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## Concept of the E-Waste Management Model on Sea-Going Ships

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**Abstract:**

**Purpose:** The article presents the issue of the e-waste management on sea-going ships. Characteristics of ship-generated waste in accordance with the international classification in force and the new category (e-waste) was defined in the first part of the article. Furthermore, the principles of its management were analysed in the context of the adopted amendments to Annex V of MARPOL 73/78. The objective of the article is to develop a preliminary concept of the e-waste management model on a sea-going ship, considering the annual variation of e-waste occurrence on ships.

**Design/Methodology/Approach:** The conducted research allowed to develop a concept of the e-waste management model on sea-going ships. The presented model was developed based on available data from both seagoing ships and selected EU ports. The universal character of the model will allow for its wide application and the implementation of its individual stages will ensure appropriate supervision and increase the efficiency of the whole process.

**Findings:** Identification and compilation of the issue of the e-waste management on sea-going ships. The universality of the model allows for its wide application and implementation of its individual stages, both on sea-going ships and in seaports.

**Practical Implications:** A natural consequence of the model will be the implementation of measures which should be predictable to reduce the risk of undesirable events resulting from bad e-waste management practices on sea-going ships.

**Originality/value:** Indication of future research directions improving the functionality solutions on ships model according to the recommendations of the circular economy.

**Keywords:** Sustainable ship waste management, environment, statistical analysis, environmental and safety aspects.

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## 1. Introduction

The increase in public awareness of environmental issues requires an increasing emphasis on activities aimed at protecting the environment. This has resulted in numerous legal provisions on the possibilities of the waste management. Currently, ships and ports are obliged to have facilities for storing and receiving waste from ships. There is an obligation to adjust ship and port procedures to the adopted laws in such a way to enable ships to deliver waste to ports, which has a positive impact on reducing amount of waste released to the environment.

There is an opportunity to reduce waste released to the environment through the proper waste management. The largest amount of waste is generated during the service of a ship. In addition to the waste that will be delivered to the port (including the e-waste analysed in the E-waste article), the emissions of exhaust gases, the amount of waste that is discharged into the water and the discharges of residual cargo must also be considered.

Operational wastes are unavoidable as they result from the normal service of a ship but can be reduced as technology advances. Emergency wastes are also a group of waste that cannot be avoided but can be reduced in frequency. Great emphasis is laid on the segregation of waste, and above all its storage in appropriate conditions and places. Waste has been classified and divided into groups due to different storage, transport, or disposal methods (Bień, 2021).

Given that the crew of each ship is required to segregate waste from their ship and that mixed waste is considered as hazardous waste, it is important that segregation activities are conducted in accordance with applicable procedures and plans (Slišković *et al.*, 2018). E-waste, which may pose a particular threat to the environment, should be treated as a separate group. Considering the specificity of a vessel, i.e., type, weight and capacity parameters, number of crew members or the amount of generated waste, appropriate procedures for the e-waste management should be developed in order not to burden a ship and its surroundings and not to cause additional costs. It should be noted that the waste limit is granted once before a ship enters the port based on the declaration and each subsequent declaration is additionally paid (Deja *et al.*, 2021).

The objective of the article is to develop a preliminary concept of the e-waste management model on a sea-going ship, considering the annual variation of e-waste occurrence on ships. While the problem of the e-waste management is widely developed in the land environment, it has been functioning on ships for a short time and at present there are no detailed procedures concerning its management. In the article, the methods of statistical analysis were used to identify ship-generated waste with the specification of the amount of e-waste and the elements of the 5S method were proposed in the concept of the e-waste management model. Such an approach, considering the current (low) level of knowledge, is necessary to develop selected aspects of the e-waste management on ships.

## 2. Theoretical Aspects of the E-Waste Management on Ships and in Ports

Considering both organisational and environmental safety aspects, it is particularly important for the organisation of reception and management of waste from ships to be familiar with their specific characteristics (Balic, 2019 and Deja *et al.*, 2018). The most important international legal instrument governing ship-generated waste is MARPOL 73/78 (IMO, 1973). It should be stressed that most downstream legal instruments, including international agreements of regional nature, make direct reference to the definitions and provisions of that Convention (Ukić Boljat *et al.*, 2020). The regulations included in the document include all types of vessels and oil platforms, except for pollution resulting from research and use of the seabed. While characterising a ship as a source of marine pollution, account should be taken of the conditions of its normal service, without emergency situations, in accordance with the classification currently in force (Table 1).

