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Bogalecka Magda

Kołowrocki Krzysztof
Maritime University, Gdynia, Poland

The process of sea environment threats generated by hazardous chemicals release

Keywords

sea accident, pollution, dangerous goods, properties of chemicals, environment threats

Abstract

The kinds of threats coming from chemicals released as a result of sea accident are distinguished. An exemplary procedure of defining states of the sea environment threats process generated by hazardous chemicals is presented. The interrelation between the sea environment threats and this environment degradation process is discussed and finally, a preliminary approach to a general modelling and prediction of the process of the environment threats caused by the process of initiating events generated by critical infrastructure accidents is presented.

1. Introduction

The sea transport of dangerous goods is pretty safe at normal environmental conditions. However, the transported goods may sweep out to the sea as a result of unexpected events such as collision, grounding, fire, damages of ship machinery, etc. These events may bring about the release of hazardous chemicals into the sea environment. Then the substances occur the sea environment threats and finally they may have disastrous influence on the human health, the ship as well as the marine ecosystem.

Therefore the risk analysis of the environment pollution coming from the transport of hazardous chemicals is based on fixing and interrelating the sea accident initiating events E, the hazardous chemicals H and their influence on the marine environment degradation, the states of environment threats S and the environment degradation effects R (*Figure 1*) [1].

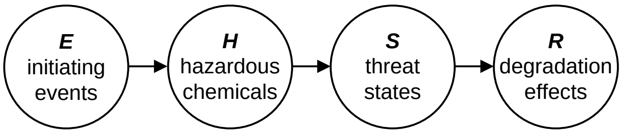

Figure 1. Interrelations of the environment degradation factors

The risk analysis of chemical spills at sea and their consequences is proposed to be based on the general model of mutual interactions between three processes: the process of the sea accident initiating events, the process of the sea environment threats and the process of the sea environment degradation.

The process of the initiating events $E(t)$ is particularly considering in [2] where the methods and procedures of its modelling, unknown parameters identification and characteristics prediction are proposed and preliminarily applied to its realization generated by the ship operating in the Baltic Sea waters. In this paper, after particular discussion on the influence of the hazardous chemicals release on the sea environment, a general model of the process of environment threats, mainly based on the results given in [6]-[10], is proposed.

2. Paper preparation

Chemical substances transported throw the sea may unexpected released into the marine environment. These substances were analysed and 9 kinds of sea environment threats coming from them were distinguished:

S_1 – explosiveness,
S_2 – flammability,
S_3 – water contamination,
S_4 – air contamination,

S_5 – corrosiveness,
S_6 – radioactive contamination,
S_7 – bioaccumulation,
S_8 – interferences with costal amenities,
S_9 – other long-term harmful effects.

The kind and range of these threats depend on the physical and chemical properties of substances. It means that the substance properties have to be analysed to point the threats of each substances. On the other hand there are some common classifications (the International Maritime Dangerous Goods Code (IMDG) [5] and classification of the United Nation Joint Group of Experts on the Scientific Aspects of Marine Pollution (GESAMP) [4]), based on substances properties and may be used to easier determine the chemical threats.

The IMDG Code contains the most important guidelines for safety transportation of hazardous materials. The IMDG classification of dangerous goods is based on the characterising physical hazard associated with dangerous substances. Packaged dangerous goods are divided into nine hazard classes: 1 – explosives, 2 – gases (compressed, liquefied, or dissolved under pressure), 3 – flammable liquids, 4 – flammable solids, 5 – oxidizing substances and organic peroxides, 6 – toxic and infectious substances, 7 – radioactive material, 8 – corrosive substances and 9 – miscellaneous substances and articles.

The GESAMP classification groups chemicals according to the potential hazard they pose in the relation to the marine environment. The GESAMP classification provides assessment ratings for the following types of hazard: A – bioaccumulation and biodegradation, B – aquatic toxicity, C – mammalian toxicity, D – irritation and other long-term health effects and E – tainting of seafood and effects on marine wildlife (additionally, the GESAMP F-rating contains remarks).

Explosiveness (S_1). Explosives are able to a rapid breakdown and simultaneous generating both a high temperature and lots of gas fumes. Explosives are grouped into six divisions of the class 1 of IMDG in accordance with their dangerous – the lower number of the division is, the larger hazard becomes (*Figure 2*).

