, it is necessary to debunk the myth of free exploration of the world. Yes, ships sail around the world, but the reality is different from what happened in the past and from the ideas about it. Very often, a seafarer simply does not have time to visit seaports. Their duties do not allow them to do so, or the possibility of leaving the port area is (in the commonly called "wild countries" by seafarers) very limited or even excluded due to the first, second, or third degree of a terrorist threat. All this effectively weakens the psychological resistance of seafarers to isolation.

However, returning to the mainstream of considerations, the probability of making mistakes by crew members has increased due to increased physical and mental load. This increases the risk of a maritime accident, including a direct threat to life and the ship and cargo safety.

The issue of wages in the pandemic also needs attention. The seafarer's contract is frequently signed on the day preceding the seafarer's departure to the ship. The shipowner's obligation to pay remuneration arises on the date appearing in the contract. However, the seafarer, in order to be able to start working on board, still has to reach the ship. During COVID-19, this required quarantine before leaving. Its duration has changed, and currently, for example, for Polish seafarers, a negative result of the PCR test is enough. However, in some countries, this requirement still applies today. Sometimes it was also necessary to undergo an additional quarantine in the country where the embarkation was to take place. In total, this could mean 28 days of isolation, in which the seafarer does not work on board, but is also not on leave. At the end of the contract, the seafarer still has to return home from the ship, which further extends the period of his "forced unemployment".

This problem concerns not only the quarantine itself but also a situation in which the waiting time of the seafarer for the ship, for reasons attributable to the shipowner (for example, vessel sale, ship scrapping of the ship, limitation or delay of rotation of substitutions, etc.), is extended to such an extent that the deadline for starting work indicated in the contract has already passed and the seafarer could not take up employment. It also applies to the repatriation of a seafarer for health or family reasons. In all these cases, it is closely linked to the issue of seafarers' remuneration. It always results from the law and the content of the seafarer's contract. On the other hand, for the shipowner, the payment of remuneration to a seafarer who does not work and is in quarantine will always be simply uneconomical. Therefore, the vast majority of contracts contain significant wording: "The Company shall pay a day rate for each day of work" and "Days of work are days spent onboard the vessel", which means that the shipowner pays only for the time worked by the seafarer on board the ship. As a result, shipowners began to give seafarers documents to sign to make changes to their terms of employment during the pandemic. These changes often concern the modification of the seafarer's working time on board, in the sense of its reduction, or a reduction in remuneration for working time on board a ship by a certain percentage or a specific amount. In such cases, seafarers shall generally receive a ready-made, signed form from the shipowner's representative, indicating that they agree to the above amendments and are only to accept and sign them. The shipowner explains such activities most often by force majeure, pandemic, and related financial problems resulting from the situation, how it has shaped the entire maritime

transport in the world, etc. Theoretically speaking, the seafarer may disagree and not sign the documents, counting on the understanding of the shipowner and the possibility of continuing further work on unchanged terms. In practice, however, as you can guess, the shipowner accepts such a solution only when he has no other choice. That is, if the refusal to change the terms of employment means the shipowner needs to terminate the contract with the seafarer, look for a substitute, and organize a replacement for him. It is prevented by the pandemic situation, epidemic regulations, or other factors, so the substitution is very difficult or impossible to implement. In different cases, it most often ends with the termination of the employment contract. This may be conducted according to the following terms (not always favorable to the seafarer) [30]:

- The shipowner shall treat the seafarer's refusal as termination of the seafarer's employment contract with notice, and the seafarer shall therefore receive all the remuneration due to him in this case, including that attributable to the period of notice;
- The shipowner will treat the seafarer's negative decision as termination of the seafarer's employment contract with immediate effect, i.e., without observing the notice period, and then he will not be entitled to remuneration attributable to the notice period;
- The shipowner will unilaterally terminate the seafarer's employment contract by referring to the provisions contained in the contract, which relate to the so-called force majeure (in this case a pandemic), which most often means for the seafarer that he will receive all the benefits due to him along with the severance pay.

It is also possible to unlawfully withhold the payment of wages to a seafarer until he agrees to the proposed conditions or immediate repatriation if he does not give such consent. It should also be borne in mind that the seafarer's consent to an unfavorable change in the conditions of employment is typically dictated by his desire to preserve the possibility of performing work for the shipowner in the future, and thus the fear of losing it. However, the problem of wages is much more complicated. Namely, if the shipowner pays only for the time worked on board the ship, the seafarer will not receive remuneration, or any other cash benefits, for the time he will be in quarantine (before/after entering/disembarking). This is logical. It is also irrelevant in this case whether the quarantine takes place before or after boarding the ship, where it takes place (at his place of residence, country of residence, or outside his borders), who decided about this place (himself, the shipowner or the authorities), and under what conditions it will take place. The same applies to the previously mentioned situation, in which the seafarer signed the contract, but did not start work under the deadline contained therein. It can be said that both of these situations have the same effects as if the seafarer is ashore before and after the voyage. The difference, however, from the seafarer's point of view, is that the time spent in quarantine or on prolonged waiting for the ship is for him, with each subsequent contract, time lost in the sense of limiting the possibility of earning. Moreover, if the seafarer has terminated his contract, disembarked, crossed the border, and during this journey home he developed symptoms characteristic of COVID-19, other symptoms, or, generally speaking, his health deteriorated, which resulted in the need to undergo quarantine in his country of residence, he is also not entitled to remuneration. On the other hand, if changes in his health are found before he disembarks, he may (depending on other circumstances) receive sickness or compensation benefits [30].

Thus, a monthly or longer period of stay of seafarers in quarantine means economic consequences for seafarers. This is lost time for healthy people who do not have the opportunity to perform paid work. On average, a seafarer can serve not one, but several contracts during the calendar year, i.e., under nonpandemic conditions. The financial loss incurred due to the necessary quarantine or waiting for the ship is large. For example, a standard contract carried out by a Polish seafarer employed on a bulk carrier or container ship may have the following time proportions: for 4 months of work at sea, there will be 4 months at home. In the case of passenger ferry crews, this relationship can be as: 2 weeks/2 weeks or 4 weeks/4weeks. As a result, it may turn out that for the reasons mentioned above, the

seafarer spends more time on land than working on the ship. However, these proportions vary. For example, Filipino seafarers often perform 9-month contracts, and their period of stay on land is much shorter than the time they work at sea. It is worth explaining that Filipino seafarers are also employed on ships operating in the Baltic Sea area. This internationality of the crews of sea-going vessels in the Baltic Sea is most often caused by the shipowners' efforts to make saving related to remuneration for their crew members. Global shipowners also share this approach, so in this case, it is necessary to look at the problem more broadly, from a global perspective, not just a local one. While the knowledge, skills, and reliability of (for example) Scandinavian, German, or Polish captains and officers are highly valued among shipowners, the national origin of the remaining crew is not so important to them. Employing a crew of Filipinos, Bulgarians, Lithuanians, and other nations from (for example) Eastern Europe brings measurable financial benefits. Regardless, in the discussed cases, the time relations between working on ship and staying on land harm the level of achievable wages, and consequently, on the level and quality of life, professional instability, and the related lack of sense of security for seafarers and their families. This is especially true for the seafarers of those nations in which the whole family contributes to the maritime education of one of family member. Then, he becomes its primary breadwinner by taking up work at sea (for example, the mentioned Filipino seafarers who, in addition, dominate the structure of employment for seafarers by shipping companies worldwide according to the nationality criterion, which proves the large scale of the phenomenon and its significance).