**Table 1.** Classification of ship-generated waste/pollution according to MARPOL 73/78 (IMO, 1973)

MARPOL 73/78	Classification of ship-generated waste/pollution
Annex I	oily bilge water; oily residues (sludge); oily tank washings (slops); dirty ballast water; and scale and sludge from tank cleaning;
Annex II	cargo residues containing noxious liquid substances (NLS) as defined in MARPOL Annex II; or ballast water, tank washings or other mixtures containing such substances
Annex IV	sewage
Annex V	garbage as defined in MARPOL Annex V (see paragraph 8), including plastics, food wastes, domestic wastes, cooking oil, incinerator ashes, operational wastes, animal carcasses, fishing gear, E-waste, cargo residues not harmful to the marine environment (non-HME) and cargo residues harmful to the marine environment (HME);
Annex VI	MARPOL Annex VI: ozone-depleting substances and equipment containing such substances, and exhaust gas cleaning residues.

**Source:** (IMO, 1973).

Detailed guidelines on management of shipboard waste were included in Annex V of MARPOL 73/78 and adopted on 31 March 1988. Under this document shipboard waste is defined as: „Garbage, as defined in MARPOL Annex V, means all kind of food wastes, domestic wastes and operational wastes, all plastics, cargo residues, incinerator ashes, cooking oil, fishing gear and animal carcasses generated during the normal operation of the ship and liable to be disposed of continuously or periodically, except those substances which are defined or listed in other Annexes to the Convention” (IMO, 1973).

In the waste record book (or official ship logbook), the waste category lists electronic wastes as one of the subcategories marked with an "I". The other groups are A - plastics, B - food product wastes, C - household wastes, D - cooking oil, E - incinerator ashes, F - operational wastes, G - animal carcass, H - fishing gear.

According to Annex V of MARPOL Convention, shipboard waste should be pre-sorted and can then be sent to port reception facilities, while in the waste management plans in individual ports e-waste may be assigned to different port reception facilities depending on the assigned waste code (e.g., in ports of Szczecin and Świnoujście only batteries and accumulators are separated from the E-waste Category, while others are assigned to the waste equipment).

According to the European Union's guidelines, e-wastes is defined as „waste electrical and electronic equipment’ or ‘WEEE’ means electrical or electronic equipment which is waste within the meaning of Article 3(1) of Directive 2008/98/EC, including all components, sub-assemblies and consumables which are part of the product at the time of discarding” (EU, 2012). In the available scientific literature on the shipboard waste management issues, the mainstream refers to both the legal aspects, methods of reception, management of waste reception in specific ports and the impact of the generated waste on the environment. The state of knowledge on this subject is still quite limited, the literature reviewed by the authors on this issue shows few publications and none of them solves the entire problem. The article (Vaneckhaute and Fazlia, 2020) identifies the best management practices for ship-generated organic waste from ports of Helsinki, Stockholm, Tallinn, Copenhagen, and Malmö. Amounts and characteristics of ship-generated waste was specified and the applicable regulations and disposal methods for the selected types of waste were analysed. The issue on food wastes was also considered by (Wilewska-Bien *et al.*, 2016) as regards its impact on the Baltic Sea environment.

Whereas the identification of factors influencing the volume of generated oil and rubbish was made in the article (Pereza *et al.*, 2017) unfortunately, e-waste has not been separated in the waste category. Its analysis shows that in most European ports there is a uniform waste reception tariff based on ship size, and other factors influencing waste generation are therefore examined. On this basis, a database of almost 6000 observations was created to assess key factors related to ship design, voyage routes number of people on board. The subject of the solid waste management on cruise ships, however, also without the separation of e-waste, was analysed in the publications (Sanches *et al.* 2020). Social, economic, and political considerations were also included in the analysis. Data on the amount of waste generated by cruise ships has been made available, with e-waste being turned into hazardous waste.

Another approach to waste management issues was presented in the publication Ulnikovic *et al.*, 2012) where recommendations for the construction of terminals and other facilities for reception and management of waste streams from ships to final treatment and storage sites were developed through an analysis of the structure of

inland transport. In the article, the authors pointed out that e-waste is one of the fastest growing waste streams in the world in terms of quantity and its environmental impact. The existence of precious metals in the e-waste stream provides significant economic benefits for the recycling industry, but due to the presence of hazardous chemicals an appropriate recycling technique is required prior to the disposal of e-waste.