Additionally, it is important to know, that some flammable gases, vapours of flammable liquids and dusts of flammable solids and oxidisers are able to explode e.g. when mixed with air, as well as surrounding temperature or pressure of vapours rise.

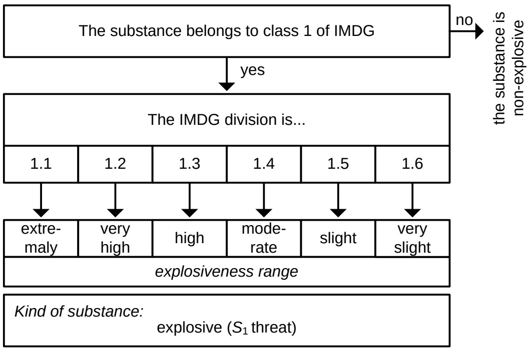

Figure 2. Defining of the explosiveness

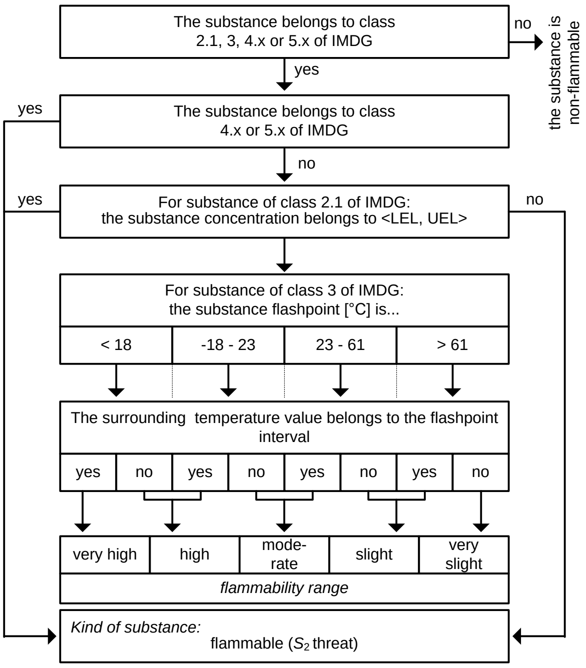

Figure 3. Defining of the flammability

Flammability (S_2). Some gases, liquids and solids are flammable. The fire could be initiated by heating these substances, their contact with an electrical spark or the open flame. For gases the presence of fire depends on the performance of the *combustion triangle*. It means that the fire will appear if the concentration of the flammable substance is between the lower (LEL) and upper explosion limit (UEL), the oxygen concentration in the atmosphere is sufficiency for the oxidising reaction and the ignition source is presented.

The flammability grade of liquids is defined by their flashpoint (the lowest temperature making the sufficient amount of vapour able to lead to the fire) – the lower flashpoint is, the larger hazard becomes.

The IMDG classification is according with the flammability of substances. Combustible gases, liquids and solids are divided into the class 2.1, 3 and 4 respectively. Moreover, the substances of the class 5.1 and 5.2 (oxidisers) may initiate a fire (*Figure 3*).