In addition, as a result of the actions taken by shipowners during the pandemic, which consisted of keeping ships tethered and manning them at that time with a minimum number of crew members, i.e., the so-called skeleton crew, reducing the size of their ships' fleets by scrapping them, or limiting the rotation of crews, there were fears among seafarers about losing their jobs.

In the conditions of the pandemic, several other problems also arise. An example is an impossibility or significant difficulty in enforcing contractual claims from the shipowner in case of a health disorder or seafarer's death due to COVID-19. The reason is the lack of appropriate provisions in the International Maritime Labour Convention (MLC 2006) or national legal solutions (e.g., in Poland it is the Maritime Labour Act of 2015 [31]). The regulations cover situations such as, for example: war zone/warlike operations areas, armed conflict zone, high-risk zone, terrorist attacks, or maritime piracy. The specificity of the pandemic means that it does not fall within its conceptual scope. For example, a seafarer will not be able to refuse further work for the shipowner or demand immediate repatriation from him while maintaining his previous employee rights. He is also not entitled to higher than normal remuneration for the risk of COVID-19 infection, nor compensation in the amount exceeding the contractual provisions. In addition, many contracts are subject to the regulations of countries other than the country of origin of the seafarer or the country of registration of the crewing agency. These, in turn, have not yet developed all the legal solutions appropriate to the pandemic, i.e., specific and exhaustive provisions regulating and detailing the activities and measures that shipowners should take during the pandemic. Another issue is the legitimacy, scope, and amount of compensation benefits for damage to health suffered by a seafarer or for health disorders which are a consequence of contracting the coronavirus. Especially since in seafarers' contracts (terms of employment, collective agreements), there is most often a provision that compensation is due only when the damage/health disorder occurred as a result of an accident at work or an occupational disease, so a link between these events and COVID-19 would have to be proven. If, as a result of infection, a seafarer requires hospitalization, he is entitled only to standard sick benefit (so-called "sick pay") due to temporary incapacity for work. Their amount corresponds to the basic salary, and they are usually paid for 16 weeks (regardless of the actual duration of convalescence). They may also receive or claim reimbursement of medical expenses incurred. In the event of the death of a seafarer (as in the case of damage to or disorder of health), the shipowner's compensation results from the seafarer's contract,

working conditions, and collective agreements. A particular case is the death of a seafarer after contracting COVID-19. If he did not have any symptoms on board, he would return home from the ship by air transport, and the coronavirus would appear only after some time. In the present case, it must be established conclusively that the infection occurred while he was performing his duties on board [32].

To sum up, today, the law is unspecified concerning the pandemic. Many seafarers' contracts do not consider the possibility of a seafarer contracting coronavirus at all, and the scope of benefits that they are entitled to for this reason is sometimes smaller than those paid due to an accident at work. Of course, the presented considerations do not exhaust the discussed problem, but only signal how important and difficult it is for seafarers.

3.3. Identification of the Root Causes and Subcauses of Infections of Sea-Going Ship Crew Members with the COVID-19 Virus

RCA (Root Cause Analysis) of the root causes of COVID-19 infections of sea-going crews allowed us to distinguish their main causes and subcauses, which include (Figure 1):

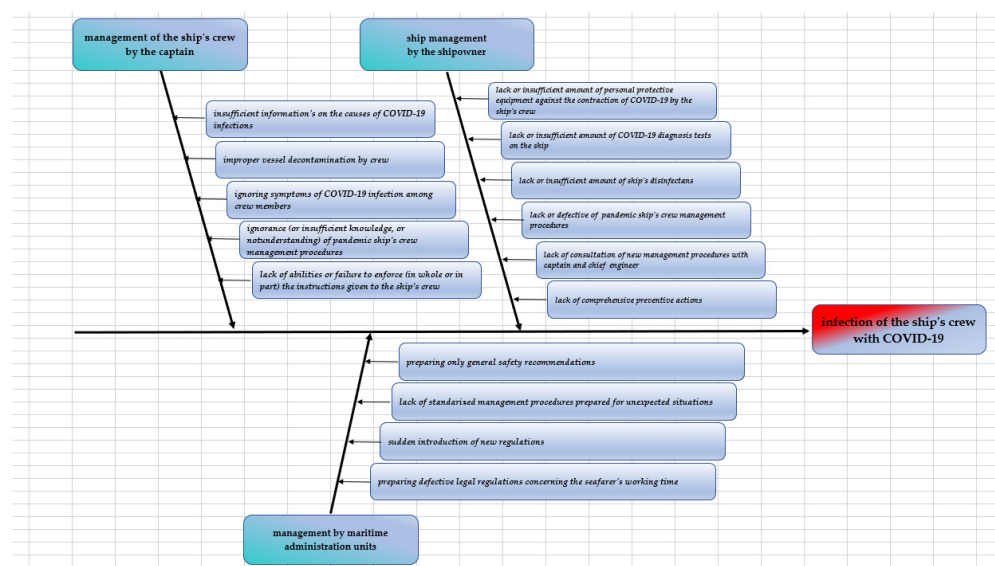


Figure 1. Ishikawa diagram determinant of COVID-19 virus infections of sea-going crew members.

1. Main reason: management of the ship's crew by the captain, and subreasons:

- Insufficient information on the causes of COVID-19 infections—failure of the captain to provide the ship's crew with sufficiently accurate information about the causes of COVID-19 infection (very important, especially at the initial stage of the development of the pandemic) or providing this information in a cursory, general, or imprecise manner;
- Improper vessel decontamination by the crew—understood as an error in the art of managing the human factor, but an error fundamental from the management in a pandemic situation and striving to prevent/reduce the risk of COVID-19 infection by the crew;
- Ignoring symptoms of COVID-19 infection among crew members—failure to ensure that diagnostic tests were performed by ship crew members despite the fact that they had symptoms of contracting the COVID-19 virus or downplaying the significance of these symptoms and attributing its symptoms to other, harmless diseases;
- Ignorance (or insufficient knowledge, or not understanding) of pandemic ship's crew management procedures—resulting from the lack of any previous experience that could be used in management or to which could be referred;
- Lack of abilities or failure to enforce (in whole or in part) the instructions given to the ship's crew—failure of crew members to comply with instructions given by the

captain or issued on his behalf by the officers, the purpose of which is to minimize the possibility of the crew contracting the COVID-19 virus. This is particularly important due to the need to maintain direct contact with people outside the crew. This may be related, for example, to: the entry and exit of the ship to/from the port with the pilot on board; control of the ship's records by port services; ship inspection; crew document inspection; ship provision; embarkation of new crew members; draft surveyor (deals with measurements of the ship's draught necessary to determine the amount of cargo unloaded/loaded on the ship); delivery to the ship of materials, tools, components, or parts needed to carry out ongoing maintenance, repairs, and overhauls performed by the crew; implementation of supply of medical, disinfectant, and personal protective equipment against COVID-19, etc.

