RIGA TECHNICAL
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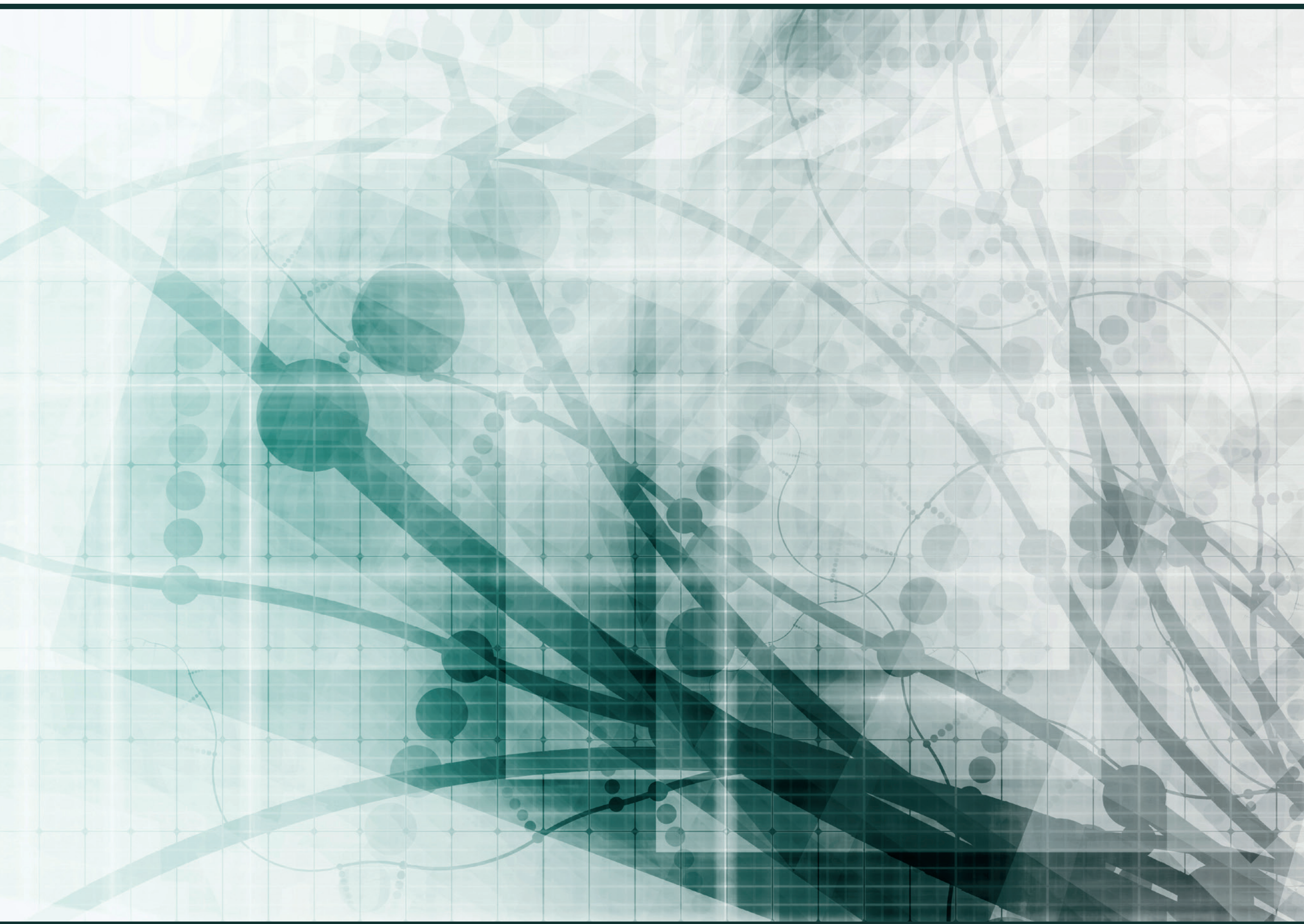
Mihails Urbans

METHODOLOGY FOR ASSESSMENT OF ECONOMIC AND ENVIRONMENTAL LOSSES IN HIGH THREAT OBJECTS

Summary of the Doctoral Thesis



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RIGA TECHNICAL UNIVERSITY
Faculty of Engineering Economics and Management
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METHODOLOGY FOR ASSESSMENT OF ECONOMIC AND ENVIRONMENTAL LOSSES IN HIGH THREAT OBJECTS

Summary of the Doctoral Thesis

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DOCTORAL THESIS PROPOSED TO RIGA TECHNICAL UNIVERSITY FOR THE PROMOTION TO THE SCIENTIFIC DEGREE OF DOCTOR OF SCIENCE

To be granted the scientific degree of Doctor of Science (Ph. D.), the present Doctoral Thesis has been submitted for the defence at the open meeting of RTU Promotion Council on September 10, 2021 at 10.00 online in *Microsoft Teams*.

OFFICIAL REVIEWERS

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DECLARATION OF ACADEMIC INTEGRITY

I hereby declare that the Doctoral Thesis submitted for the review to Riga Technical University for the promotion to the scientific degree of Doctor of Science (Ph. D.) is my own. I confirm that this Doctoral Thesis had not been submitted to any other university for the promotion to a scientific degree.

Mihails Urbans ……………………………. (signature)

Date: ………………………

The Doctoral Thesis has been written in Latvian. It consists of an Introduction; 3 chapters; Conclusions; 39 figures; 52 tables; 15 appendices; the total number of pages is 153, not including appendices. The Bibliography contains 300 titles.

CONTENTS

INTRODUCTION

The European Union (further in the text EU) and Latvia are subject to strict conditions in the field of the security system in order to maintain stability and protect the country's economy and society from technogenic accidents. One of the most notable examples is the so-called SEVESO III Directive (Directive 2012/18/EU), the conditions of which are integrated into the laws and regulations of all EU Member States. The Directive aims to maintain at least the current high level of protection against technogenic accidents and lays down requirements for increasing safety levels. In order to maintain the effective functioning of the State, independent public development in the event of an emergency situation (hereinafter – ES) or disaster, an effective safety system and high-quality performance of duties are needed in order to prevent risks with planned resources and to significantly reduce the probability of failing decisions. The effectiveness of these measures was once again demonstrated by the explosion on 4 August 2020, in Lebanon, where the uncontrolled explosion of ammonium nitrate caused significant damage to the city's infrastructure and population

Country stability is not possible without a clear and specific framework. This applies both to the rules for monitoring the operation of high threat objects (hereinafter – HTO) and to the rules governing the work of the national authorities. Today, the responsible national authorities closely monitor the functioning of HTO safety systems, but there are shortcomings in a number of planning phases and in the theoretical analysis of the damage caused by the potential consequences, and no uniform methodology has been established at national level to inform the economy and society of potential economic consequences in the event of an accident in the HTO.

Currently, according to the Environmental Monitoring State Bureau, 69 HTOs of state and regional interest have been registered in Latvia, the consequences of which may exceed their physical borders in the event of an accident and may cause significant economic losses at national and regional level[1], thereby affecting other economic sites and society, creating an internal threat to national security. At the moment, HTO managers can choose which software and risk assessment method to use for the determination and modelling of potential consequences, such as ALOHA (Areal Locations of Hazardous Atmospheres) or the guidelines for risk assessment issued in the Netherlands. However, they cover only hazards and do not include information on specific economic losses, environmental and public losses or on the means necessary to restore the environment in the event of an emergency in the HTO. It is, therefore, important to calculate economic and environmental losses, to identify the current situation in order to ensure the planned development of the entire economy, since only the methodological instruments can plan the necessary resources, as well as to determine the effectiveness of remediation measures and the extent of potential losses. The Doctoral Thesis proposes a methodology designed by the author in line with the usefulness, so that any interested party, without investing large time resources, could obtain a reliable and reasonable

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[1] Malahova, J., Urbans, M., Kiseļovs, G. (2017). Studiju priekšmeta Objekta risku novērtēšana kvalitātes nodrošināšana. *Akadēmiskās konferences "Mācību metodiskā un zinātniskā darba integrācija studiju procesā".* Rīga: RTU izdevniecība, 75–77. lpp.

result. The calculation of other economic losses, is linked to the available data and the hypothetically large amount of data required for the calculation to be carried out, therefore the full amount of losses from the HTO accident work is not under consideration.

For the reasons listed above, the supervisory authorities of the HTO and the persons responsible should be able to carry out an assessment of the situation, to define preventive measures, to determine the extent of the potential economic consequences and to prepare an action plan. Therefore, the effectiveness of the safety system, the identification of the consequences of potential accidents and the calculation of losses are important for national security and economic development.

As part of this paper, modelling of the hazards causing an emergency, compiling global emergency statistics and developing a useful, innovative methodology for the calculation of environmental and economic losses has been done, so that any interested party, without investing large time resources, can obtain reliable and reasonable results. The paper also summarises the current risk assessment methods and assesses their shortcomings and benefits, analyses the correlation between the depreciation of the sites and the increase in the frequency of emergency situations as well as the development of proposals for reducing risks during the operational life of the site, and proposes a methodology for assessing losses caused by a potential accident.

The hazard assessment methodology proposed by the author is based on the *probit* function model that so far has been very rarely used in Latvia. As part of the Doctoral Thesis, the *probit* model constants have been tested using different scenarios for potential accidents.

Aim, objectives and issues of the research

The aim of the research is to develop a science-based methodology for calculating economic and environmental losses in the event of an emergency in HTOs. In order to achieve the defined aim of the Thesis, the following objectives were set:

1. Explore and analyse the importance and development of the global technogenic environmental safety system.
2. Examine the legislative requirements of the national security system with regard to the functioning of HTOs.
3. Analyse modern methods for assessing the effects of accidents and risk management methodologies.
4. Analyse and choose an appropriate methodology for assessing medium-statistical human health damage from the emergency at HTOs.
5. Develop an appropriate methodology for the assessment of the risks of HTOs, the calculation of economic and environmental losses.
6. Experimental testing of the developed methodologies for risk assessment and the calculation of economic losses using the example of a specific HTO.

The research **object** is HTO as an element of the technogenic environment in the common safety system.

The **subject** of the study is the methodology for assessing economic and environmental losses for HTOs.

In order to achieve the aim of the study, the following **research issues** were raised:

1. What is the content of the technogenic environmental safety system: purpose, principles, implementation process; and do these elements need to be improved?
2. What regulatory enactments govern the safety system of the technogenic environment in Latvia?
3. What models exist in the world for risk and loss assessment in the event of a technogenic accident?
4. What economic loss assessment model can be used in the event of a possible HTO accident in Latvia?

Hypothesis

The hypothesis of the study has been raised in the light of discussions between specialists and experts of different sectors on the application model for hazard and risk assessment algorithms in Latvia. The hypothesis of the Doctoral Thesis is: developing a universal methodological approach for assessing economic and environmental losses in the HTO will provide an opportunity to quantify acceptable risk limits, as well as economically justify the extent of potential losses in the event of an accident.

Theses to be defended

- The methodology developed makes it possible to assess the risk of technogenic risks in HTOs.
- The developed economic and environmental loss assessment algorithm for the methodology consists of 6 core blocks included in a single system that contributes to enhancing the knowledge of the evaluator: information is provided on the level of risk of the existing HTOs, the possible extent of economic and environmental consequences, and the impact of the accident.
- The developed methodology contributes to the systematic objectivity of the evaluator’s knowledge.

Approbation of the Thesis

The results of the Doctoral Thesis have been published in reviewed scientific journals, full text proceedings of conferences, reported and discussed in international and local conferences, as well as in study subjects taught by the author.

Structure of the Doctoral Thesis

To accomplish the set objectives and achieve the aim of the Thesis, the Doctoral Thesis consists of an annotation, introduction, discussion that is divided into three sections. Each section consists of several chapters, subchapters and conclusions.

The first section “State and Importance of the Tehnogenic Environment” examines and reflects the safety system of the modern technogenic environment in Latvia and the world, as well as the terminology associated with it. This section also analyses the planning documents in the field of technogenic environmental safety, examines the nature of the safety system and its basic environmental protection system, the principles of national security, civil protection arrangements, the potential consequences for the economy and society, and the interaction between the elements of the system. The first section consists of 6 chapters as well as the conclusions of the section.

The second section “Analysis of the Methodology for Assessing the Loss of Modern Technogenic Environment” analyses and describes the world-wide methods for assessing environmental losses and air pollution losses, methods for assessing fire hazards and explosion hazard related losses, risk assessment methods that help to raise awareness of the hazards of an emergency assessment process, the risks of the technogenic environment, risk assessment models. The second section consists of three chapters as well as the conclusions of the section. Within each chapter, the relevant system and its shortcomings have been studied and analysed and proposals have been made.

The third section “Development of an Economic and Environmental Losses Assessment Methodology” sets out the economic and environmental loss assessment methodology for HTOs, as well as the practical calculation of the hazard, risk–related economic and environmental loss. This section consists of two chapters developing a methodological algorithm for calculating economic and environmental losses of a HTO. As part of each section and chapter, the author has used and analysed both the available theories and problems and the experience of other countries. An average-statistical approach for measuring human life values has been examined separately, which provides an opportunity to assess the economic consequences of possible fatal accidents in the event of a HTO accident, and on the basis of an analysis of scientific literature, it is proposed to use an algorithm to calculate average treatment costs associated with the treatment of various types of technogenic accident injuries in hospitals.

In conclusion, the results of the Doctoral Thesis are summarised.

The Doctoral Thesis includes fifteen annexes.

Annex 1 deals with the classification of the burn rate; Annex 2 calculates the average increase in gross domestic product in Latvia for the period up to 2052, taking into account the prices in 2018 that are used to establish the algorithm; Annex 3 provides information on gross domestic product and gross national income commitments in 2018, in actual prices, in thousands of euro; Annex 4 gives an example justified by losses based on human hours for loss of human sustainability, while Annex 5 provides a description of personal injury, depending on the degree of injury to a human; Annex 6 provides the information applicable to the assessment of the degree of damage to buildings and structures associated with excess pressure; Annex 7 provides information on the results of the assessment of the size of losses; Annex 8 provides a description of the size of potential losses for buildings and constructions, as well as for humans; Annex 9 summarises information on the nature of the HTO site and adjacent objects examined in the paper, as well as the estimated distances and the specified cadastral value; Annex 10 summarises the data resulting from the HTO hazard assessment; Annex 11 provides information on potential accident losses in a HTO; Annex 12 provides information on the decisions of the Crisis Management Board for the period of 2012–2019; Annex 13 sets out the results of the comparison of fireball radiation methods; Annex 14 examines the methodology proposed by the author by carrying out a practical study to assess the extent of damage to a HTO in the event of an accident; Annex 15 provides schematic information on methodologies developed by the author.