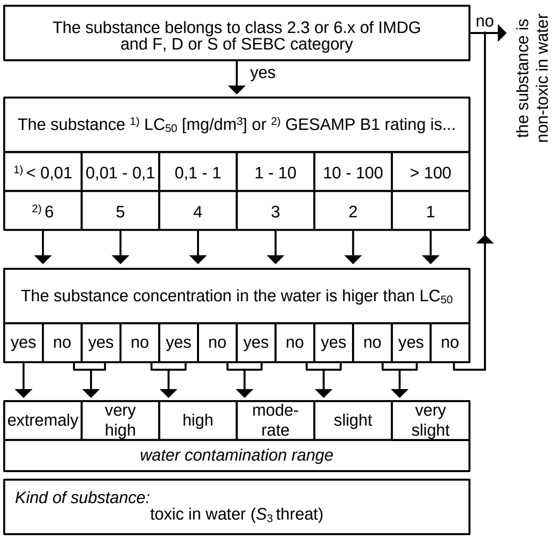

Figure 4. Defining of the water contamination

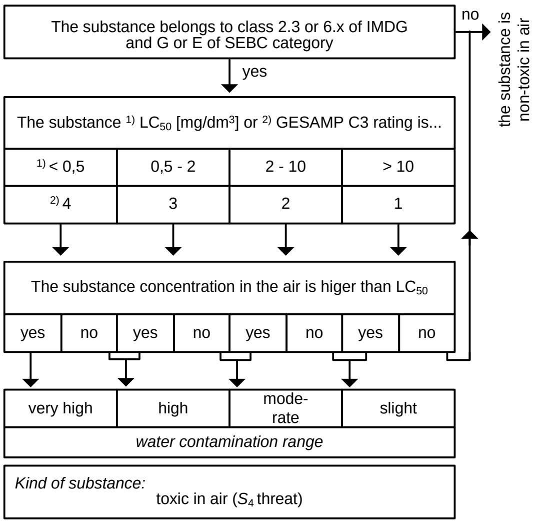

Figure 5. Defining of the air contamination

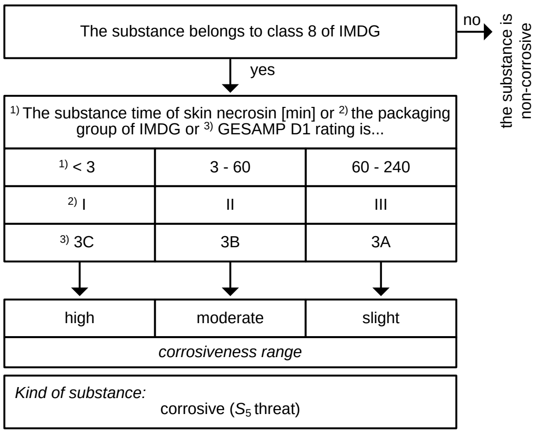

Figure 6. Defining of the corrosiveness

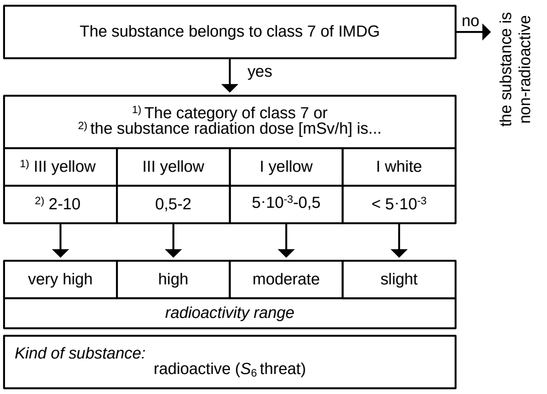

Figure 7. Defining of the radioactive contamination

Water contamination (S_3). Dissolvers and substances dispersing in the seawater may make the water contamination and impairment of organisms existing in the seawater. The amount of these substances and their exposure time influence on the toxicity degree. The toxicity is defined by the average lethal concentration (LC_{50} – it means the concentration of toxic substance dissolved in the sea water that is lethal for 50% of the experimental organisms). The higher LC_{50} value is, the smaller hazard becomes (*Figure 4*).

Air contamination (S_4). Some substances make the air contamination, therefore they are toxic by inhalation. Those substances impair the central nervous system sometimes causing a death. The substances may get to the organism through the skin or the respiratory system. The inhalation toxicity is defined by the average lethal concentration (LC_{50} – it means the concentration of the toxic substance in the air that is lethal for 50% of the experimental organisms). The toxicity of substances depends on their concentration and exposure time. On the other hand, the GESAMP classification could be used to the determination the air toxicity. The C3-rating of the GESAMP (acute mammalian inhalation toxicity) is also based on the LC_{50} value. The higher C3-rating value is, the larger hazard becomes (*Figure 5*).

Corrosiveness (S_5). Corrosive substances impair living tissues and may degrade other substances due to their reactivity. The corrosiveness is defined by the time of a skin necrosis caused by the corrosive substances. Moreover, the IMDG classification as well as GESAMP classification is based on the time of a skin necrosis. Corrosives are divided into the class 8 of IMDG and grouped into three packaging groups corresponding to D1-range indicator of GESAMP. The lower packaging group is, the larger hazard becomes (*Figure 6*).