More data on e-waste and its impact on the environment and human health can be found in the general literature, not on ship service. The publication (Noel-Brunea *et al.*, 2013) highlights the toxicity of e-waste, especially during the recycling process. The problem of the e-waste recycling itself is addressed in the publication (Kumar and Holuszko, 2016) where statistical studies on the global generation of e-waste in correlation with the gross domestic product and the national population were conducted. The article also describes the significance and advantages of recycling, presenting the currently applied methods and techniques.

The literature on the subject has no comprehensive approach to the issue of the shipboard e-waste management. While achieving the aim of this article, some of the port and shipboard waste management procedures (especially solid waste) can be used, however, there is a need to develop a separate concept for e-waste, due to its specificity and properties.

### 3. Materials and Methods

The amount of ship-generated waste can be presented as a function, depending on several independent variables, which are generated by the ship herself, her crew and her cargo:

$$W = f(P_S, P_Z, P_L, Z) \quad (1)$$

where:

$P_S$ - variables identifying the vessel;

$P_Z$ - variables identifying the crew;

$P_L$ - variables identifying the cargo;

$Z$ - sailing range.

The variables that identify the vessel may include vessel type, vessel size (capacity, weight, main dimensions), vessel age, type of equipment and installations. Among the variables identifying the crew, the most important is the number of people on board. When analysing passenger ships, the impact of different population factors on the amount of e-waste produced should be considered separately. The basic variable identifying the cargo is the type of cargo transported, with its specificity and properties strongly influencing the types of equipment and installations and, consequently, the occurrence of e-waste, which will be discussed in detail later in the article. The number of ship calls and the ship sailing range determine the number of supplies, but most importantly, they determine the volume of waste and cargo residues, including e-

waste, delivered to a given port. The ability to estimate these variables is not an easy challenge, but it may allow the expected volume of waste generated by different ship types to be clearly identified.

Considering the above, the objective of the study was to develop a preliminary concept of a model for the e-waste management on a sea-going ship using the 5S method and considering the annual variation of its occurrence on sea-going ships. Therefore, the following research hypothesis is put forward in the article: *Proper organisation of ship-to-port reception of e-waste may improve the shipboard e-waste management but also contribute to the elimination of its environmental risks.*

Achievement of an objective of the article defined in this way and verification of the hypothesis requires solving specific problems, i.e., estimation of the amount of e-waste from the ship, identification of e-waste types regarding the place of its occurrence, examination of the ship crew's activities with regard to the e-waste management, verification of applicability of the 5S method in the shipboard e-waste management model.

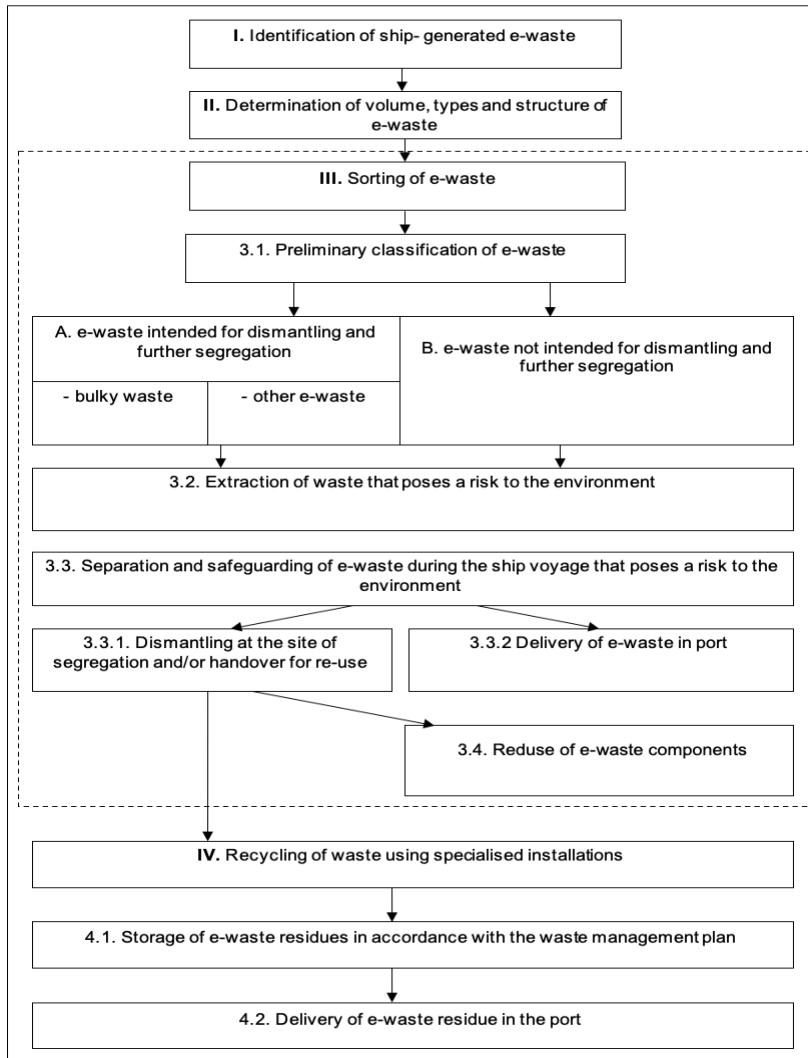
#### **4. Characteristics of the E-Waste Management Model on Sea-Going Ships**