The reports of the author of the paper at scientific conferences

1. RTU 61st International Scientific Conference "Scientific Conference on Economics and Entrepeneuship", Riga, Latvia, October 16, 2020.
2. 21st Annual International Scientific Conference "Economic Science for Rural Development", Jelgava, Latvia, May 12–15, 2020.
3. 19th International Multidisciplinary Scientific Conference "Rethinking regional Competiviness", Šiauliai University, Šiauliai, Lithuania, November 28, 2019.
4. RTU 60th International Scientific Conference "Scientific Conference on Economics and Entrepeneuship", Riga, Latvia, October 11, 2019.
5. 18th International Scientific Conference "Engineering for Rural Development", Jelgava, Latvia, May 22–24, 2019.
6. RTU 59th International Scientific Conference "Scientific Conference on Economics and Entrepeneuship", Riga, Latvia, October 18, 2018.
7. 19th International Scientific Conference "Economic Science for Rural Development", Jelgava, Latvia, May 9–11, 2018;
8. RTU Studentu zinātniskā konference "Tehnogēnās vides drošības problēmas", Rīgā, Latvijā, 2018. gada 20.aprīlī;
9. 8th International Scientific Conference "Rural Development 2017: Bioeconomy Challenges", Akademija, Lithuania, November 24, 2017.
10. RTU 58th International Scientific Conference "Scientific Conference on Economics and Entrepeneuship", Riga, Latvia, October 13, 2017.

Author's publications

1. Urbans, M., Malahova, J., Jemeļjanovs, V. Methodology for calculating adverse health effects in Latvia. In: published by Vilnius Gediminas Technical University (VGTU) Press. 2020, pp. 194–201. ISSN 2029-4441 / eISSN 2029-929X ISBN 978-609-476-231-4,eISBN978-609-476-230-7 https://doi.org/10.3846/bm.2020.618.
2. Urbans, M., Malahova, J., Jemeļjanovs, V. Compliance of fire safety measures for accommodation of people in Riga schools. Proceedings of the 2020 International Conference "Economic Science for Rural Development", No. 53, Jelgava, LLU ESAF, 12–15 May 2020, pp. 226–232 doi: 10.22616/esrd.2020.53.027 226
3. Urbans, M., Malahova, J., Jemeļjanovs, V. Assessment of Technogenic Risks in Recovering Company for Worn Tyres. Proceedings, Latvia, Jelgava, 22–24 May 2019. Jelgava: Latvia University of Life Sciences and Technologies, 2019, pp. 1616–1622. ISSN 1691-5976. Available: doi:10.22616/ERDev2019.18.N347.
4. Urbans, M., Malahova, J., Jemeļjanovs, V. Identifying Potential Risks Created by State Joint-Stock Company Latvijas Dzelzceļš Jelgava Station and Evaluating their Impact on Environment. In Proceedings: 18th International Scientific Conference

"Engineering for Rural Development". Vol. 18, Latvia, Jelgava, 22–24 May 2019. Jelgava: Latvia University of Life Sciences and Technologies, 2019, pp. 718–725. ISSN 1691-5976. Pieejams: doi:10.22616/ERDev2019.18.N020.

5. Urbans, M., Malahova, J., Jemeļjanovs, V. Functioning of Latvian Detention Institutions Safety System in Case of Technogenic Disaster Threat. NORDSCI Conference Proceedings 2018, 2018, Book 2, Vol. 1, pp. 483–490. ISSN 2603-4107. Available: doi:10.32008/NORDSCI2018/B2/V1/52.
6. Urbans, M., Malahova, J., Jemeļjanovs, V. High Hazard Objects Exploitation in Rural Regions and Identified Risk Management Problems in Latvia. In Proceedings: 19th International Scientific Conference "Economic Science for Rural Development 2018": Economic Science for Rural Development. No. 47: Rural Development and Entrepreneurship; Production and Co-operation in Agriculture, Latvia, Jelgava, 9–11 May 2018. Jelgava: 2018, pp. 341–350. e-ISBN 978-9984-48-292-7. ISSN 1691-3078. e-ISSN 2255-9930. Available: doi:10.22616/ESRD.2018.040.
7. Kiseļovs. G., Urbans, M., Malahova, J., Izglītojamo apmācība ugunsgrēku izpētes veikšanā. No: RTU IEVF Akadēmiskā konference "Mācību metodiskā un zinātniskā darba integrācija studiju procesā", Latvija, Rīga, 27.–27. aprīlis, 2018. Rīga: 2018, 60.–63. lpp. ISBN 978-9943-22-070-5.
8. Urbans, M., Malahova, J., Ieviņš, J., Radin, M. Modern Trends in Disaster Planning and Management in the World and in Latvia. WSEAS Transactions on Environment and Development, 2019, pp. 164–175. e-ISSN 2224-3496.
9. Malahova, J., Urbans, M., Kiseļovs. G., Studiju priekšmeta "Objekta risku novērtēšana" kvalitātes. No: RTU IEVF Akadēmiskā konference "Mācību metodiskā un zinātniskā darba integrācija studiju procesā", Latvija, Rīga, 27.–27. aprīlis, 2018. Rīga: 2018, 75.–77. lpp. ISBN 978-9943-22-070-5.
10. Urbans, M., Malahova, J., Ieviņš, J. Civil Defense System in Latvia and identified drawbacks in Riga. Rural development 2017 : bioeconomy challenges. Proceedings of the 8th international scientific conference, 23–24 November 2017, Aleksandras Stulginskis University, 2017, pp. 1350–1355. http://doi.org/10.15544/RD.2017.055, https://hdl.handle.net/20.500.12259/104452

1. STATE AND IMPORTANCE OF THE TECHNOGENIC ENVIRONMENT

1.1. The Essence of the Technogenic Environment

A large number of people nowadays think that technology makes their lives easier. This assumption is based on the past evolution of humanity, particularly, the rapid industrialisation of the 20th century. The effective and targeted development of people and society requires a balance between the social environment, infrastructure and technology. The consequences of the technogenic accident in the HTO are very different and can have economic, social, ecological and even political impact. One of the most obvious features of safety management is the importance of safety principles. In order to systematize and define common safety concerns, it is important to identify and analyse groups of principles of the common security system with closely related content.

In the 21st century, most people live and work in big cities, and this gives them considerable advantages compared to the population of rural areas. For example, people living in large cities have more opportunities for self-development and growth, opportunities to find a hobby and a job of interest that makes it possible to effectively realise their knowledge and reach an appropriate standard of living. All cities around the world are artificially shaped, and they are designed by human to protect themselves from the adverse effects of natural phenomena such as storms, cold, floods and the like. Such an artificial environment is known as the technogenic environment, or the urbosphere. In modern cities, infrastructure benefits are not only used to improve living conditions, but also for manufacturing, which is often associated with hazardous technologies and the storage of dangerous substances in small and large quantities. The extent of the circulation of hazardous substances and the quantity of products from the processing industry is increasing every year, and consequently consumer and hazard–qualifying indicators are also increasing. According to the World Bank, more than 50 % of the world's population live in urban areas (in 2007 the urban population was equal to the rural population), while in 2050 this ratio would exceed 65 %. Cities account for more than 50 % of global GDP, with only 3 % of land.[2]

Technoenvironment is a set of all functioning and old, non-working sites and by-products that have appeared on the ground and in space. These by-products are usually associated with changes in water, air and earth chemical composition and earth crust layers (land cultivation), as well as biogeocenological changes contributed by logging, agricultural land cultivation, drainage of swamps and the creation of artificial water reservoirs. Technoenvironment is an environmental-timely system that is a socially organised technical matter.[3]

Technoenvironment is the life environment of civilisation that has developed as a result of the industrial and technological revolution. There are different levels of technoenvironment:

- an artificial world designed to transform nature and meet human needs;

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[2] Kobza, N., Hermanonowicz, M. (2018). How to use tehnology in the service of mankind? Sustainable development in the city. *IFAC Papers on Line*. Vol. (51–30), pp. 340–345.

[3] Некрасова, Н. А., Некрасов, С. И. (2010). *Философия техники.* Учебник. Москва: МИИТ.18. стр.

- technical and other knowledge, technologies that form the intellectual core of technosphere;
- social institutes, technical organisational links through which people establish the functional sectors of the technoenvironment that ensure its functioning and development.[4]

When analysing this term, it can be concluded that the concept of *technoenvironment* is generally understood as part of the biosphere transformed by a human being, so that he can easily live and provide himself with safe conditions. It involves all sorts of residential areas, agrocenosis, mineral sites and infrastructure used by people to meet their needs. Paradoxical is the view of people as a control over nature supposedly provided by technoenvironment, and the assumption that the control acquired is proportional to the level of human safety and well-being.

Technoenvironment affects the biosphere and focuses mainly on safety concerns and, in particular, the safety of the technogenic environment. For residents, the greatest threat, excluding armed conflicts, is posed by HTOs, such as chemical plants, power plants, warehouses of hazardous substances and similar facilities. Taking into consideration the scale of the risk and the impact on the biosphere, it is necessary to highlight the sites built using physical work and human knowledge and which, in the event of an accident, pose the most direct threat to other environmental elements. The hazard illustration is given in Fig. 1.1.

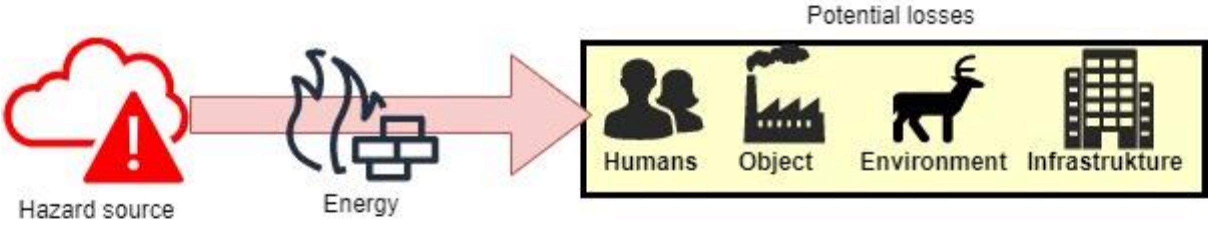

Fig. 1.1. Hazard illustration (created by the author).

In the event of an accident, the economic consequences of the HTO are the total losses related to the loss of citizens, organisations, municipalities and public organisations resulting from the localisation of the effects of the accident and the recovery of living standards in the area affected by the accident, as well as the costs to be anticipated in time when planning the development of sites, in order to avoid an escalation of a possible accident[5] and, when planning the budget, to be prepared to pay the costs of medical treatment services and compensation to victims. Economic loss indicators are investments in preventive measures related to the reduction of potential damage to the health of the population, workers, costs of death benefits, treatment, losses of material values of legal and natural persons.[6] Losses are

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[4] Калинникова, М.В. (2010). Социальные аспекты экологизации современного общества. *Известия Саратовского университета.* Т. 10. Сер. Социология, Политология. Вып. 4, стр. 11–13.

[5] Urbans, M., Malahova, J., Jemeļjanovs, V. (2018). High hazard objects exploitation in rural regions and identified risk management problems in Latvia. *Proceedings of the 2018 International Conference "Economic science for rural development"* No 47. Jelgava: LLU ESAF, pp. 341–350.

[6] Кабанов, Л. П., Исламов, Р. Т., Деревянкин, А. А., Жуков, И.В., Берберова, М. А., Дядюра, С. С. (2011). Оценка риска для АЭС С ВВЭР. *Материалы 7 международной научно-технической конференции "Обеспечение безопасности АЭС с ВВЭР.* ОКБ "Гидропресс".

usually determined during or after an accident, and material damage caused by an accident to natural persons, legal persons or the State as a whole can be avoided.

1.2. Hazard Topicality of the High Threat Objects

In the past 100 years many accidents related to specific processes in HTOs have occurred, for example, with increased pressure or temperatures. As part of this paper, it is not possible to look at the causes and consequences of all accidents, so there is a collection of information about, in the author's view, major accidents and their consequences. One of the ways of preparing for the ES is to be familiar with the elements related to the safety system hazardous processes – business management, responsible persons in the national and local authorities, activities carried out during the life cycle of hazardous chemicals, including production, use, storage, management, transportation and waste disposal, since leakage, fire and explosion can occur at any time.[7] These accidents typically involve mishandling or inaction, chaotic management, equipment damage and other potential hazards. It should be noted that the fire investigation carried out to ascertain the technical reason for the fire is one of the most difficult investigations.[8] According to the second law of thermodynamics, entropy increases throughout the lifeless environment, thus increasing chaos and deorganisation[9], and any type of HTO is subject to the provisions of this law. This means that without timely action or planning of recovery measures, it may lead to the collapse of the technogenic system with negative consequences. The term of entropy was proposed in 1865 by a German physicist, R. Clausius, with the hypothesis that, in an isolated system, energy self-flow can only move from higher level to the lower one, but not otherwise, so that the processes of reducing entropy in self-flow do not take place.

The creation of complex technological systems gives civilisation power not only over the ecosystem and nature but also over people who could be affected by the potential consequences of the accident, such as the accidents of Fukushima NPP and Chernobyl NPP, which forced citizens to evacuate and leave their places of residence for a long time. Tests by an independent investigation commission found that one of the factors why Fukushima's NPP was not prepared for an accident was many failures of management processes, carelessness and negligence. A number of scientists, including N. Behling, say that on the basis of the independent investigation commission's reporting data, one of the main organisational shortcomings remains the insufficient investment of private companies' financial resources needed to mitigate security risks, as well as the irresponsibility and unwillingness of public authorities to engage in security issues, since in 2005 the International Atomic Energy Agency recommended Japan review safety norms related to the potential threat posed by

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[7] Xuanya, L., Jingjing, L., Xinwei, L. (2017). Study of dynamic risk management system for flammable and explosive dangerous chemicals storage area. *Journal of Loss Prevention in the Process Industries* Vol. (49), pp. 983–988.