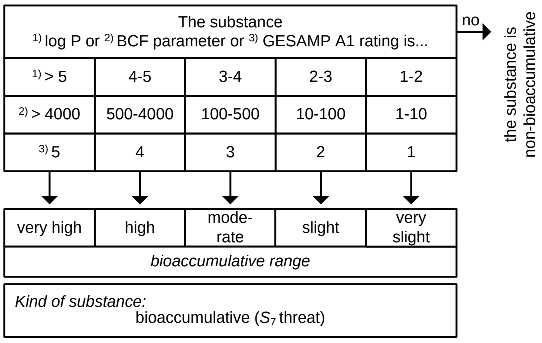

Figure 8. Defining of the bioaccumulation

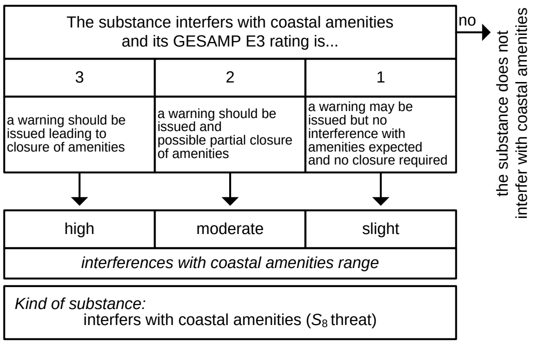

Figure 9. Defining of interferences with coastal amenities

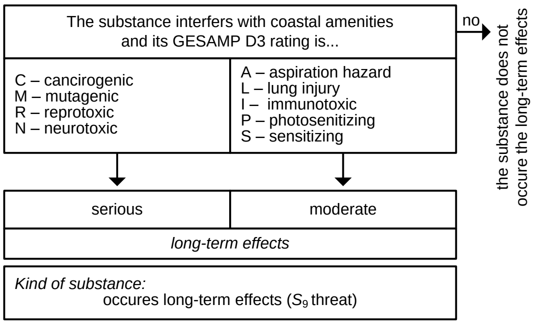

Figure 10. Defining of long-term effects

Radioactive contamination (S_6). Radioactive materials are able to emit α, β and γ radiation. Substances with the specific activity greater than 0.002 μCi/g are classified as radioactive materials and divided into the class 7 of IMDG. In accordance with the IMDG classification there are four categories of the radioactive materials. The IMDG classification is based on the radiation dose. The higher IMDG category is, the smaller hazard becomes (*Figure 7*).

Bioaccumulation (S_7). Bio-accumulative substances concentrate in the living organisms. These organisms are danger for the others of the trophic web. Additionally, bio-accumulative substances wipe out the seafood flavour. The bioaccumulation range is defined by bio-concentration factor (BCF) as well as log P parameter. The log P points the substance ability to dissolve in water and non-polar solvent. The substance better solubility in the non-polar solvent means its better bioaccumulation.
Additionally, the A1-rating of the GESAMP classification is based on log P and BCF parameters. The higher log P, BCF or A1-rating of GESAMP is, the larger hazard becomes (*Figure 8*).

Interferences with coastal amenities (S_8). The presence of some substances in the environment is connected with irritant smell, its persistency and the environment contamination. It causes the long-term or temporary closure of beaches that is described by E3-rating of GESAMP (*Figure 9*).

Other long-term effects (S_9). Chemicals, their solutions and vapours are able to cause serious or moderate long-term effects. Carcinogenic, mutagenic, reprotoxic and neurotoxic properties of substances are defined as serious long-term effects, whereas aspiration hazard, lung injury, immunotoxic, photosenitizer and sensitizing properties are defined as moderate ones. The ability to generate the long-term effects is defined by D3-rating of the GESAMP classification (*Figure 10*).

3. Exemplary identification of the sea environment threat states

The sea environment is not threatened as long as any hazardous substances are presented in the marine ecosystem. When the sea accident has happened without the dangerous substance spill or a chemical substance has realised as a result of the sea accident, but the substance is not hazardous, the sea environment threat process is at the state $s^1 = [0,0,0,0,0,0,0,0,0]$. When any hazardous substance has got out from the ship as a result of the sea accident, the sea environment threat process will transit from the sea environment threat state s^1 to any state from s^2 to s^ν, $\nu \neq 1$.
Example 1. The carbon dioxide is an asphyxiant gas than it occurs the air threat only. It means that at the moment of the release of the carbon dioxide, the sea environment threat process transits from the state s^1 to the state $s^2 = [0,0,0,1,0,0,0,0,0]$. The state s^2 will exist until the carbon dioxide has spread and diluted in the air and next it will return to the state s^1.
Nevertheless, there are not many chemicals, like the carbon dioxide, that occur one threat only.