Given that the crew of each ship are required to segregate waste from their ship and that mixed waste is treated as hazardous waste, it is important that segregation activities are conducted in accordance with applicable procedures and plans. E-waste, which may pose a particular threat to the environment, should be considered as a separate group.

Considering the specificity of the vessel, i.e., type, weight and capacity parameters, number of crew members or the amount of generated waste, appropriate logistic chains of e-waste should be developed in order not to burden the vessel and its surroundings and not to cause additional costs. It should be noted that the waste limit is granted once before the ship enters port based on the declaration and each subsequent declaration is additionally paid (Kaup *et al.*, 2019).

The recommended model (Figure 1) foresees 4 basic steps in the e-waste management. The first three steps include the shipboard e-waste management, starting with the identification of the e-waste generated on board the ship, through determining its volume, types, and structure. The most important step in this process is the classification, considering e-waste intended for dismantling and further segregation and not intended for dismantling and further segregation, and then extracting, separating, and safeguarding the e-waste that poses a risk to the environment during the ship voyage. In the next stage, the waste is processed by means of specialist installations and the remains are stored in accordance with the applicable procedures. This stage is conducted in the port.

Figure 1. Simplified model of e-waste management on board and in port



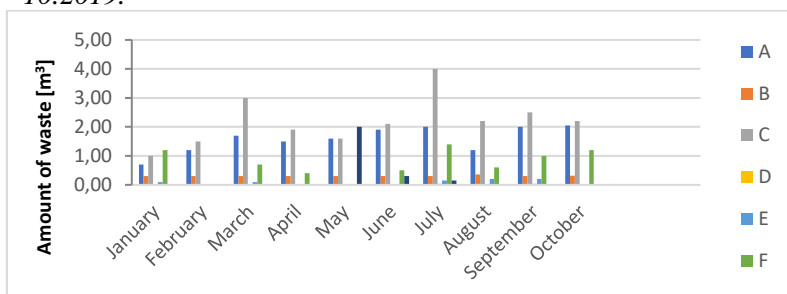
Source: Own elaboration.

E-waste recycling is becoming increasingly important as it allows the retrieval of certain, often small amounts of substances that can be reused at a later stage. It should be stressed that the treatment of secondary raw materials also requires much less energy (about 10%) than their primary production and reduces the production of pollutants. Retrieved raw materials can be reused or simply sold. This makes e-waste recycling not only environmentally friendly but also financially advantageous. Incorrect processing or illegal sales should be avoided. E-waste, if not properly recycled, can release hazardous substances and often involves high disposal costs (because it is considered as hazardous waste).

## 5. Estimation of the Amount of E-Waste on the Example of a Container Ship

This section presents the results of research conducted between January and October 2019 on a container ship with 22 crew members. The research concerned the amounts of generated waste included in Annex V of MARPOL Convention with a breakdown into individual months of the year. Figure 2 shows the distribution of waste generation by subcategory. The analysis of the results obtained shows an increasing amount of waste in March and July. In these months, quarterly deliveries were made, which resulted in an increase in the generation of waste of categories A and C. With regard to the F category waste, an increase in the generated waste is noticeable due to the delivery of used parts, filters or other waste generated during ship service.