[8] Kiseļovs, G., Urbans, M., Malahova, J. (2017). Izglītojamo apmācība ugunsgrēku izpētes veikšanā. *Akadēmiskās konference: "Mācību metodiskā un zinātniskā darba integrācija studiju procesā",* 60–63. lpp.

[9] Пекелис, В. (1986). *Твои возможности, человек!* Москва: Издательство "Знание", 27. стр.

earthquakes and tsunami.[10] Consequently, complex technologies and large capital investment problems also exist in developed countries.

1.3. Development of High Threat Objects

Information on past incidents and disasters is useful for analysing previous accidents, which are one of the most important components of any security process, which helps to reduce the probability of further accidents.[11] This paper, therefore, analyses the stages of industrialisation in the world and examines their interconnectedness, benefits and threats to society.

The risks to the industry started with the creation and development of production companies. They gained strength during the developed phase of industrialisation and have not disappeared with the transition of postindustrialisation to partial deindustrialisation. The history of technological development and social values have shaped the understanding, phobia and preconceptions of manufacturing accidents and their potential hazards.

In scientific literature, researchers generally emphasize four stages of the establishment or industrialisation of production sites in the context of a dangerous chemical industry. Industrialisation is the transition from an agrarian society to an industrial society, which includes extensive social change in the field of economic development and is closely linked to technological innovation.[12] A similar explanation of this term is described on the www.vesture.lv website: “Industrialisation-developing large-scale machine production in the economy.” [13] When, how and why certain societies went through the industrialisation process, is still a research facility for social scientists, and historical aspects have been studied for more than two centuries by analysing the relationship between production methods, transport facilities, financial intermediation, public administration, foreign trade, urbanisation, legal systems and cultures on the one hand and the pace and models of development in different economy regions of the world on the other hand[14], to explain the gradual development of the industrialisation process and its impact on society.

Process management and the safe operation of a HTO are directly related to technology safety, safe structures and their protection against technogenic, natural and unauthorised activity hazards, and use theoretical materials and practical experience, including risk theory and microparticle theory. The responsible authorities should ensure the management of the processes and analyse a number of important criteria, taking into account security, resource, viability and other factors. Digitisation creates new opportunities for the interoperability, monitoring and understanding of processes, for the equipment and processes and changes in

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[10] Behling, N., Williams, M. C., Behling T. G., Managi, S. (2019). Aftermath of Fukushima: Avoiding another major nuclear disaster. *Energy Policy* . Vol. 126, pp. 411–420.

[11] Pittman, W., Han, Z., Harding, B., Rosas, C., Jiang, J., Pineda, A., Mannan, M. S. (2014). Lessons to be learned from an analysis of ammonium nitrate disasters in the last 100 years. *Journal of Hazardous Materials* No. 280, pp. 472–477.

[12] Moore, I. (2014). Cultural and Creative Industries concept – a historical perspective. *Procedia – Social and Behavioral Sciences. Vol.* (110), pp. 738 – 746.

[13] *Industrializācija* [tiešsaite]. Vēstures enciklopēdiskā vārdnīca [skatīts 2018.gada 5.februārī]. Pieejams: *http://vesture.eu/index.php/Industrializ%C4%81cija*

[14] O’Brien, P. K. (2001). Industrialization, Typologies and History of. *International Encyclopedia of the Social & Behavioral Sciences*. pp. 7360–7367.

communication patterns and habits. The probability of an emergency situation at technogenic environmental sites depends on the level of protection of the HTO, which is also connected with the potential risk management – the larger the consequences of an accident, the lower impact is on risk management, and, although the risk of a hypothetical accident is very low and corresponds to a 10^{-11} degree, its management is practically impossible. The management role in emergency situation is shown in Table 1.1.

Table 1.1

Types of Emergency Situations and the Degree of HTO Protection[15]

No.	Emergency situation	Degree of protection	Risks
1.	Standard operating conditions	Increased	Controllable
2.	Deviation from standard operating conditions	Sufficient	Manageable
3.	Project accidents	Partial	Analysable
4.	Anticipated accidents	Insufficient	Increased
5.	Hypothetical accidents	Low	High

Damage to machine elements and structures is caused by a combination of factors affected by the peculiarities of the structures, the operating environment and extent, the physical and chemical properties of the materials, as well as environmental factors. Accident disaster prevention at HTO is one of the basic directions for ensuring safe and harmless operation based on an assessment of the situation of the threshold in the various ES development scenarios.

1.4. Statistical Survey of Modern Accidents

The analysis of accidents, disasters and other incidents occurred is one of the most efficient and frequently used methods for obtaining information and an idea of the causes of accidents at HTO, what accidents were recorded in the past and what were the losses they caused. This analysis provides invaluable information on the shortcomings of the process, and the analysis data can be used to develop accident prevention strategies or to mitigate the potential impact of the consequences of the accident. In the absence of adequate management of incidents of disaster hazards and incidents of potentially hazardous materials, dangerous accidents may cause serious problems and damage to the environment.[16]

Economic aspects include economic losses in terms of both money and physical terms: the destruction or damage of engineering networks, buildings and structures, incapacity for work, the need for substantial material costs for rebuilding and compensating processes, the establishment of insurance and other special funds, and the use of huge resources and diverse

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[15] Багров, А. И., Муртазов, А. К. (2010). Т*ехногенные системы и теория риска*. Рязань: Рязанский государственный университет имени С. А. Есенина. 29. стр.

[16] Zhang, H., Duan, H., Zuo, J., Song, M., Zhang,Y., Yang, B., Niu Y. (2017) Characterization of post-disaster environmental management for Hazardous Materials Incidents: Lessons learnt from the Tianjin warehouse explosion, China. *Journal of Environmental Management* . Vol. 199, pp. 21–30.

techniques for preventing an accident and eliminating its consequences.[17] Consequently, actual or possible social and economic losses are identified: deviations of the state of human health from the average indicators, difficulties in carrying out standard economic activity, loss of property, other material and natural losses. The assessment of these losses requires sound data on the damage caused and their significance, and therefore the existing tools should be assessed to provide reasonable results. For the different ES scenarios, the extent of the losses may vary depending on the affecting factors. When forecasting losses (W), the probability of losses depending on the distribution function must be taken into account (1.1)[18]:

$$F(w) = P(W < w). \tag{1.1}$$

The mathematically avoided losses can be expressed by Equation (1.2)[19]:

$$\Delta W = W_0 - W_1, \tag{1.2}$$

where in Equations (1.1) and (1.2), W_0 and W_1 are losses before and after taking protective measures.

In general, both equations show that risk consists of several elements that areimportant to be aware of in order to ensure the management processes of HTO and to reduce potential losses.

When assessing the results of the accident of the technogenic environment, the amount of direct, indirect, full and total losses shall be distinguished.

In the event of a technogenic hazard, it is important to assess the overall extent of the losses as well as the components of the losses when performing a posteriori assessment. The loss structure scheme is presented in Fig. 1.2. When performing an a priori assessment, one may calculate risks and potential socio-economic losses, taking into account the probability of potential impacts.

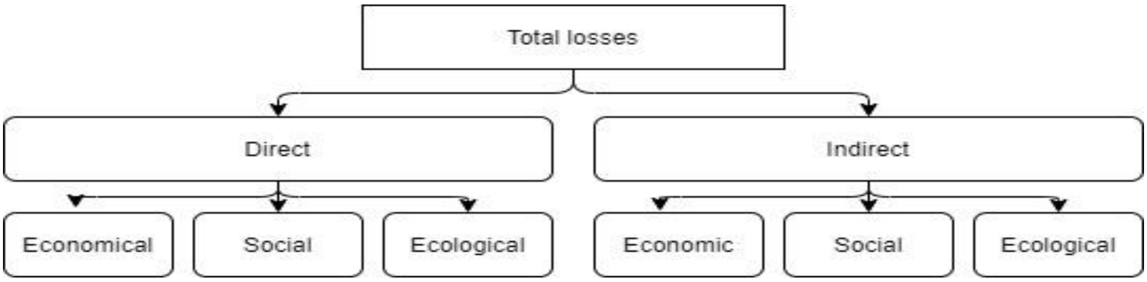

Fig. 1.2. The structure of total losses.[20]

Direct losses as a result of accidents shall be considered to be the loss of all the economic structures which were in the disaster or emergency zone. These losses relate to damage to buildings and structures, unproduced products and similar aspects. Social damage is a human

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[17] Jemeļajanovs, A., Ieviņš, J., Puškina, J. (2007). *Objekta riska novērtēšana.* Rīga: RTU izdevniecība, 33. lpp.

[18] Беляев, Г. Н. (2008). Методы оценки ущерба от техногенных чрезвычайных ситуаций. *Известия Томского политехнического университета*. Т. 312. № 5, стр. 150–152.

[19] Беляев, Г. Н. (2008). Методы оценки ущерба от техногенных чрезвычайных ситуаций. *Известия Томского политехнического университета.* Т. 312. № 5, стр.150–152.

[20] Вигдорович, В. И. (2004). Техногенный риск. проблемы и решения. *Вестник ТГУ*, т. 9, вып. 4, стр. 405–415.

injury or loss of life. Ecological losses are linked to pollution of the earth's atmosphere or water resources.

When carrying out an a priori assessment, risk assessment procedure is important for the assessment of losses, which helps to identify potential losses to the technogenic environment. The risk can be mathematically expressed as follows (1.3.)[21]:

$$R = QP, \qquad (1.3)$$

where Q *is* probability (possibility of an accident) and P is consequences (extent of losses).

The aim of the safety system is to preserve human life and the environment, to ensure economic, social and industrial development and the quality of modern life, while leading industry researchers, such as S. Dekker and K. Pitzer, argue that there are certain topical challenges to improve safety systems and to minimise adverse reactions in the field of safety.[22] T. Schuller argues that in future the government's decisions will have to be supported by evidence.[23] Statistical data is one of the best evidences to be used for reasoned decision-making.

The information available in the Emergency Database (EM-DAT) on disasters that have occurred in Latvia is presented in Table 1.2.

Table 1.2

Information on Disasters That Have Occurred in Latvia (Created by the Author)

Year	Event	The number of people affected			Total losses
		Fatality	Injuries	Other	
1999	Storm	6	–	–	0.5
2000	Influenza epidemic	–	–	102	–
2001	Extreme cold	21	–	–	–
2003	Extreme cold	15	–	–	–
2005	Storm	–	–	–	325
2006	Extreme cold	40	–	–	–
2012	Extreme cold	10	–	–	–
2013	Collapse of building	54	29	–	–

Currently it is difficult to obtain statistical data for each disaster or accident in Latvia, because Latvia does not have effective systems for collecting these data, and the extraction of data is not automated. A useful instrument for managing the risks of the technogenic environment and natural impacts would be a detailed and easily adaptable database that would reflect and store information on all types of hazards in Latvia and could be used to create statistics.

The economic losses caused by accidents caused by natural disasters between 1980 and 2015 are summarised in Fig. 1.3, showing total global economic losses. The diagram highlights the most extensive and serious accidents in the years and identifies the country

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[21] Jemeļajanovs, A., Ieviņš, J., Puškina, J. (2007). *Objekta riska novērtēšana.* Rīga: RTU izdevniecība. 7. lpp.

[22] Dekker, S., Pitzer, C. (2016). Examining the asymptote in safety progress: a literature review. *Int. J. Occup. Safety Ergon*. 22 (1), pp. 57–65.

[23] Schuller, T. (2006). Evidence and policy research. *European Educational Research Journal,* Volume 5(1), pp. 57–70 .

where they occurred. The yellow mark shows the extent of one of the largest casualties in terms of economic losses in a given year. The latest aggregated data in the *EM-DAT* database are in the form of a review, such as 396 natural disasters in 2019, affected more than 95 million people, and losses totaling $130 billion.[24]

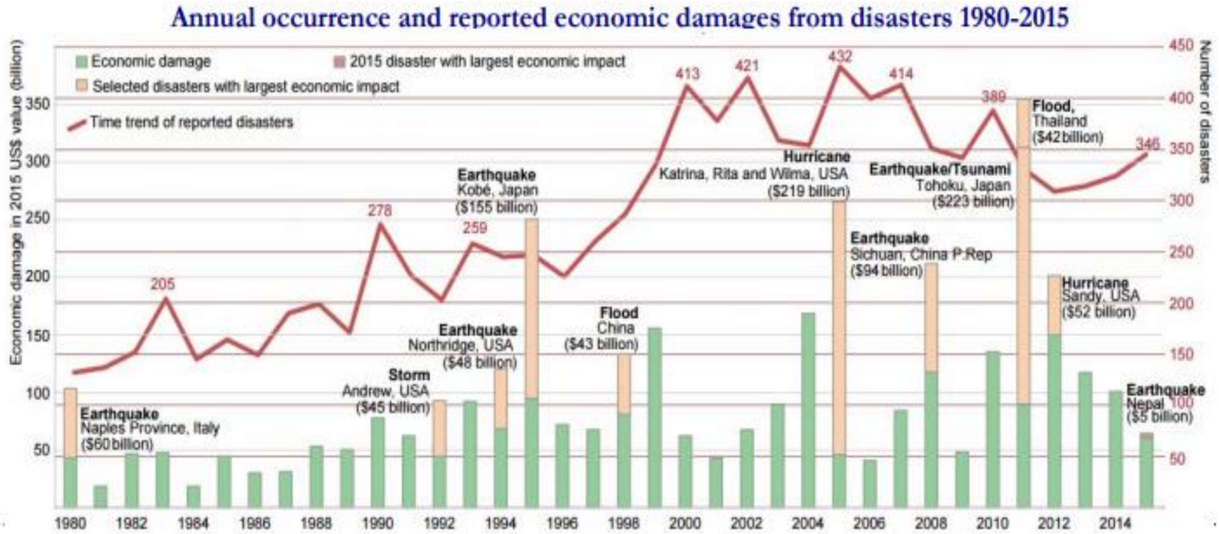

Fig. 1.3. Annual events and reports on economic damage caused by disasters between 1980 and 2015.[25]

According to United Nations, the most frequent cause of accidents caused by natural disasters in the world in terms of actual number and the number of victims is flooding and tsunami. The second most common cause is earthquakes and volcanic eruptions, but the third one is technogenic disasters. Overall, the data provided shows that, although the level of technology safety has increased, the number of accidents has not decreased but is relatively stable.