2. Main reason: ship management by the shipowner, and subreasons:

- Lack or insufficient amount of personal protective equipment against the contraction of COVID-19 by the ship's crew—in the initial stage of the pandemic, this resulted from the surprise of all entities involved in the implementation of maritime transport (including shipowners) by the appearance and development of the pandemic. The reason for the insufficient amount of these resources on board is the misunderstood search for savings by shipowners;
- Lack or insufficient amount of COVID-19 diagnostic tests on the ship—results from the same reasons as in the case of personal protective equipment, while it should be remembered that in the initial period of the pandemic, there were no tests at all, and then they were only in the development phase;
- Lack or insufficient amount of ship's disinfectants—and as a result, failure to disinfect the ship or carry it out inaccurately, so that the disinfection is not covered by the high-contact surfaces including the equipment;
- Lack of or defective pandemic ship's crew management procedures—in the initial period of the pandemic development, these procedures simply did not exist. The defectiveness of the procedures developed later resulted from the surprise associated with the rapid spread of the pandemic around the world, and therefore also from the short time that shipowners had to prepare them and from a completely new type for them in a crisis situation (previous management procedures were developed for well-known situations, such as, for example, collision, a ship running aground, oil spill, or a pirate or terrorist attack);
- Lack of consultations on new management procedures with the captain and chief engineer—lack of consultation during the development of new management procedures with people who have extensive practical experience can be treated as a simple mistake in the art of management, but due to the risks posed by COVID-19, the significance of this error should be considered very high in this case. While the captain's participation in this process does not raise any major doubts, it is worth clarifying the issue of the participation of the chief mechanic. It results from the Safety Management System adopted on board the ship, in which the division of responsibilities and powers of the ship's crew members is defined. In this case, the opinion of the chief engineer is just as important as the opinion of the master;
- Lack of comprehensive preventive actions—results from the same reasons as the defectiveness of the ship's crew management procedures developed after the unexpected appearance of COVID-19. It may also be a consequence of errors in shipowner management, understood in a broader context than the pandemic situation.

3. Main reason: management by maritime administration units, and subreasons:

- Preparing only general safety recommendations—the general nature of these recommendations, to which shipowners must comply, means that the internal management procedures developed on their basis are more or less precise or detailed. They may also not be entirely accurate. Consequently, unintentionally, neither maritime ad-

ministration units nor shipowners may ultimately increase the risk of contracting COVID-19;

- Lack of standardized management procedures for unexpected situations—refers to the emergence of a completely new, previously unknown crisis situation created by COVID-19. This is due to an increase in the likelihood of virus infection of ship crews. It should be borne in mind that the pandemic is probably not the last pandemic that humanity will face, which makes this factor particularly important, also in relation to the future;
- Sudden introduction of new regulations—results from the same reasons as the lack of standardized management procedures in previously unforeseen situations and the dynamics of the spread of the pandemic around the world;
- Preparation of defective legal regulations concerning the seafarer's working time—the example of the passage of a sea-going ship through the Panama Canal perfectly illustrates the example of the passage of a seafarer's working time. In extreme cases (extreme in the sense of the number of tasks to be performed by the crew one after the other, without time to rest), i.e., the need to: take the pilot; maneuvers; mooring; unloading, which may be accompanied by one or more simultaneous inspections of the vessel; unmooring; maneuvers; entrance directly to the Channel; its passage in transit; sometimes stopping inside between the locks for 10 h due to congestion or bad weather; leaving the Canal; stopping at anchor, during which the ship bunkers fuel and makes supplies; and only then exiting to the high seas. Therefore, in practice, there is simply no real possibility of compliance with the rules at times. The number of people on the ship's crew is limited, which means that in such and similar situations, and there are more of them, they are required to work almost continuously. As a result, the classic of ship management, as it can already be called, has become the circumvention of the law by the ship's captain, the first officer, and the crew, with all aware of this state of affairs. The first officer prepares a form for recording seafarers' working and rest time, writing down the hours so as not to break the rules. Then, he masks, bends, or intentionally falsifies the reality of ship documents. The crew then signs them, realizing this, and the captain, who is also fully aware of this, does not react. Regardless of the ego, excessive and prolonged overload of work causes increasing and prolonged fatigue. This leads to body weakening and its greater susceptibility to contracting COVID-19 and errors or inaccurate execution of the captain's orders, including those related to the prevention of the possibility of contracting COVID-19 by the crew.

The results of the above RCA analysis are shown in Figure 1.

3.4. Ranking of the Root Causes and Their Subcauses of Infections of Sea-Going Ship Crew Members with the COVID-19 Virus

In order to determine the meaning of all causes, the method of comparison in pairs was used. In the comparison matrix, a rating scale was assumed in the system: 0; 0.5; 1. In the first place, weights were established at the level of the main causes. They are shown in Table 1, and Figure 2 shows the starting shape for the weighted chart of the Ishikawa diagram.

The analysis of the relative values of the main causes showed that the greatest significance of that group of causes affecting COVID-19 infections among sea crews is the management of the ship's crew by its captain (the relative value was 0.667). In the case of the other two main causes, i.e., management by the shipowner and management by maritime administration units, their importance is much smaller. In both cases, it is 0.167 each (Table 1, Figure 2).

Subsequently, in the same way as for the root causes, relative values of second-order causes were established, as shown in Tables 2–4.

Table 1. Weights at the level of the causes of the main COVID-19 virus infections of sea-going crew members.

	Management of the Ship's Crew by the Captain	Ship Management by the Shipowner	Management by the Maritime Administration Units	$\Sigma(X)$	The Relative Value (X/Y)
Management of the ship's crew by the captain	X	1	1	2.0	0.667
Ship management by the shipowner	0	X	0.5	0.5	0.167
Management by the maritime administration units	0	0.5	X	0.5	0.167
			$\Sigma(Y)$	3.0	