Example 2. The acetic acid is a colourless and soluble in the water liquid, it occurs the water contamination and beaches closure because of its strong odour of vinegar. Then the acetic acid causes the water contamination and interferences with costal amenities threats. It means that at the moment of the release of the acetic acid, the sea environment threat process transits from the state s^1 to the state $s^3 = [0,0,1,0,0,0,0,1,0]$. When the hydrogen sulphide has removed from the ecosystem, the sea environment threat process will return to the state s^1.

Example 3. The hydrogen sulphide is a flammable gas, toxic in the air, soluble in the water, it occurs the water contamination and beaches closure because of its poisonous and irritant odour. Then the hydrogen sulphide causes the flammability, water and air contamination and interferences with costal amenities threats. It means that at the moment of the release of the hydrogen sulphide, the sea environment threat process transits from the state s^1 to the state $s^4 = [0,1,1,1,0,0,0,1,0]$. When the hydrogen sulfide has spread and diluted in the air, continued to exist in the sea water only, the sea environment threat process will change from the state s^3 to the state $s^5 = [0,0,1,0,0,0,0,1,0]$ (the water contamination and interferences with costal amenities threats). The complete removing of the hydrogen sulphide from the sea ecosystem lets the sea environment threat process to return to the state s^1.

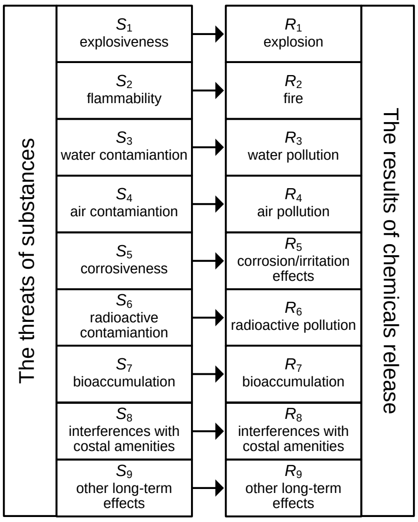

Figure 11. Interrelation between the sea environment threats and degradation effects

This simple further statistical identification of the unknown parameters of the process of sea environment threats can be perform using the methods and procedures similar to that applied to the initiating events process identification given in [2].

The threats of the marine ecosystem as a result of chemical released and the sea environment degradation effects after the sea accident are directly interrelated with one another (*Figure 11*). Then the knowledge of the sea environment threats lets to forecast the sea environment degradation effects. Nevertheless, the sea environment threats show what kind of the sea environment degradation effects may (but not have to) occur.

Thus, the future research should be concerned with modelling, identification and prediction of the generated by the critical infrastructure accidents general environment threats process and the general environment degradation process. The general model of environment threat process based on the results given in [6] is proposed in the next section.

4. The process of environment threats

4.1. Process of environment treats modelling

To construct the general model of the environment threats caused by the process of the initiating events generated by critical infrastructure accidents, we distinguish n_2, $n_2 \in N$, groups of accident consequences that may cause the sea environment degradation and denote them by $H_1, H_2, ..., H_{n_2}$. We also distinguish n_3, $n_3 \in N$ environment sub-regions $D_1, D_2, ..., D_{n_3}$ of the considered critical infrastructures operation environment region

$$D = D_1 \cup D_2 \cup ... \cup D_{n_3},$$

that may be degraded by the distinguished critical infrastructure accident consequence groups. Degrading influence of the critical infrastructure accident consequence groups on the distinguished their operation environment sub-regions is presented in *Figure 12*.

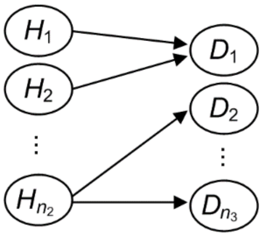

Figure 12. Hazardous accident consequences influence on the marine environment sub-regions degradation

The threat level of these sub-regions depends on $n_4,$ $n_4 \in N,$ factors $f_1, f_2, ..., f_{n_4}$, characterising critical infrastructure accident consequence groups. Simultaneously, we assume that the environment threat by the critical infrastructure accident consequence groups is depended on some of these parameters. Different ranges of these factors generating various scales of the sea sub-region environment threats are also distinguished. Namely, the factor $f_j,$ $j = 1,2,...,n_4,$ may assume the values in m_j ranges $f_{j1}, f_{j2}, ..., f_{jm_j}$.