In about 67 % of cases worldwide, the main causes of technogenic accidents registered in the Major Accidents Reporting System – MARS – are low safety level in the industry field and inefficient management of the ecological safety system.[26] The Centre for Disaster Epidemiology Research divides thehnogenic disasters into three groups: manufacturing (chemical pollution, explosions, radiation pollution, collapses), transport (accidents in the air, sea, railway tracks and elsewhere), and mixed types of disasters (occurring in other unclassified sites).

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[24] CRED Crunch 58 - Disaster Year in Review (2019). *Disaster Year in Review 2019* [tiešsaiste] Issue No.58. [skatīts 2020. gada 17. jūlijā]. Pieejams: https://www.cred.be/publications?field_publication_type_tid=All&order=field_publication_year&sort=des

[25] Centre for Research on the Epidemiology of Disasters (2016). "*Disaster Data: A Balanced Perspective*" [tiešsaiste] Issue No.41. [skatīts 2017. gada 3. novembrī]. Pieejams: https://www.cred.be/publications?field_publication_type_tid=All&order=field_publication_published&sort=desc

[26] Sychev, Y. V. (2012). Risks of the man-made disasters of modern times. *Интернет-журнал "Технологии техносферной безопасности".* Выпуск № 1 (41). стр. 1–9.

1.5. Possible External and Internal Threats

Disaster risk policy at European level addresses many issues, including natural and man-made disasters, threats to health, pandemics, industrial, nuclear and agricultural risks and other hazards. To the extent that the response to real disasters in Europe is linked to the activities of the Civil Protection (CP) services, it is clear that such risks should be reduced and appropriate feedback mechanisms should be established to prevent disasters as far as possible and to minimise their impact.

One of the most efficient and frequently used methods for obtaining information on the causes of accidents in the HTO, on the extent of previous accidents and the extent of their losses shall be considered to be an analysis of previous accidents, disasters and accidents. It shall provide invaluable information on the errors made that can be used in developing an effective strategy and in ensuring efficient management of processes to prevent further accidents or to minimise their potential consequences. Poor management of incidents of catastrophic hazards and potentially hazardous materials can result in serious accidents causing serious consequences and damage to the environment.[27] A number of databases have recorded and compiled incidents in the chemical industry worldwide. This statistics and its importance are discussed in the previous section of this paper.

Technogenic ES is one of the most common artificial processes in the world and needs to be thoroughly investigated for environmental changes related to this process. In the case of an ES, it is important to determine the reason for the event, the nature of the event, the potential consequences, and the legal situation, and to clarify whether administrative, criminal or civil proceedings may be initiated in relation to what happened in the ES. In determining the exact reason for the technogenic ES, it is possible to appropriately punish the responsible persons who allowed it or who led the site to an emergency. It is, therefore, important that the national responsible authorities should be able to clarify the regularities of the hazardous processes and to determine precisely the extent of the negative effects. The following factors shall be considered to be technogenic environmental hazards likely to cause an accident or disaster:

1) the causes of the accident or disaster, based on the unexplored regularities of the technogenic environment (some processes which humanity cannot explain at this stage of development and cannot therefore manage);
2) incorrect location of objects, which may endanger the environment;
3) significant depreciation of equipment, delayed replacement of parts and ourdated technologies;
4) increase in production, storage, transport materials and incorrect use of dangerous substances and technological equipment;
5) reduction in the sense of responsibility and duty, as well as non-compliance with the rules and regulations;
6) insufficient safety measures;

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[27] Zhang, H., Duan, H., Zuo, J., Song, M., Zhang, Y., Yang, B., Niu, Y. (2017). Characterization of post-disaster environmental management for Hazardous Materials Incidents: Lessons learnt from the Tianjin warehouse explosion. *China Journal of Environmental Management* . Vol. 199, pp. 21–30.

7) insufficient or poor supervision of the technical condition of the object;
8) low efficiency of technical control equipment, poor technical condition of process non-emergency stoppage devices;
9) insufficient readiness of personnel for action in the event of emergency;
10) inefficient use of local and centralised environmental monitoring, control, identification equipment.

In the event of urgent and critical or emergency situations, such as technogenic or natural disasters, the services, local authorities and public authorities responsible must take swift and decisive decisions. By dealing with problems professionally and by offering real solutions to mitigate threats and potential losses, it is possible to reduce the potential negative effects. It is important to make the right decisions during ES, so one should be familiar with the regularities of natural and technogenic environmental processes.

1.6. General Regulatory Framework for the Security System in the World and in Latvia

Latvia's national security system consists of a number of legislation acts aimed at guaranteeing national security, independence, well-being and stability and taking appropriate measures to promote safe planned, sustainable development. Latvia is also bound by EU laws and regulations, including safety standards and requirements as described in the SEVESO III Directive.

According to Article 2 of the European Convention on Human Rights, adopted in Rome on 4 November 1950, every human right to life is protected by law, and Article 5(1) states that "Everyone has the right to personal freedom and security" [28], so that the document provides for the protection of human rights and fundamental freedoms and states that the States are obliged to guarantee safe living conditions. Scientist E. Zio believes that security is a freedom from potential harm and that the individual has the right to it. Risk assessment in the 20th century has played an important role in ensuring these rights during the design and operation of industrial systems.[29]

The Law on National Security is one of the most important legislation acts in the field of national security, which, inter alia, requires the Cabinet to prepare the concept of National Security, based on the State threat analysis, which lays down the strategic principles, priorities and measures for the prevention of State hazards.[30] The National Security Law requires the preparation of the following hazard prevention concepts and plans: National Hazard Analysis, National Security Concept, Military Threat Analysis, State Protection Concept, National Security Plan, State Protection Plan, National Defense Plan, National Defence Operational

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[28] *Cilvēktiesību un pamatbrīvību aizsardzības konvencija* (1950). Eiropas padome [tiešsaite] "Latvijas Vēstnesis", 143/144 [skatīts 2019. gada 8. janvārī]. Pieejams: https://likumi.lv/ta/lv/starptautiskie-ligumi/id/649

[29] Zio, E. (2018). The future of risk assessment. *Reliability Engineering and System Safety.* Vol. 177. pp. 176–190.

[30] *Delfi.lv* (2012). [tiešsaiste]. interneta vietne Delfi.lv [skatīts 2018. gada 20. martā]. Pieejams:http://www.delfi.lv/news/comment/comment/kaspars-druvaskalns-nacionalas-drosibas-likums-prieks-kakiem-ne-amatpersonam.d?id=42704984

Plan, Economic Mobilisation Plan, and State CP Plan. The system of national security legislation acts is reflected in Fig. 1.4, where it appears that all overlapping legislative measures are essential for the effective functioning of the national security system. With reference to E. Bompard and other scientists, the level of security should be assessed on the basis of scientific knowledge and models capable of tracking rapidly changing geopolitical conditions and providing accurate information and quantitative data to be taken into account by national officials when taking political decisions.[31] In order to be able to effectively implement the abovementioned legislation acts, substantiated scientific models must be available, as only this way one can reach the best indicators and overcome potential crisis situations.

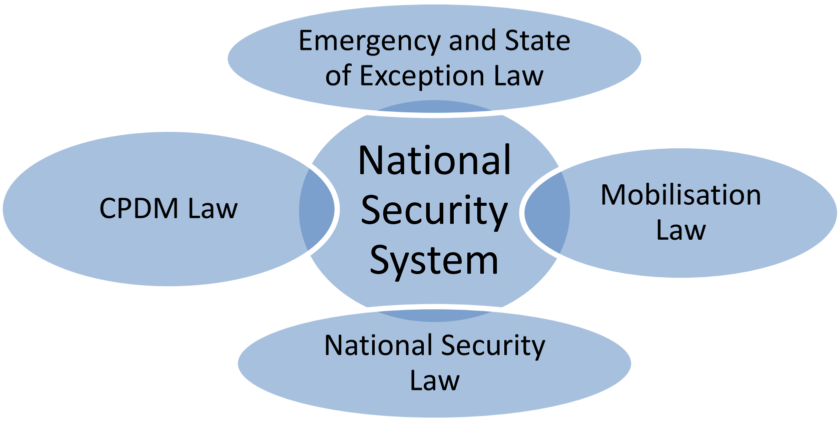

Fig. 1.4. National security system.[32]

Many regulatory enactments show that Latvia has a very complicated security system, the management of which requires different specific laws, regulations and specific instruments for each individual part of the security system. On the other hand, it shows that all parts of the system are linked and constitute a single, comprehensive national security system for the protection from different types of hazards, which is the basis for an efficient and harmonised security system. In general, it shows the relationship of the technical systems with the environment and the mutual effect of systems, which also includes humans as an element of the system. Consequently, the efficient and non-emergency functioning of the security system involves a variety of economic, technical, legal and social factors. The most important and complex aspect is that one must always be aware of the common operating algorithm of the security system in regards to how to maintain the security level and how this system works in order to identify the weaknesses of the system, assess risks and determine the extent of potential losses.

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[31] Bompard, E., Carpignano, A., Erriquez, M., Grosso, D., Pession, M., Profumo F., (2017). National energy security assessment in a geopolitical perspective. *Energy*. Vol. 130, pp. 144–154.

[32] Urbans, M., Malahova, J., Ieviņš, J. (2017) Civil defense system in Latvia and identified drawbacks in Riga. *The 8th international scientific conference Rural Development*. Conference Proceedings. pp. 1350–1355.

Summary and Conclusions of Section One

The information provided under the heading “Status and Importance of the Tehnogenic Environment” may be disclosed in the conclusions described further.

Key results of the first section:

1. The role of the technogenic environmental safety system in preserving the human life environment, ensuring economic, social and industrial development, which is the foundation of safe life today, has been examined. A number of developed management mechanisms, local and EU legislation governing the overall work of the system, on the basis of which the Cabinet rules have been issued, setting out specific security measures and requirements, has been shortly examined.
2. The origins of production accidents are described and found to be related to rapid industrialisation. The events of the previous centuries have led to a decline in industrial goods prices, which has contributed to the decline of the era of household products, since such production has turned into disadvantage with time. Industry goods could be purchased at a lower price and left more time for other jobs. This encouraged increased production volume by increasing production and reducing prices, but the lack of awareness of the risks caused the first major accidents in the industrial sector and made it necessary to develop the first regulatory framework.
3. The phases of the development of the technogenic system have been analysed and their main difficulties, as well as the disasters and extreme situations associated with the very intensive development of the production system over the last 100 years, and the causes of new, unprecedented hazards have been described. The number of major technogenic disasters in the world is still increasing, and this is due to the use of new chemicals in industry. Despite the fact that overall technology safety levels have increased, the number of dangerous accidents in HTOs has not decreased, and one of the explanations is the increased use of dangerous technologies in the less developed regions of the world where control systems are less developed.
4. Statistical data on accidents, disasters, and emergency cases have been assessed, which enabled the identification of the regularities of the ongoing processes and anticipating possible developments on the basis of experience of past negative or positive changes, enabling the responsible services to plan in time the necessary measures to reduce the potential risks to the certain economy sector.
5. The problems in the existing risk assessment approach have been identified, the process of setting up a technogenic environment has been described, examples have been provided.

Main conclusions of the first section:

1. It was found that technogenic disasters depend on nature-related factors, such as ecosystem processes, which are affected by an increase in the number of natural casualties, which poses an additional external risk to technogenic environment sites. An accident caused by a natural disaster occurring at such sites may deteriorate the situation and the extent of the losses may increase. Most technogenic accidents are

caused by human or occurred as a result of malfunctioning, organisation failures or technical damage to equipment.

2. In order to implement the management of the technogenic environment, the public must understand the extent and consequences of potential losses, identify its current knowledge of the technogenic system and take reasonable protective measures to improve the environment and reduce the consequences. Accordingly, planning documents based on the assessment of potential a priori losses are a topical issue.
3. The 21st century technogenic environment is closely linked to human life and directly influences the quality of human life. The public and human can hardly exist without the effects of manufacturing. A number of approaches have been developed to assess losses from the accident at HTO. The use of the hazard assessment procedure shall be capable of responding to potential external and internal hazards, providing information on potential consequences. When HTO changes, the algorithms for the hazard assessment system are adapted and the risk management process should be regularly adapted to the HTO changes. This highlights the need for a new approach to risk assessment that is related to the identification of real money losses.
4. The development of the technogenic environment has not reduced the number of ES cases and the negative effects are only increasing, despite developments in security systems and overall world development.
5. The structure of the national security system related to the operation of the HTO in Latvia, has been examined. This system provides an opportunity to control the functioning of the HTO, to reduce potential risks by protecting citizens, infrastructure, the environment from impacts, but nevertheless 100 % safety is not achievable within the framework of the technogenic environment, so the system needs to be prepared to respond effectively to existing risks and to plan resources to overcome risks and remove consequences.

2. ANALYSIS OF METHODS FOR ASSESSING MODERN TECHNOGENIC ENVIRONMENT LOSSES

2.1. Methods of Assessing the Environmental Losses and Air Pollution Losses

The part analyses and describes the world–wide methods for assessing environmental losses and air pollution losses, methods for assessing fire hazards and explosion hazard related losses, risk assessment methods that help to raise awareness of the assessment process for emergency consequences, the risks of the technogenic environment, and risk assessment models.

The technogenic risk analysis methodology is a specific instrument that can help to make substantiated management decisions by ensuring the safety of manufacturing process, fire safety and environmental safety in the HTO. In the absence of a comprehensive assessment of potential losses in HTOs at present, it is also necessary to develop methods for calculating losses related to toxic and other effects on humans and environment. A common methodological method has been selected for the assessment of the risk of technogenic accidents using the Gauss function with the upper integration limit *probit* or probability. It helps to identify probability and predict risk levels and make more substantiated decisions. The potential consequences of technoenvironmental hazards are summarised in Fig. 2.1.