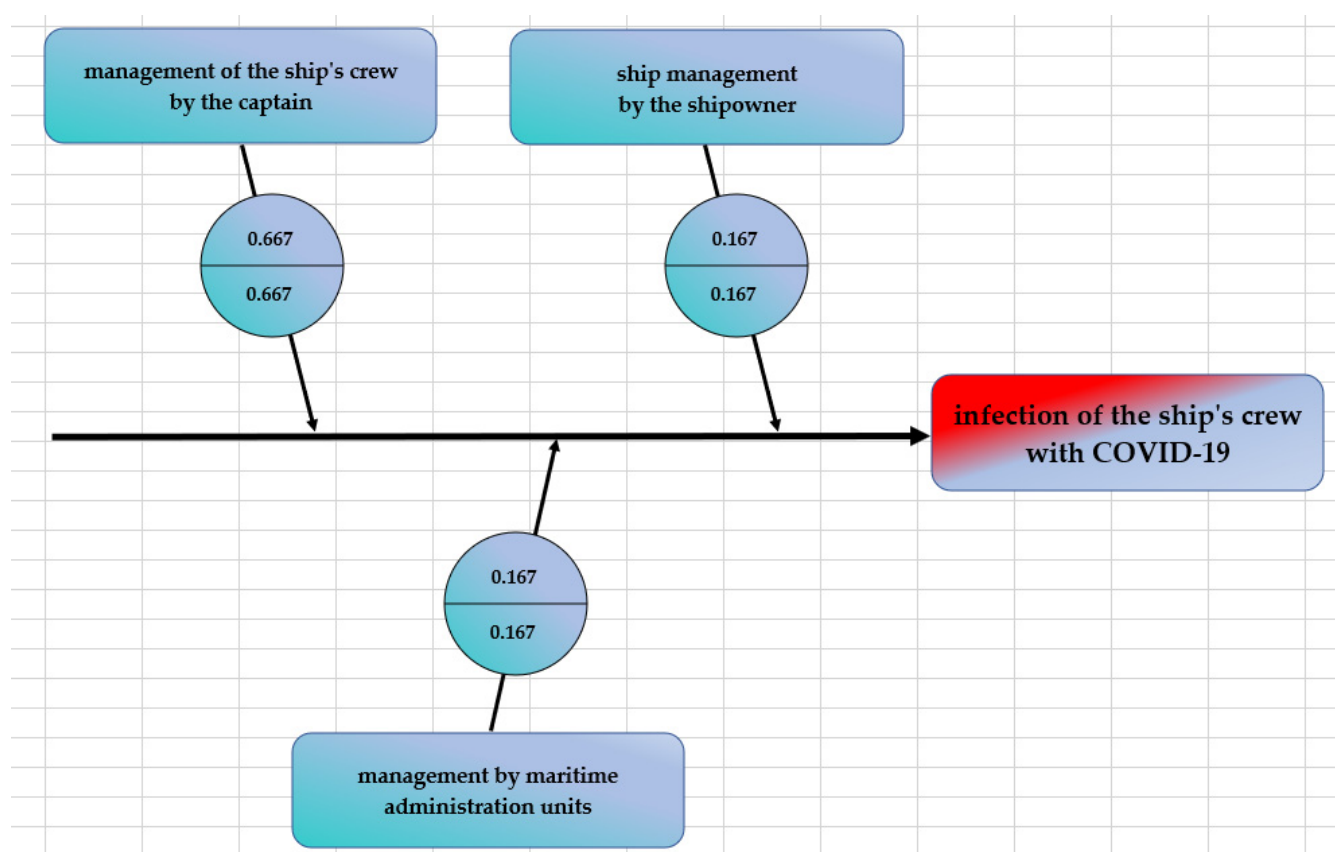
**Figure 2.** The initial form of the Ishikawa diagram for the analysis of the causes of COVID-19 virus infections of members in the crews of sea-going ships.

Table 2. Relative values of second-order causes for the causes of major COVID-19 infections of sea-going crew members—management of the ship’s crew by the captain.

Management of the Ship’s Crew by the Captain	Insufficient Information’s on the Causes of COVID-19 Infections	Improper Vessel Decontamination by Crew	Ignoring Symptoms of COVID-19 Infection among Crew Members	Ignorance (or Insufficient Knowledge, or not Understanding) of Pandemic Ship’s Crew Management Procedures	Lack of Abilities or Failure to Enforce (in Whole or in Part) the Instructions Given to the Ship’s Crew	$\Sigma(X)$	The Relative Value (X/Y)
Insufficient information’s on the causes of COVID-19 infections	X	0.5	0	0	0.5	1.0	0.100
Improper vessel decontamination by crew	0.5	X	0	0.5	0.5	1.5	0.150
Ignoring symptoms of COVID-19 infection among crew members	1	1	X	1	1	4.0	0.400
Ignorance (or insufficient knowledge, or not understanding) of pandemic ship’s crew management procedures	1	0.5	0	X	0.5	2.0	0.200
Lack of abilities or failure to enforce (in whole or in part) the instructions given to the ship’s crew	0.5	0.5	0	0.5	X	1.5	0.150
$\Sigma(Y)$						10.0	

Among the subcauses identified for the root cause—management of the ship’s crew by the captain (Table 2), the most important of them all is ignoring symptoms of COVID-19 infection among crew members (0.400). Insufficient information on the causes of COVID-19 infections (0.100) has the least impact.

Among the subcauses identified for the main reason—ship management by the shipowner (Table 3), the largest of them all are two subcauses: lack or insufficient amount of personal protective equipment against the contraction of COVID-19 by the ship’s crew (0.267) and lack or insufficient amount of COVID-19 diagnosis tests on the ship (0.267). Additionally, the most negligible impact has two subcauses: lack of consultations of new management procedures with captain and chief engineer (0.067) and lack of comprehensive preventive actions (also 0.067).

Among the subcauses identified for the root cause—management by maritime administration units (Table 4), the most important of them all is the subcause: preparing defective legal regulations concerning the seafarer’s working time (0.417). The most negligible impact is caused by preparing only general safety recommendations (0.167) and lack of standardized management procedures prepared for unexpected situations (0.167).

Table 3. Relative values of second-order causes for the main cause of COVID-19 virus infection of sea-going crew members—ship management by the shipowner.

Ship Management by the Shipowner	Lack or Insufficient Amount of Personal Protective Equipment against the Contraction of COVID-19 by the Ship's Crew	Lack or Insufficient Amount of COVID-19 Diagnosis Tests on the Ship	Lack or Insufficient Amount of Ship's Disinfectants	Lack or Defective of Pandemic Ship's Crew Management Procedures	Lack of Consultations of New Management Procedures with Captain and Chief Engineer	Lack of Comprehensive Preventive Actions	$\Sigma(X)$	The Relative Value (X/Y)
Lack or insufficient amount of personal protective equipment against the contraction of COVID-19 by the ship's crew	X	0.5	0.5	1	1	1	4.0	0.267
Lack or insufficient amount of COVID-19 diagnosis tests on the ship	0.5	X	0.5	1	1	1	4.0	0.267
Lack or insufficient amount of ship's disinfectants	0.5	0.5	X	0.5	1	1	3.5	0.233
Lack or defective of pandemic ship's crew management procedures	0	0	0.5	X	0.5	0.5	1.5	0.100
Lack of consultations of new management procedures with captain and chief engineer	0	0	0	0.5	X	0.5	1.0	0.067
Lack of comprehensive preventive actions	0	0	0	0.5	0.5	X	1.0	0.067
$\Sigma(Y)$							15.0	

The next step was to calculate the values of absolute weights for second-order causes determined as the product of the value of their relative weights and the value of the relative root cause to which the subcause belonged (Table 5).