Definition 1. A matrix

$$[S_{ij}^{(k)}]_{n_2 x n_4} = \begin{bmatrix} S_{11}^{(k)} & S_{12}^{(k)} & . & . & . & S_{1n_4}^{(k)} \\ S_{21}^{(k)} & S_{22}^{(k)} & . & . & . & S_{2n_4}^{(k)} \\ . & . & . & . & . & . \\ S_{n_2 1}^{(k)} & S_{n_2 2}^{(k)} & . & . & . & S_{n_2 n_4}^{(k)} \end{bmatrix},$$

where

$$S_{ij}^{(k)} = \begin{cases} 0, & \text{if a factor } f_j \text{ does not have influence on} \\ & \text{the sub-region } D_k \text{ threat by the critical} \\ & \text{infrastructure accident consequence} \\ & \text{group } H_i, \\ f_{jl}, & \text{if a factor } f_j \text{ has influence on the} \\ & \text{sub-region } D_k \text{ threat by the critical} \\ & \text{infrastructure accident consequence} \\ & \text{group } H_i \text{ and this factor} \\ & \text{is in the range } f_{jl}, \ l = 1,2,...,m_j, \end{cases}$$

for $i = 1,2,...,n_2,$ $j = 1,2,...,n_4,$ $k = 1,2,...,n_3,$ is called the threat state of the sub-region $D_k,$ caused by a group of critical infrastructure accident consequence H_i.

Definition 2. A set

$$S^{(k)} = \{S_l^{(k)}: \ S_l^{(k)} \in \{[S_{ij}^{(k)}], i = 1,2,...,n_2, \\ j = 1,2,...,n_4\}, l = 1,2,...,\upsilon_k\}$$

where

$$S_{l_1}^{(k)} \neq S_{l_2}^{(k)} \text{ for } l_1 \neq l_2, \ l_1, l_2 = 1,2,...,\upsilon_k,$$

is called the set of the environment threat states of the sub-region $D_k,$ $k = 1,2,...,n_3,$ while a number υ_k is called the number of the threat states of this sub-region.

Definition 3. A function $S^{(k)}(t)$ defined on the time interval $\langle 0,T \rangle$ and having values in the threat states set $S^{(k)}$, i.e., such that

$$S^{(k)} : \langle 0,T \rangle \to S^{(k)}, \ k = 1,2,...,n_4,$$

is called the process of the environment threats of the sub-region $D_k,$ $k = 1,2,...,n_3,$ caused by the CI accident consequences.

Definition 4. A function $S_l^{(k)}(t)$ defined on the time interval $\langle 0,T \rangle$ and having values in the threat states set $S^{(k)},$ i.e., such that

$$S_l^{(k)} : \langle 0,T \rangle \to S^{(k)}, \quad k = 1,2,...,n_3, \ l = 1,2,...,v,$$

is called the conditional sub-process of the environment threats of the sub-region $D_k,$ $k = 1,2,...,n_3,$ while the process of initiating events $E(t)$ is in the state e^l. We assume a semi-Markov model of the sub-process $S_l^{(k)}(t),$ $k = 1,2,...,n_3,$ $l = 1,2,...,v,$ and denote by η_{kl}^{ij} its random conditional sojourn times in the state $S_i^{(k)}$ while its next transition will be done to the state $S_j^{(k)},$ $i, j = 1,2,...,\upsilon_k,$ $i \neq j$. Then, this sub-process is defined by the vector of probabilities of its initial states at the moment $t = 0$

$$[p_{kl}(0)] = [p_{kl}^1(0), p_{kl}^2(0), ..., p_{kl}^{\upsilon_k}(0)]$$

and by the matrix of probabilities of transitions between the states

$$[p_{kl}^{ij}]_{\upsilon_k x \upsilon_k} = \begin{bmatrix} p_{kl}^{11} & p_{kl}^{12} & . & . & . & p_{kl}^{1\upsilon_k} \\ p_{kl}^{21} & p_{kl}^{22} & . & . & . & p_{kl}^{2\upsilon_k} \\ . & . & . & . & . & . \\ p_{kl}^{\upsilon_k 1} & p_{kl}^{\upsilon_k 2} & . & . & . & p_{kl}^{\upsilon_k \upsilon_k} \end{bmatrix}, \quad (1)$$

where $p_{kl}^{ii} = 0$ for $i = 1,2,...,\upsilon_k$.