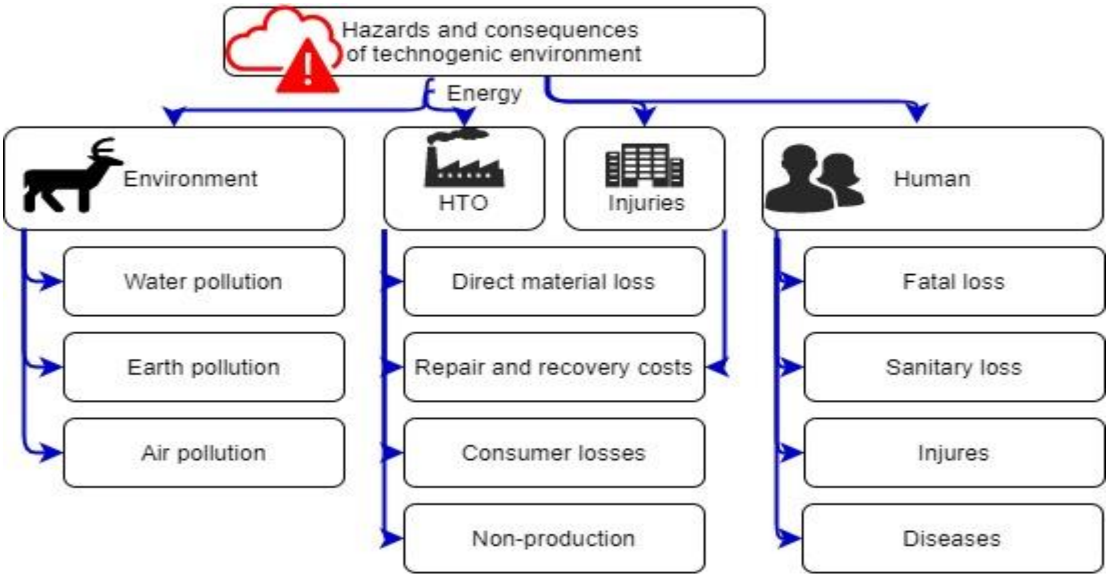

Fig. 2.1. Potential consequences of technoenvironment hazards (created by the author).

Modelling of the distribution of hazardous substances in the atmosphere from source to specific site is very important and complex, and there are many modelling methods worldwide for determining concentrations of hazardous substances in the air. One of the typical atmospheric pollutants is smoke released in the process of burning substances and materials. Smoke is a permanent dispersion system consisting of small particles contained in the suspended state in the gas. Smoke containing solid particles between 10^{-7} and 10^{-5} is one of the most dangerous factors of the fire.[33] Smoke in the low layers of the atmosphere will pollute the surrounding environment, and smog and mist can be formed in adverse weather conditions.

The types of accidents associated with releases of hazardous substances into the atmosphere are shown in Fig. 2.2.

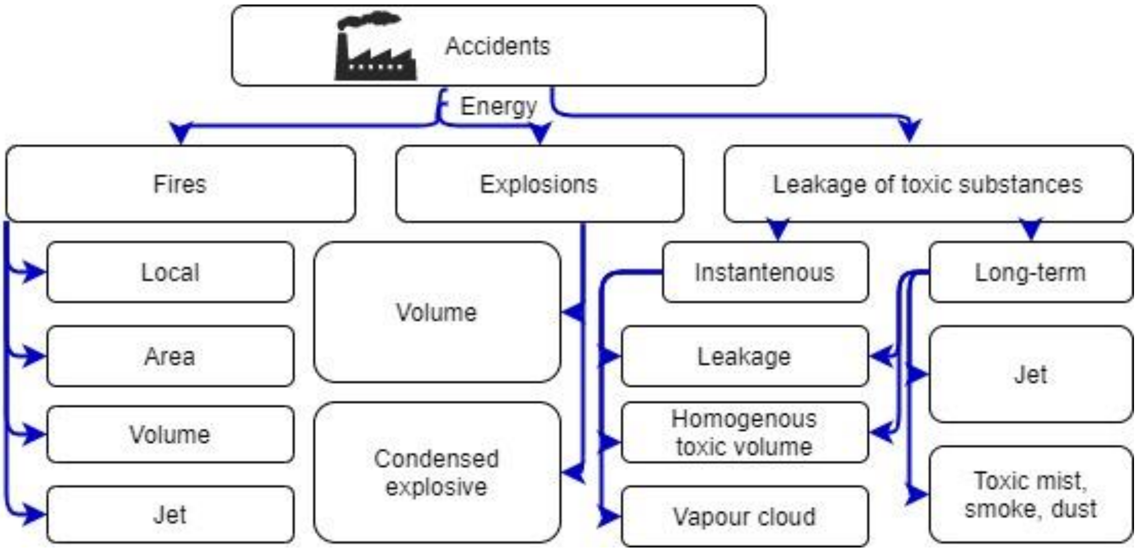

Fig. 2.2. Scheme illustrating the development of a potential accident with dangerous substances entering the atmosphere.[34]

There is currently no single model in the world to identify all factors affecting the release of hazardous substances into the atmosphere. The assessment generally takes into account such factors as wind speed and direction, atmospheric pressure and other meteorological parameters which help to determine the negative effects of pollutants at a certain point x_i with coordinates (x, y, z).

Many studies have shown that the global economic costs associated with air pollution will gradually increase and could reach 1 % of global GDP by 2060, where China, the countries of the Caspian Sea region and the countries of Eastern Europe will suffer the largest GDP losses.[35] These economic consequences are directly related to the high concentrations of hazardous substances present in the air,as well as to the ageing population and high health costs. Direct costs increase evenly and proportionally to economic activity but will significantly increase indirect costs. As Latvia is part of the Eastern European region, the spotlight on this problem is self-evident.

The first international documents in the field of reducing atmospheric pollution and its negative impacts, which mention the protection of the atmosphere against the effects of the technogenic environment, were the International Vienna Convention on the Protection of the

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[33] Šmidre, P., Jemeļjanovs, A., Ieviņš, J. (2008). *Vides aizsardzība no tehnogēno avāriju un katastrofu ģeneretajiem piesārņojumiem*. Rīga: RTU izdevniecība. 30. lpp.

[34] Романов, В. И. (2006). *Прикладные аспекты аварийных выбросов в атмосферу*. Москва: Физматкнига. 11. стр.

[35] Lanzi, E., Dellink, R., Chateau, J. (2018). The sectoral and regional economic consequences of outdoor air pollution to 2060, *Energy Economics.* Vol. 71, pp. 89–113.

Ozone Layer, which was signed on 22 March 1985, ratified by Latvia on 28 April 1995, as well as the Montreal Protocol of 1987 on the Ozone Layer Depleting Substances.

One of the typical atmospheric pollutants is smoke released in the process of burning substances and materials. Smoke is a permanent dispersion system consisting of small particles contained in the suspended state in the gas. Smoke containing solid particles between 10^{-7} and 10^{-5} is one of the most dangerous factors of the fire.[36] Smoke in the low layers of the atmosphere pollutes the ground–level environment, but smog and mist can be formed in adverse weather conditions.

In order to obtain reliable data on atmospheric pollution with hazardous substances released in the event of leakage by burning or evaporating toxic fluids, very many experiments should be carried out using samples of gas aerosols that are expensive. Timely planning of the necessary risk reduction measures for determining the dangerous concentration of substances and the radius of distribution in order to reduce potential damage to the population and nature may allow calculating the risk of ecological hazards mathematically

HTOs, where liquefied and explosive gases are stored, can pose a serious threat to human health and life, as well as to the environment, as intense evaporation leads to large toxic and explosive clouds.[37] The composition of smoke formed as a result of the combustion of dangerous substances is influenced by a variety of factors, such as the burning area, type of fire, meteorological conditions, surroundings, the burning substance or material, and other factors. The most common cause of human death is the effects of toxic gases[38]. The spotlight of this section of the Doctoral Thesis is evident, since the modelling of air pollution helps to determine and use the fire-fighting methodology to protect residents and employees of the State Fire and Rescue Service from the effects of concentrated hazardous substances, as well as to reduce the adverse effects on nature and to determine the extent of potential consequences.

As part of the work, the author proposed and used the ALOHA simulation programme based on the Gauss dispersion model for assessing air pollution, explosive, and heat exposure zone. The simulation model was developed jointly by a number of organizations, including the U.S. Environmental Protection Agency, the Chemical Accidents Preparedness and Prevention Bureau and the U.S. National Oceanic and Atmospheric Administration's Office of Response and Reinvestment.[39] ALOHA is a free program available to everybody interested. This model helps to simulate the dispersion of more than 900 chemicals and is

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[36] Šmidre, P., Jemeļjanovs, A., Ieviņš, J. (2008). *Vides aizsardzība no tehnogēno avāriju un katastrofu ģeneretajiem piesārņojumiem*. Rīga:RTU izdevniecība. 30. lpp.

[37] Старовойтова, Е. В., Галеев, А. Д., Поникаров, С. И. (2013). Оценка последствий аварийного выброса сжиженного аммиака с использованием вероятностного критерия поражения. *Вестник Казанского технологического университета*. стр. 259–261.

[38] Šmidre, P., Jemeļjanovs, A., Ieviņš. J. (2008). *Vides aizsardzība no tehnogēno avāriju un katastrofu ģeneretajiem piesārņojumiem.* Rīga: RTU izdevniecība, 32 lpp.

[39] Tseng, J. M., Su, T. S., Kuo, C. Y. (2012). International Symposium on Safety Science and Technology Consequence evaluation of toxic chemical releases by ALOHA. *Procedia Engineering* Vol. 45, pp. 384–389.

normally used for the simulation of accidental leakage of hazardous substances[40] and for the dispersion of chemical vapours. When entering initial leakage data, such as weather conditions, substance quantity, location and other parameters, the ALOHA simulation model can identify the area, concentration, thermal radiation intensity, and excess pressure potential consequences of the toxic area, which can be used in the composition of methodology developed by the author to calculate losses. In forecasting losses for humans and infrastructure, the extent of probability and consequences cannot be assessed if there is no known concentration area for hazardous substances and distances for exposure to heat and excess pressure, and, therefore, the ALOHA programme is used for modelling the extent of accidents and assessing the adverse effects of exposure.

It is not possible to assess the economic consequences for the environment and infrastructure only with ALOHA, so the author developed a methodology including all stages of assessment in the performance algorithm.

An approach based on the use of *probit* or *Erfik* functions, which can be combined with the calculation of ALOHA programme, has been developed worldwide to assess potential harmful effects. The *probit* model, by pooling data on the technological properties of regions and potentially hazardous sites, can identify potential impacts on humans by accurately identifying potential sanitary losses and fatal losses depending on the consequences of risks that depend on the pressure step (steam and gas explosions), thermal radiation (e.g. leakage fires, fireballs, jet fire), mechanical effects when collapsing structures under the influence of an explosion or other factors, and toxic effects if dangerous substances enter the human body. In the non-equation formula of the *probit* model (2.1), a and b are constants of each substance that describe the degree and effect of hazard. Essentially, Pr is the upper limit value of Gauss' error function, the so-called *Erfik* function Q used to determine the probability of certain losses. For the calculation of the function $Q = erf(Pr)$ and for the calculation of the *probit* limits, which make it difficult to apply coefficients, two methods shall be used: $Q = erf_f(Pr = 0)$ and $Q = erf_f(Pr - 5)$. For various hazardous substances, Pr functions are different constants. The total expression of the *probit* model in the analytical form is given in Equation (2.6).[41]

$$Pr = a + b\ln(D), \tag{2.1}$$

where a and b are constants; D is the numerical size identifying the negative effects on the exposed person or the dose of adverse effects.

Scientist N. Eisenberg was the first who developed coefficients and created an equation for assessing the probability of harm using a *probit* model that evaluates the relationship between dose effects and human response to heat radiation, toxic substance and excess pressure.[42] The data were obtained by analysing the effects of heat in the event of nuclear

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[40] I, Y.P., Shu, C. M., Chong, C. H. (2009). Applications of 3D QRA technique to the fire/explosion simulation and hazard mitigation within a naphtha-cracking plant. *J. Loss Prev. Process Ind.*, Vol. 22, pp.506–515.

[41] Cozzani, V., Salzano, E. (2004). The quantitative assessment of domino effects caused by overpressure Part I. Probit models., *Journal of Hazardous Materials* Vol. A107, pp. 67–80.

[42] Eisenberg, N. A. Lynch, C. J.. Breeding, R. J. (1975). Vulnerability model: a simulation system for assessing damage resulting from marine spills, Report CG-D-136-75, Enviro Control Inc., Rockville, MD.

explosion. This method is based on the assumption that exposure to the same level in different cases (amount of absorbed substances, radiation dose, pressure impulse, etc.) may have a different effect of severity on different human – exposure effects are closely linked to the principle of probability. The *probit* model was often used in the past because it was simple and adaptable[43]. In medical statistics the *probit* model is widely used to predict the effects of toxic substances, the effects of explosion waves and thermal effects.

The *probit* model parameters for evaluating the effects of the toxic substance on humans are determined using Equation (2.2) [44]:

$$Pr = a + b\ln(C_{\mathrm{ppm}}^{n}\,\tau), \tag{2.2}$$

where a, b and n are constants for each chemical substance; τ is the duration of exposure, min; C_{ppm}^{n} is substance concentration in each pollution site, ppm; and n is a degree indicator, determined by performing medical biological examinations, as with indicators a and b.

2.2. Methods of Assessment of Losses Related to Fire and Explosion Hazard

In the 40s of the 20th century, after trials and applications of nuclear weapons in Hiroshima and Nagasaki, it was found to be difficult to carry out a quantitative analysis of the effects of thermal radiation. In Latvia, a methodology for assessing the effects of thermal radiation is required because many HTOs in which hydrocarbons are stored are operated where one of the most likely hazards is different types of fires as a result of an accident, while the main factor of negative effects is thermal radiation transmitted to an installation by radiation and convection. Fire is a major threat to people and material values and is, therefore, a topical socio-economic challenge.