A weighted Ishikawa graph of the causes of COVID-19 infections by seafaring crew members is shown in Figure 3.

Table 4. Relative values of second-order causes for the main cause of COVID-19 infection of sea-going crew members—management by maritime administration units.

Management by Maritime Administration Units	Preparing Only General Safety Recommendations	Lack of Standardized Management Procedures Prepared for Unexpected Situations	Sudden Introduction of New Regulations	Preparing Defective legal Regulations Concerning the Seafarer's Working Time	$\Sigma(X)$	The Relative Value (X/Y)
Preparing only general safety recommendations	X	0.5	0.5	0	1.0	0.167
Lack of standardized management procedures prepared for unexpected situations	0.5	X	0.5	0	1.0	0.167
Sudden introduction of new regulations	0.5	0.5	X	0.5	1.5	0.250
Preparing defective legal regulations concerning the seafarer's working time	1	1	0.5	X	2.5	0.417
$\Sigma(Y)$					6.0	

Table 5. Root causes, subcauses, and their severity.

Main Reason	Subreason	The Value of Subreason		The Value of Main Reason
		The Relative Value	The Absolute Value	The Relative Value
Management of the ship's crew by the captain	Insufficient information's on the causes of COVID-19 infections	0.100	0.067	0.667
	Improper vessel decontamination by crew	0.150	0.100	
	Ignoring symptoms of COVID-19 infection among crew members	0.400	0.267	
	Ignorance (or insufficient knowledge, or not understanding) of pandemic ship's crew management procedures	0.200	0.133	
	Lack of abilities or failure to enforce (in whole or in part) the instructions given to the ship's crew	0.150	0.100	
Ship management by the shipowner	Lack or insufficient amount of personal protective equipment against the contraction of COVID-19 by the ship's crew	0.267	0.045	0.167
	Lack or insufficient amount of COVID-19 diagnosis tests on the ship	0.267	0.045	
	Lack or insufficient amount of ship's disinfectants	0.233	0.039	
	lack or defective ship's crew management procedures	0.100	0.017	
	Lack of consultations of new management procedures with captain and chief engineer	0.067	0.011	
	Lack of comprehensive preventive actions	0.067	0.011	

Table 5. Cont.

Main Reason	Subreason	The Value of Subreason		The Value of Main Reason
		The Relative Value	The Absolute Value	The Relative Value
Management by the maritime administration units	Preparing only general safety recommendations	0.167	0.028	0.167
	Lack of standardized management procedures prepared for unexpected situations	0.167	0.028	
	Sudden introduction of new regulations	0.250	0.042	
	Preparing defective legal regulations concerning the seafarer's working time	0.417	0.070	

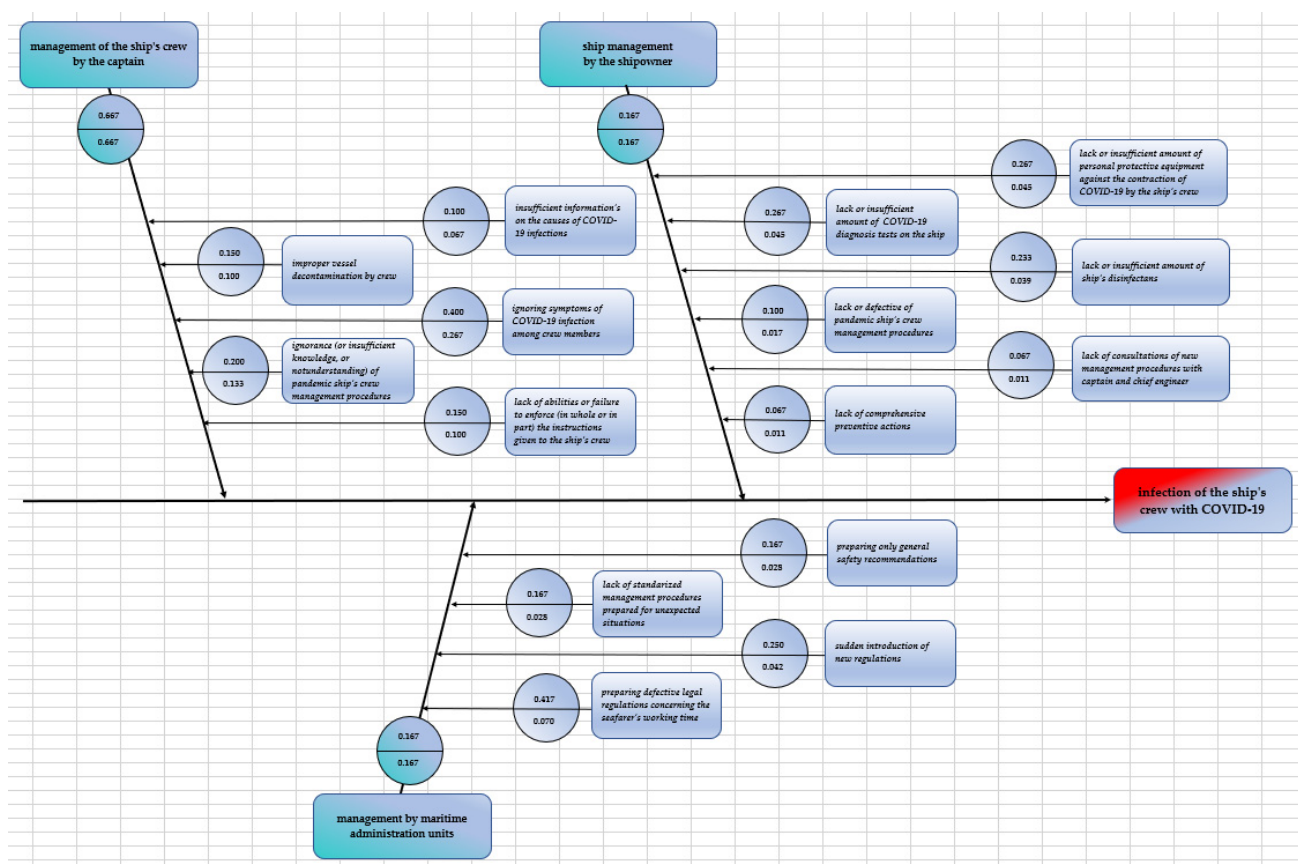


Figure 3. A weighted diagram of Ishikawa's causes of COVID-19 infections by seafaring crew members.

3.5. Stratification Analysis and Lorenz-Pareto Chart

The execution of the weighted Ishikawa diagram was necessary for stratification analysis and the development of the Lorenz-Pareto chart. Only on this basis can a complete picture of the situation be obtained. Those with the greatest impact on COVID-19 infections among seafarers can be distinguished from all subcauses.

To do it, it was necessary to draw up Table 6 (based on Table 5), which contained a list of subcauses from a weighted Ishikawa diagram. They were arranged in terms of absolute weight value from the largest to the smallest. Their cumulative values have been calculated, which are also the coordinates of the Lorenz-Pareto curve shown in Figure 4. Based on the Pareto rule (80:20), the subcauses with the highest value were refined.