Moreover, this process is defined by the matrix of conditional distribution functions of sojourn times η_{kl}^{ij} of the process $S_l^{(k)}(t)$ in the state $S_i^{(k)}$ while is next transition will be done to the state $S_j^{(k)},$ $i, j = 1,2,...,\upsilon_k,$ $i \neq j,$

$$[H_{kl}^{ij}(t)] = \begin{bmatrix} H_{kl}^{11}(t) & H_{kl}^{12}(t) & \dots & H_{kl}^{1\upsilon_k}(t) \\ H_{kl}^{21}(t) & H_{kl}^{22}(t) & \dots & H_{kl}^{2\upsilon_k}(t) \\ . & . & \dots & . \\ H_{kl}^{\upsilon_k 1}(t) & H_{kl}^{\upsilon_k 2}(t) & \dots & H_{kl}^{\upsilon_k \upsilon_k}(t) \end{bmatrix},$$

where $H_{kl}^{ii}(t) = 0$ for $i = 1,2,...,\upsilon_k$ and by corresponding to it the matrix of conditional densities of the sojourn times η_{kl}^{ij}

$$[h_{kl}^{ij}(t)]_{\upsilon_k x \upsilon_k} = \begin{bmatrix} h_{kl}^{11}(t) & h_{kl}^{12}(t) & . & . & . & h_{kl}^{1\upsilon_k}(t) \\ h_{kl}^{21}(t) & h_{kl}^{22}(t) & . & . & . & h_{kl}^{2\upsilon_k}(t) \\ . & . & . & . & . & . \\ h_{kl}^{\upsilon_k 1}(t) & h_{kl}^{\upsilon_k 2}(t) & . & . & . & h_{kl}^{\upsilon_k \upsilon_k}(t) \end{bmatrix},$$

where $h_{kl}^{ii}(t) = 0$ for $i = 1,2,...,\upsilon_k$.

Under these assumptions the expected values $E[\eta_{kl}^{ij}]$ and variances $D[\eta_{kl}^{ij}]$ of variables η_{kl}^{ij} are determined by

$$M_{kl}^{ij} = E[\eta_{kl}^{ij}] = \int_0^\infty t h_{kl}^{ij}(t) dt, \qquad (2)$$

$$D_{kl}^{ij} = D[\eta_{kl}^{ij}] = \int_0^\infty (t - E[\eta_{kl}^{ij}])^2 h_{kl}^{ij}(t) dt$$

$$= E[(\eta_{kl}^{ij})^2] - [M_{kl}^{ij}]^2, \qquad (3)$$

where M_{kl}^{ij} are given by (2) and

$$E[(\eta_{kl}^{ij})^2] = \int_0^\infty t^2 h_{kl}^{ij}(t) dt.$$

4.2. Process of environment treats identification

The statistical identification of the unknown parameters of the process of environment threats i.e. estimating the probabilities of this process of staying at the states at the initial moment, the probabilities of this processes transitions between its states and the parameters and forms of the distributions fixed for the description of this process conditional sojourn times at their states can be performed in the similar way to that presented in [2] and [6]. Therefore, we omit it.

4.3. Process of environment treats prediction

Unconditional distribution functions of sojourn times η_{kl}^{i} of the process $S_l^{(k)}(t)$ in states $S_i^{(k)}$ $i = 1,2,...,\upsilon_k$, are determined by

$$\forall i = 1,2,...,\upsilon_k \;\; H_{kl}^{i}(t) = \sum_{j=1}^{\upsilon_k} p_{kl}^{ij} H_{kl}^{ij}(t),$$

and their density functions are given by

$$\forall i = 1,2,...,\upsilon_k \;\; h_{kl}^{i}(t) = \sum_{j=1}^{\upsilon_k} p_{kl}^{ij} h^{ij}(t).$$

The expected values $E[\eta_{kl}^{i}]$ and variances $D[\eta_{kl}^{i}]$ of variables η_{kl}^{i} are determined respectively by

$$M_{kl}^{i} = E[\eta_{kl}^{i}] = \sum_{j=1}^{\upsilon_k} p_{kl}^{ij} M_{kl}^{ij}, \qquad (4)$$

$$D_{kl}^{i} = D[\eta_{kl}^{i}] = E[(\eta_{kl}^{i})^2] - [(M_{kl}^{i})]^2,$$

where M_{kl}^{i} are given by (10) and

$$E[(\eta_{kl}^{i})^2] = \int_0^\infty t^2 h_{kl}^{i}(t) dt = \sum_{j=1}^{\upsilon_k} p_{kl}^{ij} (M_{kl}^{ij})^2$$

for $i = 1,2,...,\upsilon_k$, where p_{kl}^{ij} and M_{kl}^{ij} are respectively given by defined by (1) and (2).