Thermal radiation or infra-red radiation is electromagnetic radiation of an optical range adjacent to visible light on the side of long waves and not visible to the human. The fire risk and explosion hazards of substances and materials shall be expressed as the limit value and maximum hazard for burning conditions. Thus, the thermal radiation in a HTO may be formed as a result of technological processes or uncontrolled burning. Explosion hazards are mainly associated with excess pressure arising from the rapid release of a large amount of energy in a substance or material. In fact, thermal radiation and explosion are closely linked, since the explosion may result in the release of heat, and thermal radiation may cause an explosion. Types of heat transfer are radiation, convection, thermal conductivity and a combination of these types.

Using the *probit* model formula, there is a real chance of generating an automatic algorithm with a computer to predict sanitary and lethal losses in the HTO impact area of the technogenic environment in the case of ES and potential consequences.

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[43] Hosseinnia, B., Khakzad, N., Reniers, G. (2018) Multi-plant emergency response for tackling major accidents in chemical industrial areas. *Safety Science* Vol. 102, pp. 275–289.

[44] Sato, T., Watanabe,Y., Toyota, K,. Ishizaka, J. (2005). Extended probit mortality model for zooplankton against transient change of PCO2. *Marine Pollution Bulletin* Vol.50, pp. 975–979.

Operational assistance to all victims of heat is possible on the basis of the equation *deva-effect* related to thermodynamic parameters and influence factors expressed by medical criteria in the event of thermal damage.[45]

Thermal radiation from a dissolved liquid or solid substance can be calculated in different ways. The following Formulae (2.3) [46] and (2.4) [47] are used in this paper:

$$q = E_f F_q \tau, \tag{2.3}$$

$$q = E_p F_v \tau, \tag{2.4}$$

where E_f, E_p – the average surface density of the flame heat span (kW/m^2) shall be determined using experimental data. Highly inflammable liquid (further in the text – HIL) or Liquefied Hydrocarbon Gas (further in the text – LHG). For LHG leakage fires: for petroleum products 40 kW/m^2, LHG 100 kW/m^2;[48] F_q, F_v is radiation direction ratio; and τ is the atmosphere penetrability ratio.

The assessment of material loss to damaged buildings, structures and infrastructure summarises the objects entering the impact area taking into account the cadastral value or residual value and the extent of damage that can be calculated using Equation (2.5):

$$Y_{lk} = N_{lk} a_l A_{\ oblk}\ , \tag{2.5}$$

where N_{lk} is the number of objects affected by the degree I damage of type A; the a_l ratio is defined depending on the degree of the damage to the object (see Annex 8); $A_{\ oblk}$ is the cadastral value of objects in the impact area with the degree I damage of type K.

It is not appropriate to re-construct an object the structural construction of which has been damaged as a result of severe damage, and such structures must be demolished by providing for the construction of a new site, if necessary. The probability of damage is determined using the *probit* model.

The explosion of gas tanks or the burning of LHG in the atmosphere depends on the amount of burning substance that has entered the atmosphere, which may result in an explosion, a jet fire or the formation of fireball. Fireball is a gas cloud completely filled with a burning substance mixed with air, depending on the way it is produced, but it cannot detonate and starts to burn around its external borders – this is how a fireball is formed. Fireball is not considered to be a standard fire and is capable of affecting the environment at a very long distance.

A jet fire usually occurs in the event of damage to the tank and when LHG is released under pressure to form a combustion jet (a quasi-static condition) if there is a source of fire.

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[45] Еналеев, Р. Ш., Теляков, Э. Ш., Красина И. В., Гасилов, В. С., Тучкова, О. А. (2013). Системный подход в прогнозировании последствий воздействия опасных факторов пожара. Вестник технологического университета, т. 15, в. 8, стр. 322–333.

[46] Куликов, В. В. Гаврилин, И. И. (2014). *Огненный шар*. Екатеринбург УрГУПС. 12. стр.

[47] Sellami, I., Manescau, B., Chetehouna, K., Izarra, C., Nait-Saida R., Zidani, F., (2018). BLEVE fireball modeling using Fire Dynamics Simulator (FDS) in an Algerian gas industry. *Journal of Loss Prevention in the Process Industries*. Vol. 54, pp. 69–84.

[48] Федоров, А. В., Кузьмин, А. А., Романов, Н. Н., Минкин, Д. А. (2018). Метод оценки эффективности огнезащиты стальных конструкций на объектах нефтегазового комплекса в условиях открытого пожара. *Научно-аналитический журнал “вестник Санкт-Петербургского университета государственной противопожарной службы МЧС России”.* 34–43 стр.

Burning with fire load formation can often develop and become an explosion if the event involves a large amount of burning liquid, if the fluids are heated, and in the event of an instantaneous reservoir or tank collapse. Burning with fireball occurs in cases where there is an instantaneous source of fire and LHG or HIL have not been able to blend with the air. If there is a delayed ignition, when the substances were able to blend with the air, it will cause an explosion of these substances.

2.3. Methods for Technogenic Risk Assessment

Significant progress has been made over the last hundred years in the field of safety science, as well as in relation to the development of the theory of sociotechnical systems, factors for identifying human error, and methods have been developed to help anticipate potential hazardous factors.

The hazard assessment of any system should consider a number of possible event scenarios, which may involve many elements and components, possible causes of failure to act, in order to facilitate the understanding of the hazards, existing risks and potential consequences of the system by the parties concerned. As a result, it is possible to identify in good time the weaknesses of the system, make appropriate decisions, identify the measures to be taken and address shortcomings, and this can be based on game theory and research. Scientific, social, economic and cultural aspects must be taken into account in identifying risks, based on the probability of risks. Risk assessment methods are constantly changing – new risk assessment methods are adopted and existing methods are updated and supplemented.

The purpose of the risk assessment is to develop recommendations to increase safety (risk management) based on the results of the risk assessment.[49] Almost all European national legislation requires HTOs to carry out risk analysis but does not require strict use of a specific methodology, so entrepreneurs can use the requirements laid down in their national legislation.[50] Scientists T. Aven and E. Zio believe that there is lack of well-defined and commonly understandable terms in the field of risk assessment and management.

In 2016, Australian scientists C. Dallat, P. M. Salmon and N. Goode summarised information from literature sources on the most popular risk assessment methods in the world, their shortcomings and benefits, and marked seven basic risk assessment methods:

1. Qualitative and expert evaluation methods.
2. Methods of Hazard and Operability Studies HAZOP.
3. Methods for analysis of the failure mode and effect.
4. Methods of analysis of event tree.

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[49] Л. П.Кабанов, Р. Т.Исламов, А. А.Деревянкин, И. В.Жуков, М. А.Берберова, С. С.Дядюра. (2011). Оценка риска для АЭС С ВВЭР. *Материалы 7 международной научно-технической конференции “Обеспечение безопасности АЭС с ВВЭР”*. ОКБ “Гидропресс”.

[50] Никитин, Н. А., Ивахнюк, Г. К., Трофимов. И. В. (2013). Основы обеспечения безопасности на потенциально опасных объектах обращения нефтепродуктов. Научно-аналитический журнал. Выпуск №3, стр. 27–37.

5. Methods for Human Reliability Analysis – HRA – and human error identification – HEI.
6. Quantitative risk assessment methods.
7. Methods of analysis of systems[51].

Qualitative methods shall be used to assess risks in the absence of reliable and accurate data.[52] Quantitative risk assessment methods shall be used if there is sufficient data or if the data can be obtained by simulating the process.[53] The risk assessment often uses semi-quantitative methods suitable for data with quantitative and qualitative characteristics.[54]

When conducting a safety analysis, it is essential to determine which elements or components of an organised system may cause damage to the safety system at the critical moment and how to avoid any danger to that system. In T. Aven's opinion, currently the main uncertainty among analysts and risk management professionals is how to prevent unexpected potential accidents and their consequences in complex systems, such as energy systems and financial systems.[55] Most safety system analysis techniques are based on an informal reasoning methodology that depends heavily on the skills and knowledge of a security engineer.[56] The main challenge of risk management is to identify all possible early causes of the accident, to take them into account and not to overstate their relevance. A good possible risk management system is characterised by the components of a preventive system such as observation of results and signals, assessment of expected risks, probability and severity degree.

Summary and Conclusions of Section Two

Section 2 analyses the existing global risk assessment approaches (methods), the construction of components and the implementation of the risk assessment process with a view to identifying weak and strong sides. The assessment methodology for HTOs, related to thermal radiation, excess pressure, toxic effect assessment algorithms have been examined, the deficiencies and benefits of risk assessment methods have been analysed. It has been established that a number of risk assessment methods can be applied within the framework of economic and environmental assessment in Latvia, in general a sequence determined by several methods provides an opportunity for the effective implementation and use of the methodology.

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[51] Dallat, C., Salmon, P. M., Goode, N. (2017). Risky systems versus risky people: To what extent do risk assessment methods consider the systems approach to accident causation? A review of the literature. *Safety Science*. Vol. 119, pp. 266–279.

[52] Fletcher, W. J. (2005). The application of qualitative risk assessment methodology to prioritize issues for fisheries management. *ICES Journal of Marine Science.* Vol. 62 (8), pp. 1576–1587.

[53] Naderpour, M., Lu, J., Zhang, G. (2014). A situation risk awareness approach for process systems safety, *Safety Science* Vol. 64 (3), pp. 173–189.

[54] Garvey, P. R., Lansdowne, Z. F. (1998). Risk matrix: an approach for identifying, assessing, and ranking program risks. *Air Force journal of logistics* Vol**.** 22 (1), pp. 18–21.

[55] Bjerga, T., Aven, T., Zio, E. (2016). Uncertainty treatment in risk analysis of complex systems: The cases of STAMP and FRAM. *Reliability Engineering and System Safety* Vol. 156, pp. 203–209.

[56] Ortmeier, F., Reif W., Schellhorn. G. (2005). Deductive cause-consequence analysis (dcca). *IFAC Proceedings Volumes.* Vol. 38, Issue 1, pp. 62–67.

Key results of Section Two:

1. The hazard assessment algorithms based on the *probit* function are described, related to the effects of heat exposure, excess pressure, toxic effects. The appropriateness of using the *probit* function has been concluded, as well as the *probit* function constants have been identified and verified.
2. The hazard of depreciation of HTO equipment is described and it is concluded that this factor affects the overall position of the site and increases the hazard values.
3. Different types of technogenic risk assessment methods have been examined, analysing their advantages and disadvantages.
4. The information on the severity of the effects on humans and infrastructure, limit zones of losses in the event of a technogenic accident in the HTO have been summarised.
5. A comparison of different methods for assessing the effects has been carried out on the example of the fireball effect, and it has been found that each method provides a variety of calculation results that have a significant impact on the risk assessment procedure. As a result, specialists are able to make variations with the size of the hazard areas by applying different *probit* function constants, resulting in reducing or increasing the risk level of HTO. An example of fireball provides an opportunity to view the modelling of the effects of the HTO accident and the extent of the consequences of thermal radiation.

Following the tests carried out in Section 2, the following conclusions may be presented:

1. Environmental loss assessment methods are examined for the ES related to exposure to excess pressure, heat radiation and exposure to toxic substances, humans and infrastructure. The use of mathematical models describes the possible patterns of hazardous impacts.
2. Based on the use of a mathematical solution for the *probit* model, it is proposed to carry out a probability and impact assessment using certain verified equations. It has been demonstrated that by using the *probit* equation data it is possible, within an apriori assessment, to assess the effects of an accident in the HTO, to determine the probability of the sanitary and fatal outcomes of the affected people, and to assess the probability of damage to the environment associated with damage to the infrastructure.
3. The nature of ALOHA computer program is described, linking to the Gauss diffusion model and examining the possibility of the program to calculate potential hazard areas for the environment in the event of emergency in HTO. It is concluded that the use of this programme makes it possible to significantly reduce the time of the actual calculation and to demonstrate the effects of hazardous factors on cartographic material.
4. In accordance with the risk assessment methods described in Section 2, it is possible to compile these methods and on the basis of them to establish a common methodology algorithm for assessing economic and environmental losses from the emergency in HTO.

3. DEVELOPING THE METHODOLOGY FOR THE ASSESSMENT OF ECONOMIC AND ENVIRONMENTAL LOSSES

Section 3 establishes the economic and environmental loss methodology of the HTO, as well as the practical calculation of the hazard; the degree of risk and the environmental loss has been done. This section consists of two chapters in which the author developed an innovative methodological algorithm for assessing and calculating economic and environmental losses of HTO. As part of each section and chapter, the author has used and analysed both the available theories and challenges and the experience of other countries. Separately, the author examined a moderate approach for measuring human life, which is an innovative solution and provides an opportunity to assess the economic consequences of possible fatal cases in the event of an HTO accident. Based on the analysis of scientific literature, the author proposes to use the innovative model as a basis for assessing the extent of economic damage. The proposed algorithm is based on an assessment of the average cost of treatment associated with the treatment of various types of technogenic emergency injuries in hospitals.

3.1. Methods for Assessing the Harm to Human Health

The assessment of the value of human life is a complex interdisciplinary problem, the solution of which is necessary for the adoption of national laws on compensation, as well as for families who lost a family member as a result of an accident. This is also necessary in order to develop reasonable safety measures for citizens and to ensure the effective functioning of the life insurance and health system. When assessing the value of human life, it can be determined what amount of money the country is willing to invest to raise safety, reduce hazard factors and mitigate hazards to the technogenic environment. There is currently no uniform methodology for assessing the value of human life in Latvia

Objective economic indicators shall be used to assess the material losses to society and households caused by untimely human deaths. As part of this method, the value of life is assessed as a total loss in the context of GDP in the context of the ES in HTO which led to the death of a statistically average person. The following formula shall be used (3.1)[57]:

$$VSV = \sum_{i=k}^{n} PIKP, \tag{3.1}$$

where VSV is average statistical value of human life; $PIKP$ is an estimated value of GDP per capita at ith year, constant price level (excluding inflation); k is the first year after untimely human death; n is the expected year of natural death, assuming that a person would live the average life expectancy (on average or by sex), where the difference $n - k$ is the number of years lost as a result of a fatal outcome.

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[57] Зубец, А. Н., Новиков, А. В., Сазанакова, А. С (2016). Оценка “стоимости” человеческой жизни с учетом морального ущерба. *Вестник Финансового университета* № 2(22), стр. 6–15.