Table 6. Stratification analysis of the causes of COVID-19 infections among seafarers.

Number	Subreason	The Absolute Value	The Cumulative Value	The Reference
1	Ignoring symptoms of COVID-19 infection among crew members	0.267	0.267	3.738
2	Ignorance (or insufficient knowledge, or not understanding) of pandemic ship's crew management procedures	0.133	0.400	5.200
3	Improper vessel decontamination by crew	0.100	0.500	6.000
4	Lack of abilities or failure to enforce (in whole or in part) the instructions given to the ship's crew	0.100	0.600	6.600
5	Preparing defective legal regulations concerning the seafarer's working time	0.70	1.300	13.000
6	Insufficient information's on the causes of COVID-19 infections	0.067	1.367	12.303
7	Lack or insufficient amount of personal protective equipment against the contraction of COVID-19 by the ship's crew	0.045	1.412	11.296
8	Lack or insufficient amount of COVID-19 diagnosis tests on the ship	0.045	1.457	10.199
9	Sudden introduction of new regulations	0.042	1.499	8.994
10	Lack or insufficient amount of ship's disinfectants	0.039	1.538	7.690
11	Preparing only general safety recommendations	0.028	1.566	6.264
12	Lack of standardized management procedures prepared for unexpected situations	0.028	1.594	4.782
13	Lack or defective of pandemic ship's crew management procedures	0.017	1.611	3.222
14	Lack of consultations of new management procedures with captain and chief engineer	0.011	1.622	1.622
15	Lack of comprehensive preventive actions	0.011	1.633	0.000

The report field in Figure 4 is an indicator of the division and is formed by the area of the rectangle determined by a given point of the Lorenz-Pareto curve. The size of the reference field is calculated by multiplying the cumulative value by N ($N = 15 - n$), where 15 is the number of all subcauses and n is the sequence number of the subcause. It reached its maximum for subcause No. 5 (preparing defective legal regulations concerning the seafarer's working time) and amounted to 13.000.

After the stratification analysis, the weighted Ishikawa diagram shown in Figure 3 changed. It includes only the most important five subcauses (Figure 5).

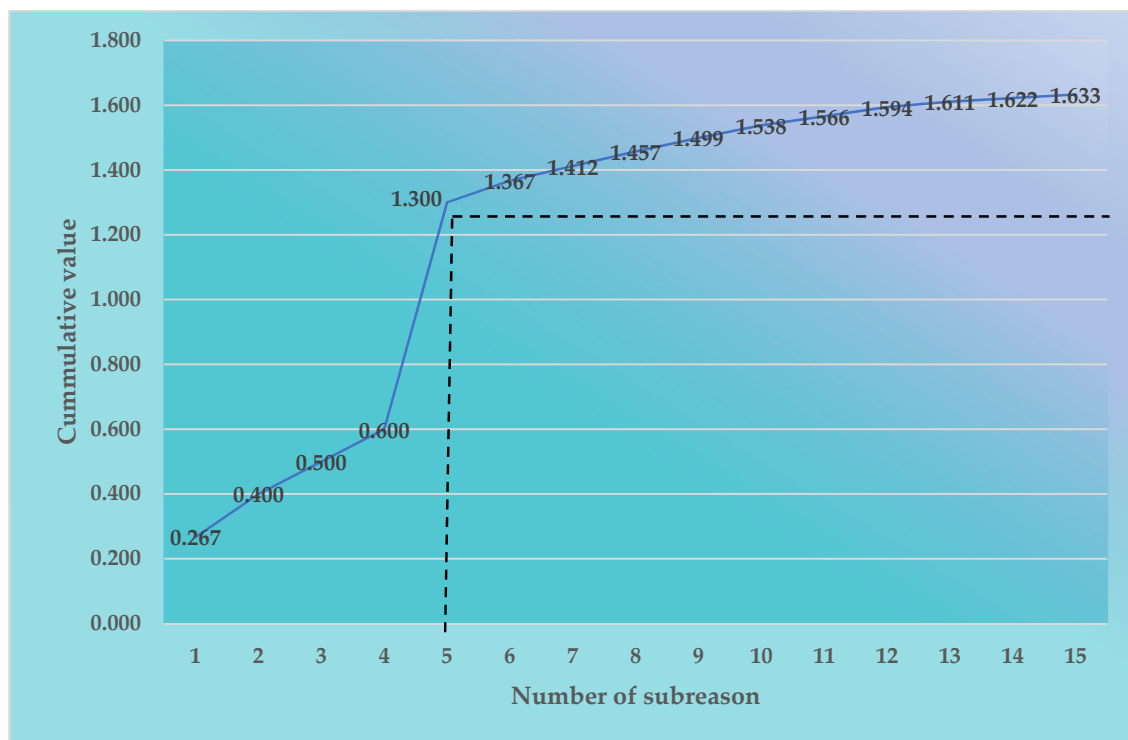


Figure 4. Lorenz-Pareto curve.