Boundary values of the instantaneous probabilities of the sub-process of the environment threats $S_l^{(k)}(t)$ in its particular states

$$p_{kl}^{i}(t) = P(S_l^{(k)}(t) = S_i^{(k)}), \; i = 1,2,...,\upsilon_k, \qquad (5)$$

are calculated from the formula

$$p_{kl}^{i} = \lim_{t \to \infty} p_{kl}^{i}(t)$$

$$= \frac{\pi_{kl}^{i} M_{kl}^{i}}{\sum_{j=1}^{\upsilon_k} \pi_{kl}^{i} M_{kl}^{j}}, \; i = 1,2,...,\upsilon_k, \qquad (6)$$

where probabilities π_{kl}^i satisfy the system of the following equations

$$\begin{cases}[\pi_{kl}^i] = [\pi_{kl}^i][p_{kl}^{ij}]\\ \sum_{j=1}^{\upsilon_k} \pi_{kl}^j = 1,\end{cases}$$

Where

$$[\pi_{kl}^i] = [\pi_{kl}^1, \pi_{kl}^2, ..., \pi_{kl}^{\nu_k}]$$

and $[p_{kl}^{ij}]$ is determined by (1).

The asymptotic distribution of the sojourn total time $\hat{\eta}_{kl}^i$ of the process $S_l^{(k)}(t)$ in the time interval $\langle 0,\theta \rangle$, $\theta > 0$, in the state $S_i^{(k)}$ is normal with the expected value

$$\hat{M}_{kl}^i = E[\hat{\eta}_{kl}^i] = p_{kl}^i \theta, \ i = 1,2,...,\upsilon_k,$$

where p_{kl}^i are given by (12).

Afterwards, applying the expression for total probability and considering equations (5) given in [6] and (5), we can find unconditional probabilities of the process of the environment threats of the sub-region D_k, $k = 1,2,...,n_3$, in its particular states according to the following formula

$$\begin{aligned} p_k^i(t) &= P(S^{(k)}(t) = S_i^{(k)}) \\ &= \sum_{l=1}^{v} P\big(E(t) = e^l\big) \cdot P\big(S^{(k)} = S_i^{(k)} \big| E(t) = e^l\big) \\ &= \sum_{l=1}^{v} P\big(E(t) = e^l\big) \cdot P\big(S_l^{(k)} = S_i^{(k)}\big) \\ &= \sum_{l=1}^{v} p^l(t) p_{kl}^i(t), \ t \geq 0, \ i = 1,2,...,\upsilon_k. \qquad (7) \end{aligned}$$

Hence, for sufficiently large t, the boundary probabilities of the environment threats process of the sub-region D_k, $k = 1,2,...,n_3$, in its particular states are given by the following approximate formula

$$\begin{aligned} p_k^i &= \lim_{t \to \infty} P(S^{(k)}(t) = S_i^{(k)}) \\ &\cong \sum_{l=1}^{v} p^l p_{kl}^i, \ i = 1,2,...,\upsilon_k, \qquad (8) \end{aligned}$$

where p^l are determined by (26) in [2] and p_{kl}^i are determined by (6).

5. Conclusion

After the analysis of hazardous chemicals release dangerous influence on the sea environment the model of the process of the environment threats caused by the process of degradation initiating events generated by the critical infrastructure accident that is presented. This model is a second part of a general model of critical infrastructure accident consequences that are dangerous for its operation environment. In the next step, the procedures of its practical application are going to be proposed and illustrated in the modelling, identification and prediction of the environment threats process caused by the initiating events process generated by the critical infrastructure accident like a ship carrying hazardous materials, an oil piping transportation system operating at Baltic Sea region.

Presented in this paper the model and tools are supposed to be very useful in the critical infrastructure accident consequences modelling, identification, prediction, optimization and mitigation the losses in the scope of the project EU-CIRCLE concerned with the strengthening critical infrastructure resilience to climate change that is just going to start [11].

Acknowledgements

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