Based on Formula (3.1), knowing the age of a particular person at the time of a fatal outcome, it is possible to determine the loss to society. Average value of human life – average loss to society in the case of the average statistic human death – can be calculated using Formula (3.2)[58]:

$$n = k + \alpha - \beta, \tag{3.2}$$

where k is the following year; α is average expected human life span next year; β is average age of the country's population next year.

The assessment of economic losses is mainly determined by the direct costs associated with the hospital treatment of injured persons. Indirect costs include those related to reduced work capacity, surgeries, emotional injuries and disability.[59] The calculation mainly takes into account the most common types of injuries and minor injuries; in some cases, also serious bodily injury such as burns.

The type of injuries resulting from exposure of the human body to heat radiation are burns and they are classified into external – associated with direct exposure of human bodies to heat, and internal – resulting from the inhalation of hot air. It is important to assess the economic impact of injuries caused by burns, as the costs of treating burns are topical within this paper. The consequences of severe burns are usually death, sickness and the economic and social costs covered by the victim, his family members, health authorities or the public in general. Burn care is one of the most expensive forms of healthcare, since a long-term hospital stay is needed during the treatment – severe burns usually require multiple surgery and expensive equipment, which greatly increases the costs of treatment.[60] The cost of treating burns is higher than many other common health problems, such as stroke and AIDS.[61] Scientist V. Patil estimated that the average cost of treating burns per patient per day in the UK is USD 1512, in France – USD 934, in Germany – USD 726, and in Hungary – USD 280.12[62]. In Latvia, hospital treatment per person costs EUR 103 per day, but treatment at the Intensive Therapy Clinic, in the intensive therapy ward of Toxicology and Sepsis Clinic and in the so-called stroke unit costs EUR 401 for one person per day.[63] The proportions of lethal outcomes for patients with different burn areas are presented in Table 3.1.

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[58] Urbans. M., Malahova, J., Jemeļjanovs.V. (2020) Methodology for calculating adverse health effects in Latvia. Published by VGTU Press, pp. 195–201.

[59] *WHO and the International Society for Burn Injuries issue new fact sheet on burns* [tiešsaite]. World Health organization [skatīts 2018. gada 18. septembrī]. Pieejams: *http://www.who.int/violence_injury_prevention/publications/other_injury/en/burns_factsheet.pdf 1-5pp*.

[60] Sahin, I., Ozturk, S., Alhan, D., Açikel, C. and others (2011). Cost analysis of acute burn patients treated in a burn centre: the Gulhane experience. *Fire Disasters.* Vol. 24(1). pp. 9–13.

[61] Lopez Bastida J., Serrano Aguilar P., Monton A., et al. (2003). The economic burden of stroke in Spain. *Value Health*. Vol. 6. pp. 615–615.

[62] Patil V., Dulhunty J. M., Udy A., et al. (2010). Do burn patients cost more? The intensive care unit costs of burn patients compared with controls matched for length of stay and acuity. *J Burn Care Res*. Vol. 31. pp. 598–602.

[63] *Maksa par ārstēšanos stacionārā un dienas stacionārā* [tiešsaiste]. Aslimnīca.lv [skatīts 2019. gada 16. septembrī]. Pieejams: *https://www.aslimnica.lv/lv/saturs/maksa-par-arstesanos-stacionara-un-dienas-stacionara*

Table 3.1

Lethal Outcomes for Patients with Different Burn Areas[64]

Indicator	Burn area of a human body, %				Total number of patients
	0–19	20–39	40–59	60–100	
Total number of patients	2519	175	71	35	2800
Number of dead patients	42	27	34	27	130
Lethal outcomes, %	1.67	15.43	47.89	78.26	4.36

The author has proposed to use the following algorithm for assessing injury and the costs of treatment, which has been supplemented with information provided by several authors on the treatment and duration of various types of injuries. During the period of 2005–2008, I. Sahin carried out a study at the Burn Centre of the Gulhane Military Medical Academy in Turkey, Ankara, calculating the average cost of treating an average patient with burns. On the basis of the study criteria, forty-three patients with severe burns were identified, with an average duration of hospital stay of 73 ± 33 days, while the average surface area of the burned body was 36 ± 7 %. The total average cost was USD 15 250[65] . Thus, care for patients with burns is one of the most expensive areas of healthcare due to a long-term hospital stay, many surgeries needed, and expensive modern equipment. It is important to determine not only the burn rate but also the burn area on the human body, as the outcome of fatal cases depends on it. Scientist E. Zhilinsky carried out a study to determine the number of people who have suffered burns and who do not recover depending on the burn area of the body; the results of the study are presented in Table 3.3. Combined effects typically occurring as a result of an accident in HTO may significantly worsen the burn injury forecasts.[66]

In assessing the severity degree, which depends on effects on health, scientist J. Ilinskaya linked the duration of treatment to the severity of the injury obtained according to the breakdown provided in Table 3.2, where the first two indicators comply with the criteria specified in the Law *On the Procedures for the Coming into Force and Application of the Criminal Law*.

Table 3.2

Degree of Human Injury Severity[67]

No.	Duration of effects on health, days	Severity of health effects
1.	7–21	Mild
2.	>21	Average
3.	>120	Heavy

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[64] Жилинский, Г. В., Часнойть, Е. В., Алексеев, А. Ч., Дорошенко, С. А. (2014). Анализ летальности, основных прогностических факторов и осложнений среди пациентов с ожоговой травмой. №11. *Медицинские новости.* стр. 87–91.

[65] Sahin, I., Ozturk, S., Alhan, D., Açikel, C., and others (2011). Cost analysis of acute burn patients treated in a burn centre: the Gulhane experience. *Fire Disasters.* Vol. 24(1). pp. 9–13.

[66] Brusselaers, N., Monstrey, S., Vogelaers, D., Hoste, E., Blot, S. (2010). Severe burn injury in europe: a systematic review of the incidence,etiology, morbidity, and mortality.(Research)(Report) *Critical Care*, Vol. 14, p. 188.

[67] Ильинская, Е. Г., Исаев, Ю. С. (2008). Особенности судебно-медицинской оценки степени тяжести вредаб причиненного здоровью человека в случаях термической травмы. *Судебно-медицинский журнал* No. 14, стр. 45–47.

As part of this work, the data from the studies of I. Sahina and E. Zhillinsky have been used to assess the economic consequences of the treatment of victims, including the effects of thermal radiation, taking into account the average of days spent in the hospital for a period between three and 73 days, and 36 % of body surface burns. The cost of treating burns in Latvia is EUR 401 per day, as it relates to the care of victims in intensive therapy and the side effects of the disease in particularly serious cases, such as infectious diseases. The total cost of treatment per patient for 73 days treatment is EUR 29 273, which overall meets the worldwide burn treatment criteria. 1–2.3 % of people become disabled because of burns caused by a heat radiation, while 40 % of patients with moderate or severe burns need further surgery after leaving the hospital.[68]

The consequences of toxic effects on the organism shall be considered to be moderate or severe poisoning, in the case of which 2–3 weeks[69] of hospital treatment is required depending on the composition of the chemical which entered the atmosphere. In order to assess the consequences for people with moderate or severe poisoning, let us assume that the average duration of hospitalisation is 2 weeks or 14 days. In Latvia, the place in the hospital costs EUR 103 per day, so the total cost of treatment for 14 days in the hospital will be EUR 1442.

As a result of excess pressure, the most common type of injuries is bone fractures. The average duration of treatment for all types of fractures is 137.5 ± 2.85 days spent by a person when being on a sick leave, 79 ± 2.45 days in hospital and 64.41 ± 2.08 days – monitoring in a health centre.[70] The total cost of 79 days of hospital treatment is EUR 8137. The average cost of treatment of injuries in the hospital and the total number of days, depending on the heat radiation, exposure to toxic substances or excess pressure related injuries, are given in Table 3.3.

Table 3.3

Summary of the Costs of Treating Injuries in Hospital[71]

No.	Type of injury	Affecting factor	Number of days in hospital	Costs for one day, EUR	Total direct costs, EUR
1.	Burns	Heat radiation	43	401	29 273
2.	Intoxication	Toxic substances	14	103	1442
3.	Bone fractures	Excess pressure	79	103	8137

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[68] Унижаева, А. Ю., Мартынчик , С. А. (2013). Медико-экономическая оценка затрат и качества стационарной помощи при ожоговой травме. *Социальные аспекты здоровья населения* №ФС77-28654 стр. 1–11.

[69] Остапенко, Ю. Н., Дмитриев, А. В. (2008). *Медицинские аспекты ликвидации аварий, вызванных некоторыми химически опасными веществами.* Методические рекомендации Nr. 24. Москва 7. стр.

[70] Попова, Л. А. (1991). *Сроки восстановительного лечения и временной нетрудоспособности больных с переломами костейконечностей при реабилитации их методом чрескостного остеосинтеза по Илизарову*. Курган 11. стр.

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As can be seen, treatment of injuries caused by thermal radiation is the most costly in a hospital, i.e. EUR 29 273, while the treatment of injuries resulting from excess pressure is the longest.

3.2. Methods for Assessment of Economic and Environmental Loss

The methodology is developed on the basis of a quantitative hazard assessment method identifying potential hazards and existing risk levels to reasonably assess environmental damage, infrastructure and potential accidents in HTOs, as well as taking the necessary management decisions, thereby reducing the level of risk.

In general, the simplified flowchart of the proposed method is shown in Fig. 3.1, which summarizes the basic content information for each block.

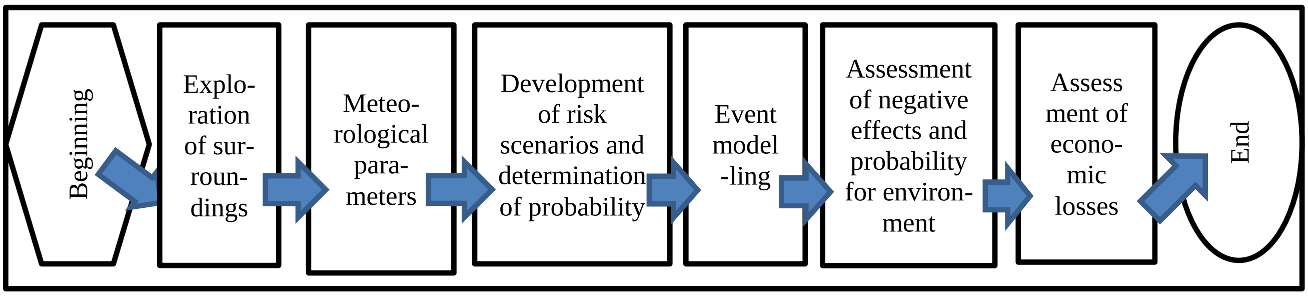

Fig. 3.1. Simplified flowchart of the proposed methodology (created by the author).

Overall, the hazard analysis consists of 6 core blocks, which are recommended to be completed sequentially. You can swap some blocks for places, but you should stick to a logical sequence for a better result.

According to the first block provided in Fig. 3.2, an exploration of the HTO area and surroundings must be carried out first to identify the sites in the area and their distance from the modelled event (emergency) site, and it should also be clarified how many people are in the territories and premises at each time of day. One of the possible options for gathering information is shown in Table 3.4, where the required information is to be entered in each column. Each object must have its own identification number marked in the situation scheme (map).

The total recommended algorithm for Block 1 operations consists of 6 steps. See Fig. 3.2.

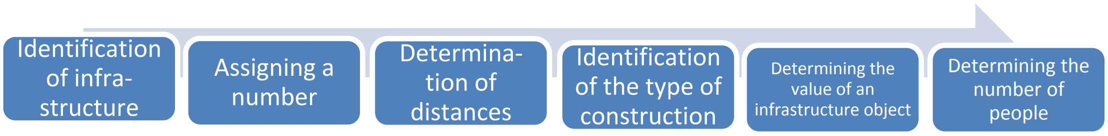

Fig. 3.2. Recommended algorithm for executing Block 1 (created by the author).

Table 3.4

Description of the Surroundings of the Accident Site to be Modelled (created by the author)

Major objects in the vicinity of the emergency site: ⭕ 🔵 🟢			Number on the map	Distance, m	Address	Cadastral or residual value, EUR	Description of buildings, infrastructure and other structures	Area, m²		Number of employees			Heat radiation area	Excess pressure area
								Total		In premises	In the territory	Total	kW	area
Area 1 (distance: 0–100 m)														
1.	XX Ltd.	🟢	50	1	X Str.	11111	R–2	10 00	10 00	1	1	2		

Block 1. According to the algorithm defined in Fig. 3.3, the information in Table 3.5 must be compiled first. When dividing infrastructures according to the zones, it is recommended that the size of the zone is determined from the range of ~50–2000 m by area, depending on the accuracy of the main hazard factor and the required data. For example, the effects of excess pressure, heat radiation, toxic substances, as well as from the distance of the emergency site, the farther from the site of the event, the larger usually is the area.

Block 2. According to the list in Fig. 3.1, meteorological information shall be determined in the second block, including the worst weather conditions, wind direction, air temperature, atmospheric stability class and the probability of still. These data can be obtained by the help of reference sources (e.g. the LEGMC website www.meteo.lv) and used when modelling an emergency scenario. In the second block, the recommended performance algorithm is shown in Fig. 3.3.

Fig. 3.3. Execution algorithms (meteorological information) of Block 2 (created by the author).

Block 3. According to the listing in Fig. 3.6, the third block identifies the hazardous substances and their main hazard indicators, as well as the possible emergency hazard scenarios, and calculates the probability of risk using the event tree method. If an event is associated with HIL or LKG, the probability given in Table 3.9 can be used to create an event tree. An example of the event tree in the event of a complete collapse of the LKG reservoir is presented in Fig. 3.7.

In a long-term operated HTO there should also be determined the depreciation of the analyzed equipment in order to determine whether there is an increased probability of an emergency of the equipment. The depreciation rate also influences the value of the equipment. Figure 3.4 gives the recommended execution algorithm in Block 3.