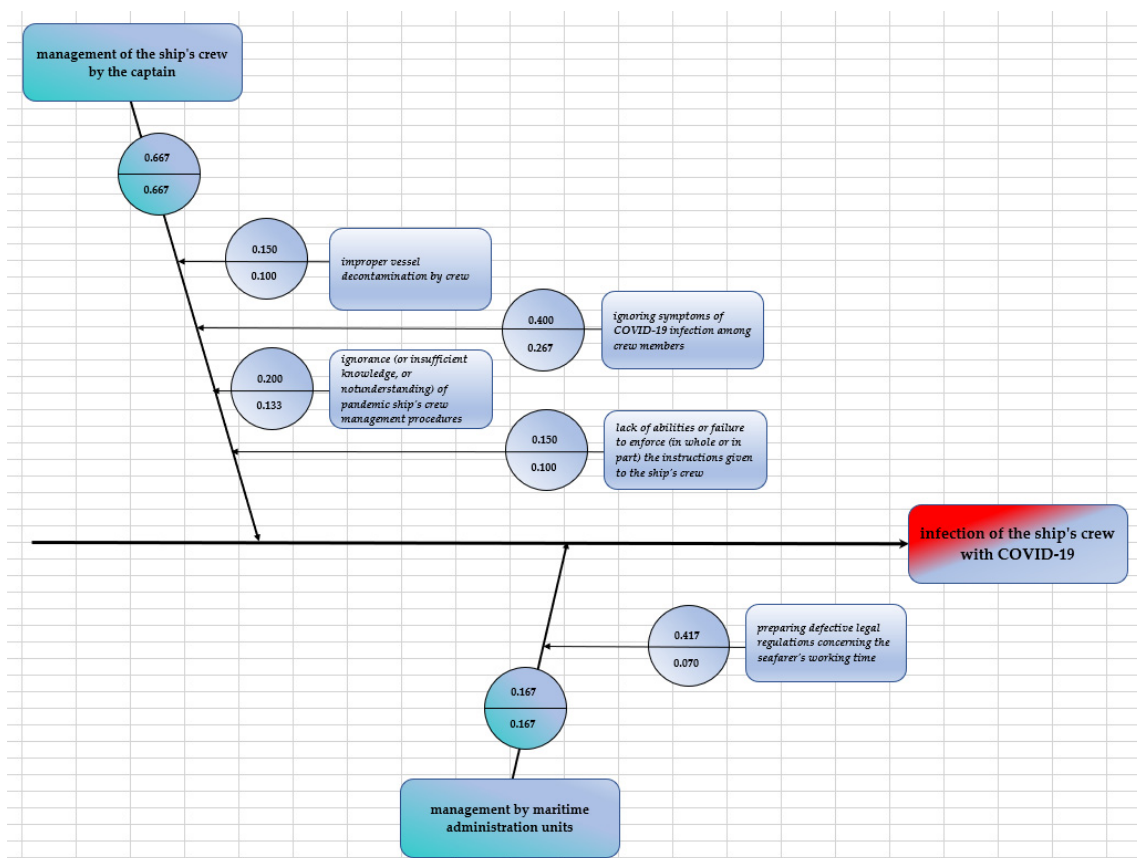


Figure 5. A weighted diagram of Ishikawa's causes of COVID-19 infections among crew members after stratification analysis.

According to the stratification analysis, out of 15 identified subcauses of COVID-19 infections among sea-going crews, only 5 leading ones were distinguished:

1. Ignoring symptoms of COVID-19 infection among crew members—which also includes the lack of sufficient human resource management skills; this reason means: the captain's error in the sense of downplaying this issue and the lack of sufficient control over the actions of the crew, which does not perform tests often enough to the situation;
2. Ignorance (or insufficient knowledge, or not understanding) of pandemic ship's crew management procedures—resulting from the captain's lack of previous experience with such a crisis situation as a pandemic; this is also a reason from the group of main reasons management by the shipowner, specifically: lack of or defective pandemic ship's crew management procedures;
3. Improper vessel decontamination by the crew—this is, again, a mistake in the art of human resource management;
4. Lack of abilities or failure to enforce (in whole or in part) the instructions given to the ship's crew—i.e., failure of crew members to comply with instructions given by the captain or issued on his behalf by the officers; once again, an error in the art of crew management;
5. Preparing defective legal regulations concerning the seafarer's working time—a cause completely independent of either the master or the shipowner; lack of influence and the possibility of changing it by both.

Therefore, the captain primarily decides on crew safety on a sea-going ship in the aspect of the pandemic. Its improvement, and therefore (in macro terms) the decrease in the incidence of COVID-19 among seafarers, depends directly on it. Still, their socio-economic costs are borne primarily by seafarers and shipowners.

A weighted Ishikawa diagram and stratification analysis provide knowledge on which problems to focus on and solve so that there are fewer COVID-19 infections on ships. Subcauses 1, 3, and 4 result from broadly understood errors in the art of management, which the captain can commit. Eliminating cause No. 5 is the hardest, most complicated, and takes the most time. However, the easiest to eliminate, possible to implement in a short time is cause No. 2, especially since it is also partly within the responsibility of the shipowner. Therefore, in the next, final stage of the research, the focus was on the development of a universal model of conduct on sea-going ships in pandemic conditions.

3.6. Model of Procedure on Board in Pandemic Conditions

The essence of modeling is to simplify the degree of complexity of the studied fragment of reality by eliminating elements irrelevant to its purpose. For modeling procedures on sea-going ships, the UML language was used with the use of Visual Paradigm software, which gives the ability to manage the complexity of procedure transformation and their variability resulting from changing general guidelines of conduct, technology, or legal regulations. It is, at the same time, an ideal and comprehensive software for the needs of quick construction and subsequent management of procedures, and the use of UML also gives excellent ease of control over them. This is very important in managing the ship and its crew since it requires good organization, coordination, and cooperation between all entities involved in transport processes and experts and specialists in many fields. In turn, using Guide through processes allows you to build so-called multidomain teams, which may include shipowners, maritime administration, ship captains, or, for example, programmers. Visual Paradigm seamlessly integrates them and enables you to manage procedures and programming processes. The use of Visual Paradigm also gives the opportunity to quickly extend the procedure, which is developed according to the model, in a situation where the primary threat will be a secondary threat, which will be the result of the former. The only requirement that had to be met during the modeling was to create a complete and unambiguous model and one that would be able to define the structure and behavior of all model elements in the event

of a COVID-19 threat. It is also worth emphasizing that after formalizing the simulation model, its transformations can be made, but they do not change its structure.

The procedure was modelled in two cases of occurrence of COVID-19 virus among the crew: from a new crew member alerted to the ship or from persons outside the crew during the ship's entry/exit to/from the port (from the pilot) or from the ship's berth in the seaport (from persons outside the crew). The embarkation of a new crew member depends on the results performed on him before signing the seafarers' contract, and then boarding, RT-PCR, IgG, and IgM tests diagnosing the coronavirus. The first is a test recommended by the WHO and the State Sanitary Inspections. Obtaining a positive result unequivocally confirms the diagnosis of COVID-19, but at the same time, a negative result does not exclude the presence of the virus. Hence, only a positive result guarantees that we will not be able to get on the ship of an infected person. A negative result is inconclusive. A PCR test with a certificate for travelers is performed at any time, provided that they do not develop symptoms of infection [33]. The other two are screening tests in the IgM and IgG antibody classes, which appear in the human body at different times after contacting the COVID-19 virus. IgM antibodies are present 7–10 days after infection and may indicate a still-active infection. In turn, IgG antibodies can be detected only after 11–14 days after the onset of symptoms of the disease. They testify to their past contact with the coronavirus, i.e., that the person has already been infected, and the possible acquisition of immunity to it, but they remain in the body only for about 6–8 months [34]. Therefore, performing these tests greatly reduces the risk of embarking an infected person on the ship but does not eliminate it. It should be emphasized that this is the current state. At the initial stage of the development of the pandemic, these tests have not yet been carried out. With regard to the latter situation, it is always possible to infect one or more crew members through their contact with outsiders. Still, carrying out the tests mentioned for that circumstance is not always possible. Medical services perform the PCR test, so it can only be conducted while the ship is in port, and cassette tests detecting IgM and IgG antibodies are not always available on ships in sufficient quantity. The model for both situations shown in Figure 6 is a simplified version of the model obtained using Visual Paradigm.

If cassette tests are available on the ship, the most important information will be the result of the IgM test, which will inform you whether we are dealing with COVID-19 infection. If the result is negative, the symptoms that occurred in the crew member should not be interpreted as symptoms of infection with the coronavirus, but rather as symptoms of, for example, a cold or flu. In this case, the result of the IgG test may be negative (if the person did not have IgG antibodies in his body before being put on the ship, i.e., if he or she was not previously infected and did not undergo the disease and is not currently infected, he/she will not have them) or positive (if he/she was ill before entering the ship). On the other hand, if the result is positive, the infected crew member should be isolated from the others, and the ship should head to the nearest port. He/she should be in a separate cabin and keep in touch with only one other crew member who will deliver meals or medicines to the cabin door. Contact between them should be kept at a distance. It should not be direct. Isolation is also necessary when performing any tests on the ship is impossible. After the ship enters the nearest port (regardless of whether the person has been tested on the ship or not), the infected/suspected crew member will be subjected to all tests again by the ground services. Depending on their results, he either will return to the ship and continue his voyage, or he will be quarantined, following the applicable regulations, in the country where he disembarked and performed the test or in his home country. After quarantine, at least 6 weeks must elapse after the person has been re-embarked on the ship.