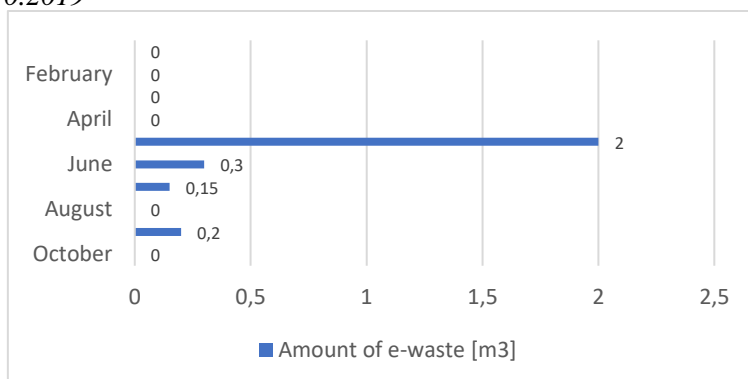
**Figure 2.** Amount of waste (garbage) generated on a container ship during the period 01.2019 - 10.2019.



*Source:* Own elaboration.

Based on the research conducted in the analysed period, the amount of electrical and electronic waste generated on the container ship during her normal service has been presented (Figure 3).

**Figure 3.** The amount of e-waste generated on a container vessel during the period 01.2019-10.2019



*Source:* Own elaboration.



The analysis showed that 0 to 2 cubic metres of e-waste per month were generated on the vessel in the examined period. The highest amount of waste was observed in May, which resulted from the replacement of office, navigation, and cabin equipment. Works related to the replacement of equipment were conducted from May to July. It should be emphasized that the presented statistical data do not include all e-waste generated during individual voyages on the surveyed container ship. Damaged elements of refrigerated containers, which constituted an integral part of the transport equipment, were collected directly by the container operators. A distinctive feature of e-waste is its varied occurrence strongly dependent on repair and modernisation works performed on the ship. The average monthly amount of e-waste determined on the example of the analysed vessel is only 0.265 m<sup>3</sup>, however, this value is insignificant in the case of the waste management planning, as much higher values can be expected periodically. Such a situation may cause an increase in the ship service costs due to the failure to report the need to handle this type of waste in port, especially in cases of failure of electronic and electrical equipment, which needs to be replaced at the nearest port of call.

Forecasting the amount of e-waste in the current level of knowledge is practically impossible as there is no obligation to fully identify the different e-waste types that are delivered in ports. It is still classified as hazardous waste, which also includes other waste types. There is a need to record more accurately the volume, types, and structure of e-waste in order to obtain sufficient data for the development of reliable and authoritative statistical forecasting models.

## **6. Activities of the Ship Crew on the E-Waste Management**

Observations also included a detailed analysis of the e-waste generated on the container ship and the place of its occurrence. Table 2 presents e-waste, which was created in the period from January 2019 to October 2019. This information is particularly important from the point of view of finding the best solutions for the shipboard waste management.

To solve the detailed problems, the ship crew's activities were analysed (Table 3). The tasks performed were divided into two groups and included the master and other crew members. The research conducted showed that due to the specific nature of this group of waste and the ecological hazard it poses, most crew members were involved in the process of the shipboard e-waste management.

Environmentally safe waste may be stored outside the place protected against fire. This is done by adding additional containers (consisting of non-flammable materials) in the place of storage and segregation. Waste management is governed on each ship by a Waste Management Plan. The guidelines include the storage, collection and segregation of all waste generated during ship service.

**Table 2.** *E-waste types generated on the container ship in the period 01.2019-10.2019*

Shipboard e-waste generation places	E-waste types
Superstructure	Used household appliances and audio-visual equipment, computer hardware, sensors, used navigation equipment, controllers, lighting elements (fluorescent lamps, luminaires, energy-saving lamps), control panels.
Engine room	Electric engines, automation and accessories for machinery and auxiliaries, luminaires, energy-saving lamps, fluorescent lamps, smoke detectors, heat regulators, thermostats, measuring devices and control panels
Deck	Used parts of refrigerated containers (compressors, electrical cables, controllers, electrical systems), electric engines of on-board equipment, onboard electrical equipment, energy-saving lamps, fluorescent lamps, luminaires, electrical components of unloading equipment,
Holds	Used parts of refrigerated containers (compressors, electrical cables, controllers, electrical systems), electric engine fittings, smoke detectors, heat regulators, thermostats, measuring devices and electrical control panels (cargo hold ventilation, electrical installation for powering refrigerated containers), luminaires, energy-saving lamps, fluorescent lamps, electrical detectors.