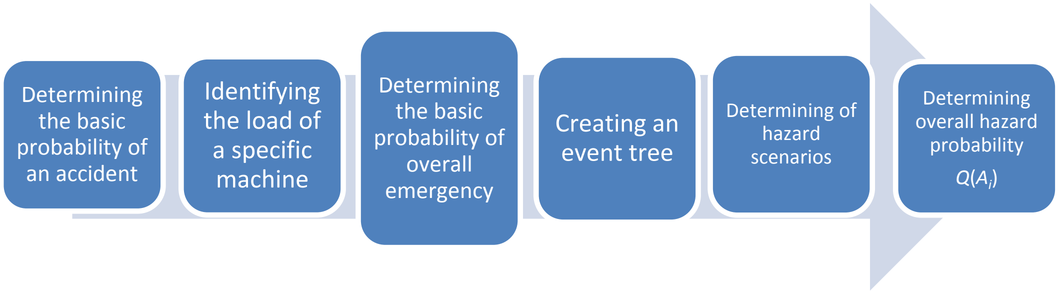

Fig. 3.4. Execution algorithm of Block 3 (created by the author).

Block 4 simulates an event using ALOHA or other computer program that allows for faster calculation and detection of hazard areas. For this purpose, mathematical modelling may also be used to determine the impact of the risk and the area of the impact zone depending on the impact scenario by calculating with formulas and drawing hazard zones on the map. According to the list in Fig. 3.5, the fourth block selects the modelling of emergency scenarios, the methodology for calculating the negative effects, models using the predefined methodology. The LKG vapour cloud explosion distances in the event of an excess pressure developing in the form of detonation by modelling with ALOHA programme provide an opportunity to visually assess the magnitude of the effects of accident with a minimum time consumption, as well as the data obtained for hazard analysis, environmental and ecoonomic loss assessment.

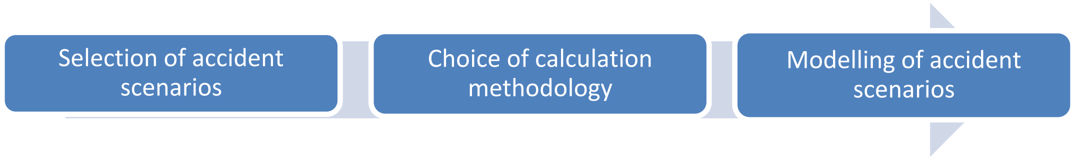

Fig. 3.5. Execution algorithm of Block 4 (created by the author).

Block 5. Awareness of the negative effects and their probability for the environment. According to the listing in Fig. 3.6, the fifth block analyses negative effects, including exposure distances to the event and environmental impacts, selects the methodology for calculating negative effects and models using the previously chosen methodologies.

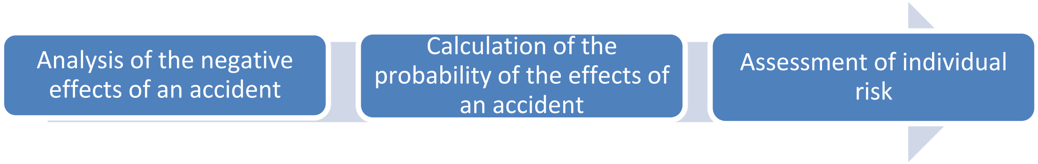

Fig. 3.6. Execution algorithm of Block 5 (created by the author).

Block 6. Assessment of economic losses.

According to the listing in Fig. 3.7, the sixth block analyses the economic consequences based on the analysis of information on the effects of an accident, their probability, etc. in previous blocks. It is necessary to calculate the average human value, treatment costs, environmental losses and infrastructure, after that calculating all losses together.

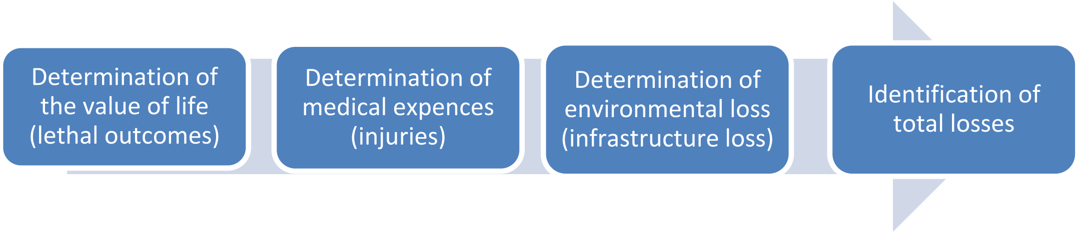

Fig. 3.7. Execution algorithm of Block 6 (created by the author).

In order to calculate the average economic loss resulting from injuries, the average time spent in the hospital shall be determined and multiplied by the cost of treatment in the hospital for each day spent there.

Based on the proposed method and using the data obtained, the risk level for the HTO can be calculated and the potential economic, environmental losses depending on the impact of the risk and the nature of the accident may be assessed.

Summary and Conclusions of Section Three

In the third section the author examines the content of the developed economic and environmental loss assessment methodology based on the sequential execution of the 6-core block algorithm. On the basis of the proposed methodology algorithm, a model with a possible design of hazardous scenarios for HTO with a purpose to test the proposed methodologies for performance, a specific assessment of economic and environmental losses from the hypothetically likely accidents in HTOs has been carried out.

Key results of Section Three:

1. The implementation of each unit of methodology is described, the parameters and indicators of the assessment are described. The appropriateness of the methodology for assessing HTO’s economic and environmental losses is concluded.
2. Testing and selection of the method for assessing the value of human life has been carried out within the framework of the developed methodology. The method of determining the average value of human life has been examined, and it has been established that the method can be used to assess the economic consequences of the fatal outcome. The method is included in a 6-block algorithm.
3. The assessment of the economic consequences of injuries from accidents in HTOs has shown that the costs of treatment of different types of injuries differ, but the methodology offers an optimal method for determining the ambulatory costs associated with the duration of hospital treatments for traumatised people (sanitary losses) in the hospital depending on the nature of the HTO accident.
4. The assessment of economic losses is mainly determined by the direct costs associated with the hospital treatment of injured persons. Indirect costs include those related to reduced work capacity, surgeries, emotional injuries and disability. Thus, an estimate of the cost of treatment for Latvia has been performed, as well as an estimate of the average duration of treatment of the various types of injuries possible in the case of ES in HTOs.

Following the surveys carried out under the heading section 3 “Practical application of methods for assessing economic and environmental losses”, the following conclusions may be drawn:

1. An algorithm has been proposed and an apriori assessment methodology consisting of six core blocks has been developed, which makes it possible to forecast environmental losses in the case of the ES in HTO, including infrastructure losses and human sanitary and fatal losses. The proposed algorithm can be used by the HTO management and the responsible national services assessing the potential impacts of HTOs in the surrounding areas, issuing permits for new building and planning the development of the site in the HTO area. This methodology may be used to anticipate the potential consequences of a specific decision, for example, what consequences are possible as a result of a HTO accident on another site. The methodology proposed may be used by insurance companies for calculating the amount of the premium by concluding the HTO insurance contracts. The national authorities may use this methodology when planning budget expenditure, assessing economic losses as a result of a potential accident, as well as planning the costs for injured persons in connection with hospital treatment.
2. Using the *probit* model, it is possible to calculate the probability of an emergency in HTO and predict the probability of a specific type of loss, depending on how far the object is from the site of the event.
3. The ALOHA programme may significantly shorten the calculation time, determine the area of the risk zone and assess the extent of the negative impact, and may be used before the calculation of potential losses with the probit model.
4. Using two different methods estimation of the average value of human life as a result of the loss of life in 2020 has been made. The extent of potential costs related to human treatment costs, depending on the type of injury, have been assessed. Potential losses in the event of a disability caused by an HTO accident have been identified. A model for measuring the value of human life, taking into account economic indicators and life expectancy, is developed and tested. It is concluded that this assessment algorithm, which reflects the average number of days of treatment in the hospital, provides an opportunity to use this model not only in Latvia but also in other countries around the world.
5. The obtained results show that the proposed methodology can be used effectively for assessing the hazards of any HTO, the operation of which involves storing, transporting, reloading chemicals and products. The main hazard factors of HTOs to which the methodology can be applied are related to heat exposure, excess pressure and toxic effects. Losses can be calculated by an apriori evaluation, depending on the key indicators adopted in the modelling process.
6. The approbation of the developed methodology, based on the performance profile of HTO “Latvijas propāna gāze” ltd., shows that there are possible different reasons for the ES with different consequences. A specific calculation of economic losses has been made for worst scenarios in the event of a LKG-related accident in a HTO. The

modelling of worse situation provides an opportunity to calculate potential economic losses, since it is possible to determine not only the size of risk but also the extent of potential objective losses during the ES a posteriori evaluation phase, as well as to take the necessary measures to encourage the HTO management to reduce potential risks.

7. The technological equipment of HTOs analysed in the Doctoral Thesis has to be replaced urgently, as, continuing to use the existing equipment, the probability of an accident is increased by 50 %, which is considered to be a significant increase in hazards.
8. Actual direct damage in the event of an accident in the HTO various accident scenarios is assessed.
9. Analysing the probability of a domino effect, the possibility that wood ignited as a result of the effect of adverse factors near a HTO and the potential concentration of hazardous substances and the potential effects of burning products on human health have been identified.
10. In order to improve the safety level of HTOs, an emergency risk analysis should be carried out in order to make effective management decisions on the most dangerous sites in the plant and storage of substances. This process should take into account the HTO technological scheme in order to effectively manage the operation of the site and to ensure the safety of the environment.
11. The study confirmed a theoretically important relation: the closer to the examined HTO are other objects, including people, the greater the damage caused by the need to count on the higher costs of rebuilding these sites, as well as the higher are human losses related to people being in the workplace. Therefore, it is important to be aware of the potential consequences and to carry out the planning of sites in accordance with the hazard assessment. When planning the construction of new sites in the areas of potential danger to HTOs, it is necessary to select the structures and technologies that are capable of maximum enduring the identified major HTO hazards. The construction of such objects which do not constitute a domino effect, as well as losses in the event of an HTO accident would be minimal, for example, warehouses for goods which are minimally affected by heat exposure, excess pressure, are acceptable.

CONCLUSIONS

The objective of the Doctoral Thesis "Methodology for the Assessment of Economic and Environmental Loss in High Threat Objects" to develop a science-based methodology for calculating economic and environmental losses in the event of an emergency, strengthening the national security system and addressing problematic issues, was achieved by carrying out a series of **tasks**:

- The global technogenic environmental safety system, its relevance and development has been explored and analysed, which allowed the definition of global trends related to human life environments and the identification of problems with existing security situations.
- The development of safety systems worldwide and their shortcomings have been explored. The structure of the Latvian national security system has been studied in relation to the operation of HTOs, which identified the existing components of the system, the principles of governance affecting the HTO safety, as well as specifying the requirements to be set for the system.
- Methods for assessing the consequences of accidents are analysed, the summary of the results of assessing the effects of fireball is made.
- The methodology for evaluating the risks of the technogenic environment, describing assessment processes, approaches and shortcomings related to HTO work are analysed.
- Methodology for the assessment of damage to statistically average human health as a result of the accident in HTO is offered. The algorithm developed by the author allows the assessment of the economic consequences that are related to the average human life value, as well as the average duration of treatment in the hospital of the typical effects of the accident in HTO. Latvian costs for hospital treatment of a person due to the consequences of an accident have been determined.
- A methodology is developed by the author for assessing and calculating HTO's economic and environmental losses with the open possibility of generating further injury assessment tasks in the total 6-core block algorithm which the user of the methodology would consider necessary.
- The approbation with detailed information on the assessment of HTO hazards and the calculation of economic and environmental losses is developed.

The theoretical results obtained **have been implemented in practice:**

- The methodology for assessing economic and environmental losses developed in the doctoral thesis "Methodology for the Assessment of Economic and Environmental Loss in High Threat Objects" was approbated within Interreg project, assessing a total of 6 (six) HTO risk and hazard levels in Latvia and Lithuania, as well as proposing practical solutions to reduce the risk levels.
- The methodology developed in the student training process allows to acquire knowledge and an idea of the apriori assessment, the level of risk in the HTO, potential economic losses and environmental losses. The methodology should be used within the framework of different HTO safety systems and infrastructure hazard assessment process, systems acquisition and use process.

The development of the methodology and the approbation of its results allows to make the following conclusions:

- The developed methodology makes it possible to carry out an apriori assessment of risks and losses, to provide the analysis of the missing information.
- The analysis of the results of the developed methodology allows to identify shortcomings in the current HTO risk analysis and impact assessment situation; a full assessment of the potential hazardous situation is possible based on the developed assessment algorithm.
- The possibility of verifying the usefulness of a new HTO disposition already at the design stage enables experts from different areas to plan the use of nearby areas, as well as to assess potential social, economic and environmental losses.

The results of the Paper allow the approval of the arguments put forward for defence. The approbation of the developed methodology leads to the conclusion that the proposed algorithm shows actual hazards, allows to look at the extent of the potential consequences, assesses economic, social and environmental losses. The methodology compiles a variety of input information on the situation in HTO and the environment, analyses it and provides reasonable information on the existing risk levels and impact extent. Integrated methodology algorithms provide an opportunity to use this approach to a broad range of stakeholders and specialists, as well as evaluation algorithms give an objective assessment for each HTO.

The directions for **further research**:

- Approbating the proposed algorithm in order to supplement the required assessment loss criteria, such as assessing losses for hydroresources, earth interiors, including sanation costs.
- To supplement the consequences of economic losses with an additional calculation of indirect losses. The inclusion of such consequence estimates in the algorithm would allow to supplement the methodology and provide a more complete assessment of potential losses.

As a result of the existing conclusions, it is possible to conclude that any assessment method can be used for risk assessment in Latvia at present, as there is no uniform methodology within the framework of the law. As a result, the assessment of the consequences and risks of accidents does not provide accurate information, since the assessment of one HTO by different methods may lead to different results. The developed methodology for “Methodology for the Assessment of Economic and Environmental Loss in High Threat Objects” provides an opportunity to assess HTO hazards in a number of objects and to compare the potential consequences of an accident on a single algorithm basis.

In fact, the above conclusion points out that the hypothesis of the study on developing a universal methodological approach for the assessment of economic and environmental losses in HTO, which provides an opportunity to quantify the limits of the risk allowable, as well as to justify economically the extent of the damage likely to occur in the event of an accident, was granted an approval.

In the process of demonstrating the hypothesis, the author has developed solutions that make it possible to assess the level of risk in an HTO, the extent of the economic and environmental consequences.

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