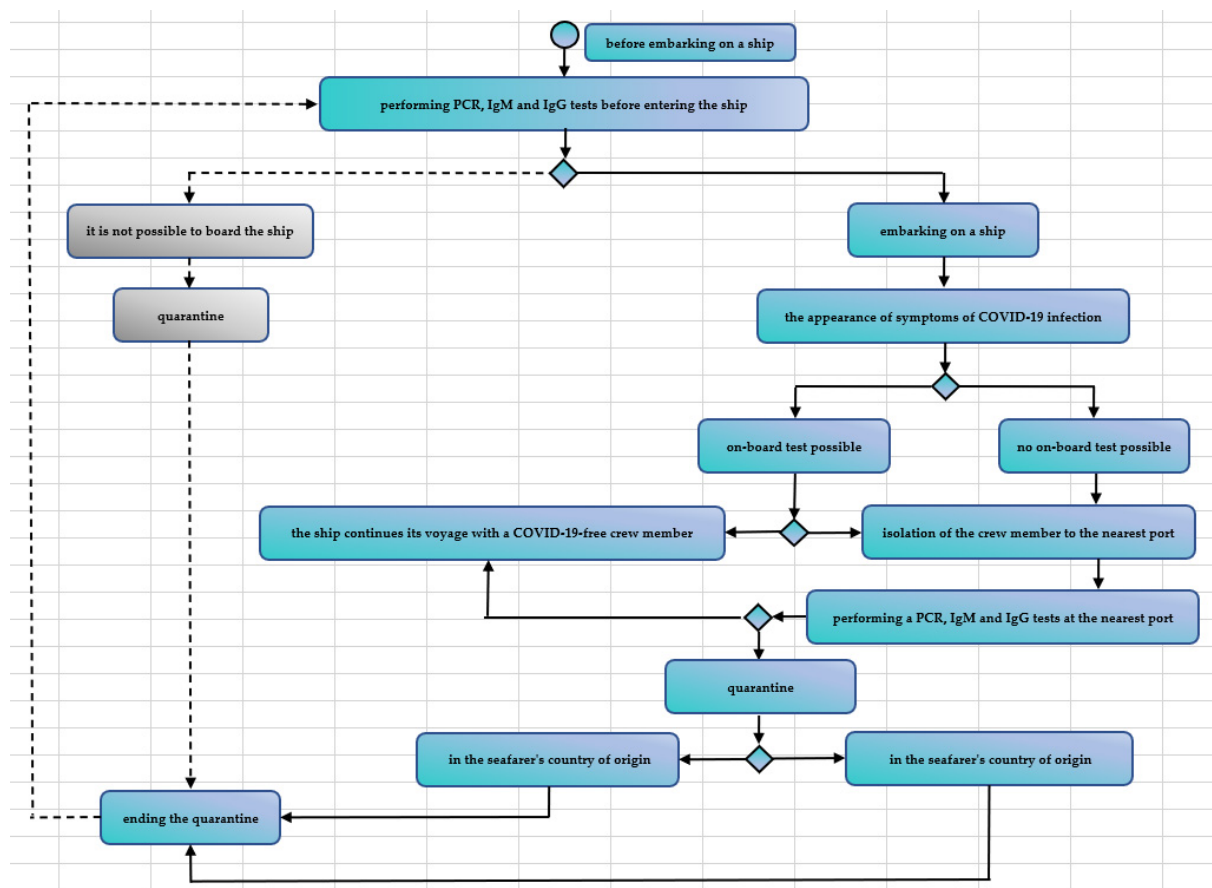


Figure 6. A model of the procedure to be followed in the event of the COVID-19 threat.

4. Summary

The pandemic caused many far-reaching consequences for the functioning of maritime transport and the entire world economy and took everyone by surprise. This article focuses on those that directly affected seafarers and shipowners and were of an economic and social nature. They have a macro dimension, but also apply to ordinary people. Many ship workers were painfully affected by the pandemic in terms of economy and health, and some of them even died due to infection. Shipowners also faced the need to deal with this situation, which was also a challenge for many international organizations and maritime administration units (and not only).

Identifying and describing the socio-economic consequences of the pandemic for seafarers of sea-going ships and their owners was a subobjective [C₁] of the research. This goal can be considered achieved, although it was impossible to describe all the effects of a pandemic on maritime transport. The authors had to select and choose the most important in their opinion. Of course, one can argue that the ones described in the article are the leading ones, but they are indeed essential. The choice, in addition to the ongoing monitoring of the situation development and the literature review on this topic, was greatly facilitated by discussions with representatives of shipowners, ship crews, or maritime administration units, and then questionnaire surveys.

Another achieved goal was the analysis of the management and conduct procedures on sea-going vessels in the pandemic situation [C₂]. On its basis, the conclusion was drawn that despite compliance by shipowners with the standards and guidelines of international organizations, national regulations, and flag states, they differ in many respects.

A natural consequence of this state of affairs was that the authors undertook the verification of the subgoal [C₃], which consisted of identifying, describing, and prioritizing the causes of infections. This ultimately made it possible to achieve the main goal research

[C₀], i.e., the development of a universal model of the procedure to be followed on a sea-going ship in pandemic condition by identifying and assessing the significance of determinants of COVID-19 infection of its crew in terms of the risk of coronavirus infection (carried out and discussed above).

Procedures are an effective management tool for both the owner and the crew. They greatly simplify the decision-making process, as long as they are clear and understandable. One should not go overboard with their number and degree of detail, because, as the practice of management shows, it may have adverse effects. However, they are undoubtedly helpful in unfamiliar and unexpected situations, and their strength lies in their simplicity.

The model of the procedure to be followed on the ship was created specifically for the COVID-19 pandemic, but it is constructed in such a way that depending on what pandemic disease will be faced by humanity in the future and on what progress medicine will make, it will be enough to its slight modification to meet the requirements of new pandemic conditions. An intermediate step toward the goal was the identification and description of the main factors causing infections on sea vessels. The research also confirmed the ship's captain played a significant role in this respect, and a wide range of other important factors may be the subject of further research.

Author Contributions: Conceptualization—V.J. and J.K.; literature review—J.K. and V.J.; methodology—V.J. and J.K.; survey research—V.J.; calculations—V.J. and J.K.; writing, supervision, and editing—J.K. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by Ministry of Education and Science; 1/S/PUBL/WIET/2022.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Survey research according to a questionnaire developed by V.J.

Conflicts of Interest: The authors declare no conflict of interest.

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