**Source:** *Own elaboration.*

**Table 3.** *Tasks to be performed by the ship crew with regard to the shipboard e-waste management*

Entity	Ship
Master	Increasing the crew's awareness of the dangers of improper segregation and storage of e-waste; Supervising and implementing the waste management according to ISM (International Safety Management); Enforcing crew to implement procedures in accordance with the ISM (International Safety Management) waste management system; Reporting the amount and type of e-waste to port reception facilities; Contacting the entity receiving e-waste in order to determine the date and conditions of service provision; Organising the crew and preparing the ship for the efficient delivery of waste and cargo residues to the collection facilities.
Other crew members	Implementing activities in accordance with the shipboard waste management system and enforcing ISM, i.e. the waste management system in accordance with ISM ( <i>International Safety Management</i> ); Qualifying and segregating e-waste in accordance with the shipboard waste management plan, taking into account the specificities of hazardous materials; Preparing and securing a place on board the ship for the storage of e-waste, taking into account the specificities of hazardous waste (in a place provided in accordance with the waste management plan); Permanent supervision over the stored waste; Preliminary dismantling of the e-waste in order to secure e-waste/reuse of individual elements;Preparing e-waste to be delivered to port.

According to the guidelines there should be places to collect and segregate waste as well as to store it. Most often the waste is collected and segregated in work places such as: workshop, bosun's storeroom or galley and pantry. Storage takes place in a separate room for this purpose or waste containers placed on board. The new regulations have forced the Company to provide additional space for the segregation of electrical and electronic waste on the ships, without the possibility of increasing the space for its storage. The additional space should be provided at the place intended for storing waste, unfortunately at the expense of space for other waste. Environmentally safe waste may be stored outside the place protected against fire. This is done by adding additional containers (consisting of non-flammable materials) in the place of storage and segregation.

### 7. Application of the 5S Method in the Shipboard E-Waste Management Model

The 5S method is one of the basic tools of Lean Manufacturing and Lean Management at Łopatowska (2002) and Jędrzejak *at al.* (2014). The method determines the techniques supporting the maintenance of high-quality workplace organisation. Analysing the examples of method implementation in companies operating on land, one can notice an analogy to the proposed concept of the e-waste management model on a ship. The individual steps of implementation and application of the 5S method are as follows:

1. S – Sort (Jap. Seiri),
2. S – Set in Order (Jap. Seiton),
3. S – Shine (Jap. Seiso),
4. S – Standardize (Jap. Seiketsu),
5. S – Sustain (Jap. Shitsuke).

By implementing the 5S method for the shipboard e-waste management, the following activities can be assigned to each step (Table 4).

**Table 4.** *Activities within the implementation of the 5S method for the shipboard e-waste management*

Stage	Activities
1S	Sorting is aimed at identifying the e-waste generated on board the ship and is also assumed to overcome the habits of the crew to store unnecessary items, including materials, tools, equipment, etc. Sorting should eliminate electronic and electrical components or tools. Due to the application of selection, it is possible not only to keep the workplace clean, but also to pre-classify e-waste.
2S	Setting in order refers to the detailed planning of e-waste according to its type and its arrangement in separate rooms for this purpose or waste containers placed on board. For this purpose, it is important to determine where and how unnecessary items are stored during the voyage. At this stage, it is worthwhile to use the principles of proper marking of e-waste storage places so that no mistakes can be made in proper waste segregation by ship crew members.

