EXPERT ASSESSMENTS IN DECISION MAKING:

RISKS AND SAFETY

Scientific Route

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Collective monograph

Edited by
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Scientific Route

Tallinn
Estonia

Published in 2023
by Scientific Route OÜ
Narva mnt 7-634, Tallinn, Harju maakond, Estonia, 10117

DOI: 10.21303/978-9916-9850-2-1
ISBN 978-9916-9850-2-1 (eBook)

ISBN 978-9916-9850-2-1 (eBook)

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ABSTRACT

The monograph "**Expert assessments in decision making: risks and safety**" presents studies that address the problems of expert assessments and the formation of decisions based on expert opinions in some areas of human activity. The results of decisions based on such assessments have a direct impact on safety and the risks that may follow. The problems are considered in the following aspects.

An innovative approach to the formation of a list of types of forensic examinations and expert specialties.

It has been established that the existing classification of forensic examinations by branches of specific examination used in their conduct is outdated and does not meet modern requirements. This creates difficulties not only for forensic experts and persons wishing to become them, but also for the court, participants in the trial and all citizens interested in obtaining a forensic expert's opinion. A discrepancy has been established between the types of forensic examination and the specialties of experts for which the qualification of a forensic expert is assigned in departmental lists.

It has been proposed to unify the interdepartmental approach to the classification of forensic examinations in order to avoid errors that could lead to illegal and unfounded court decisions. The issue of unification can be resolved by developing a general approach to the classification of types and types of forensic examinations, enshrined in an interdepartmental regulatory act, which should be based on the criteria of the general theory of forensic examination. The creation of a unified list of types of forensic examinations and their corresponding expert specialties can open up ways to solve many issues facing the expert community. Taking into account the fact that at the time it is planned to provide opinions by experts in electronic form, the creation of a forensic expert's office and its integration with the Unified Judicial Information and Telecommunication System, the creation of a modern unified list by types of forensic examinations and their corresponding expert specialties is on the agenda.

Blood cell image recognition using texture and neural networks for leukemia diagnosis.

Morphological analysis of blood cell images is usually performed manually by an expert, but this method has many disadvantages, including slow analysis, low accuracy, and the results depend on the skill of the operator. This reduces the chance of a correct diagnosis in detecting acute lymphoblastic leukemia, a potentially fatal blood cancer if left untreated.

The study developed and presented an automated method for identifying and classifying leukocytes using microscopic images of peripheral blood smears. The proposed

neural random threshold classifier achieved a recognition rate of 98.3 % when the data was divided into 80 % training set and 20 % test set. The proposed system can be implemented as a computational tool to detect other diseases in which blood cells undergo changes, such as Covid-19. This will eliminate the subjective factor that is invariably inherent in the case of assessment by experts, focusing only on their experience. Therefore, the system is important for conducting expert assessments in medical diagnostics, as part of a decision support system that reduces the likelihood of risks of incorrect diagnosis of diseases.

Analysis of the capabilities of the Internet of Things in monitoring the physiological state and location of personnel on an offshore oil platform.

The possibilities of using the Internet of Things (IoT) to ensure personnel safety on an offshore oil platform were explored. For this purpose, IoT applications and technologies for monitoring the physiological state and location of personnel are analyzed. The use of cloud technologies, big data technologies and artificial intelligence for the development of systems that allow monitoring and, if necessary, making appropriate decisions through systematic monitoring of personnel status is considered. The basis for decision making is expert assessments of deviations of real-time parameter values from the norm. Practical problems associated with the use of Internet of Things technologies in various areas of healthcare are presented.

Methodological approaches to intelligent management of human factors on offshore oil and gas platforms.

The problems of increasing the efficiency of managing the safety and health of shift workers in the offshore oil and gas industry through the prism of the human factor have been studied. The environmental features, hazards and risks, working and professional conditions in the offshore sector are taken into account. The concept of a person-centered approach to personnel safety and health management is proposed, which involves the inclusion of employees in the management loop as the main component of their contextual environment. This involves constant remote monitoring of vital health indicators of employees and, at the same time, parameters of the context-dependent environment of each of them, as well as an expert assessment of the deviation of these parameters from the norm.

Decision support in a remote health monitoring system for shift workers on an offshore oil platform.

A methodological approach to the synthesis of solutions in a geographically distributed intelligent health management system for oil workers working in the maritime industry is proposed. A functional model of the health management system for workers employed on offshore oil platforms has been developed and implemented in three stages: monitoring and assessment of health indicators and environmental

parameters of each employee, as well as decision-making. These interacting operations integrate layers of a distributed intelligent healthcare management system.

Appropriate approaches to implementing decision support processes are presented and one of the possible methods for assessing generated data and making decisions using fuzzy pattern recognition is described. Models of a fuzzy ideal image and a fuzzy real image of the employee's health state have been developed and an algorithm for expert assessment of the deviation of the formed medical indicators from the norm is described.

Expert assessment of engineering and planning solutions to improve the safety of vulnerable road users in Ukraine.

The study is devoted to the analysis of the main methodological provisions for conducting an expert assessment (audit) of engineering and planning solutions, organizational and management measures to ensure road safety (RS) for vulnerable road users.