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- 3S Another task is to maintain routine cleaning work involving dismantling of used and/or broken electrical and electronic parts from different rooms of the ship. This activity allows the identification and elimination of disorderly sources, as well as a kind of inspection for the purpose of maintaining full operational readiness of machinery and equipment on board. As part of this step, specific e-waste management tasks should be assigned to individual persons in the shipboard and engine departments.
- 4S Standardisation is the result of the preceding stages, which are aimed at maintaining the principles already introduced. At this stage, it is required to develop procedures for the e-waste management in order to develop specific habits among crew members. The standards and procedures must be simple, clear, and understandable, taking into account the national and language diversity of the ship crew. It is important that it is the crew members who are actively involved in the development of these procedures, which will best take into account the specificities of each workplace on the ship.
- 5S At this stage, shipboard e-waste management habits and skills should be developed in accordance with settled standards.  
Crew members at operational and management level should understand the need to apply the procedures developed. This is the most difficult stage to implement as it requires a change in thinking and behaviour. The process of self-discipline can be aided by visualising the consequences (e.g., environmental) of inadequate e-waste management. In some cases, fines are not excluded.
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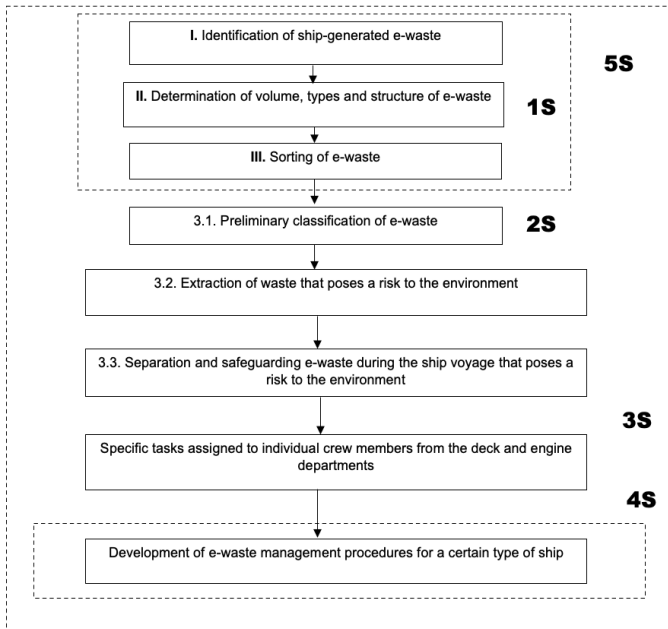
The introduction of the above method can yield several positive results, including:

- a) eliminating obsolete electrical and electronic components which will protect machines and equipment from damage and destruction,
- b) better use of space on board the ship by properly arranging and storing e-waste,
- c) facilitating the estimation of the e-waste amounts prepared for deliveries at the port, resulting from the systematic collection of e-waste in specific sites,
- d) increasing the reliability of forecasting the amount of e-waste per year and thus reducing port costs,
- e) improving workplace safety by separating particularly hazardous e-waste.

In Figure 4, the individual steps of the 5S method are assigned to the steps of the developed shipboard e-waste management model (first 3 steps of the model in Figure 1).

While in the case of applying the 5S method for companies the steps are consecutive, in the case of ship-to-ship e-waste management the individual steps of the 5S method can be implemented in different stages of the model developed. Phase 5S includes all previous steps as the introduction of appropriate habits among the crew members should take place from the moment the e-waste appears on board the ship until it is delivered in port.

Figure 4. Application of the 5S method in the e-waste management model



Source: Own stud

## 8. Conclusions

Most of the shipboard waste can be treated by incineration or compression with a crusher, which excludes e-waste. Therefore, its management poses a separate challenge to the ship crew, in particular its storage and proper preparation for deliveries in port. Given the increasing cost of handling waste in ports and the environmental issue, this subject is an important part of the onboard waste management plan. In addition, the proper e-waste management has a significant impact on reducing the e-waste volume, which is causally related to the ship safety (elimination of fire hazards, environmental protection).

The research conducted in the article confirms this hypothesis. It can be stated that a proper organisation of e-waste reception at the ship-port level may improve the shipboard management of e-waste but also contribute to the elimination of the risks it poses. Literature studies and own research conducted in the article showed the lack of a comprehensive approach to the issue of the shipboard e-waste management. The authors filled the existing gap by proposing a 4-stage model of e-waste management covering the ship-port area. The model includes both the identification of the ship-generated e-waste and the determination of its volume, types, and structure.

The article analyses only the amount of electrical and electronic waste generated on the container ship. As it is practically impossible to forecast the amount of e-waste

amount at the present level of knowledge, it was pointed out that it is necessary to record more precisely the volume, types, and structure of e-waste to obtain enough data to develop reliable and authoritative statistical forecasting models. For the analysed container ship, the generated e-waste was additionally identified together with the place of its occurrence and tasks to be performed by the ship crew were identified.

The last part of the article is a proposal of implementation of the 5S method for the shipboard e-waste management with indication of several benefits resulting from it.

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