The results of the study are presented in the form of the authors' opinions on the following problems (areas of activity) in the field of road safety, which are subject to expert assessment:

– the real level of road accidents among the main categories of vulnerable road users in Ukraine;

– modern scientific, methodological and engineering planning approaches to the formation of individual elements of an effective and safe transport infrastructure, as well as progressive traffic management systems (TS);

– the possibilities and feasibility of implementing engineering and planning solutions, organizational and management measures to improve road safety (RS).

Keywords

Forensic examination, expert specialty, classification of forensic examinations, special examination, legal regulation, image processing, neural classifiers, expert assessment, Internet of Things technology, human-centered approach, remote monitoring, decision making, risk, road safety.

CIRCLE OF READERS AND SCOPE OF APPLICATION

The category of readers includes, but is not limited to, specialists involved in decision-making, or consumers of such decisions for their practical activities, including those related to the need to reduce risks and increase personnel safety.

The scope of application of the research results presented in the monograph includes:

– conducting forensic and forensic medical examinations,

– use of expert systems in medical diagnostics,

– development of safety systems for personnel working on rotation in harsh operating conditions, in particular in the offshore oil and gas industry,

– development of safety systems for road users

The application of the research results presented in the monograph may be useful in other areas of human activity directly related to management activities, which are based on the opinions and conclusions of experts.

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Expert assessments: taking into account the human factor

Dmytro Domin

Human factor. This terminology is familiar to every person. Even at the everyday level, everyone uses this concept when discussing certain events that led to some consequences. These can be not only accidents or disasters. This may be a way out of a person's comfort zone caused by external circumstances. Changes in the route of movement of vehicles, which lead to delays on routes and delays, failure to receive any services or poorly provided services, which require additional time for a person, etc.

Who is to blame for all these unwanted events? Obviously, there are fundamentally three answers to this question: uncontrollable external circumstances are to blame, the system is to blame, or people are to blame. In the first case, someone is powerless, because it is impossible to prevent, for example, natural disasters. It is only sometimes possible to predict their occurrence based on the use of modern technical and technological means and systems, but with a certain degree of probability. In the second case, it is possible to predict and purposefully manage events, preventing the occurrence of undesirable ones by continuously monitoring process parameters and implementing automatic control over them. In the third case, if a forecast is possible, it is only with a huge degree of uncertainty. However, even in the first two cases it is impossible to do without human participation. Such a person may be an operator who, due to his/her incomplete competence or fatigue, or under the influence of other factors, such as psycho-physiological nature, makes mistakes. Therefore, there are always risks of undesirable events, and even if their probability is minimal, it cannot be ignored.

The operator's activity comes down to control and management, which is inherent in the technical systems themselves. Therefore, with high qualifications and a high level of professionalism of the operator, such systems operate with very high reliability indicators, which guarantees the safety of everyone who uses them. However, the mechanisms of functioning of technical systems are based on the fundamental laws of physics, chemistry, mathematics, etc., that is, they are characterized

DOI: 10.21303/978-9916-9850-2-1.introduction

mainly by the certainty of controlled parameters. The situation becomes more complicated when it comes to organizational and technical systems, where people appear as components of control. And this is where uncertainty arises. In this case, the operator must have assistants, for example in the form of decision support systems. Such systems generate tips and recommendations for the operator, built in advance on the basis of an analysis of the functioning of specific organizational and technical systems. However, given the fact that in such systems there is an uncertainty factor in the assessment of states, some adequate criteria for such assessment are necessary. The lack of completeness of data and fundamental knowledge about objects makes it impossible to accurately describe such systems using known laws, which is replaced by the use of expert assessments. A new subject emerges – the expert. This is a person who has a certain set of knowledge, competencies, experience in a specific subject area, who can be the bearer of opinions about specific systems, their functioning, features, etc.

The appearance of an expert makes it possible, on the one hand, to obtain some data about systems in qualitative and quantitative terms. In the absence of accurate knowledge about the system, this is still the only way to obtain more or less reliable information. However, on the other hand, the human factor component is increasing, and not only at the level of systems management, be it organizational, technical, social, or any other systems. In this case, it is the experts who are involved in creating decision support systems, which generate tips and recommendations for operators.

Involving experts to form ideas about an object necessarily requires compliance with the principle of collegiality in the sense that each expert must express his/her judgment, after which all judgments are processed in some way to develop a common decision that is accepted as the final conclusion. It should be noted that such processing of opinions, which actually requires assessing the degree of agreement between experts' opinions, is based on the use of well-known statistical methods. Therefore, the opinion of experts is assessed quantitatively, as a rule, on a point scale or in some standardized units. This is quite convenient, however, even if we do not take into account possible strong differences in the opinions of individual experts even on one specific issue, such an assessment is initially based on a not entirely correct methodology. This is due to the fact that the expert's opinion is not a random variable. Therefore, strictly speaking, it cannot be described by some kind of distribution law due to the fact that it is impossible to obtain the distribution density of an expert's opinion precisely because it is not a random variable. An expert's opinion is a fuzzy quantity, for the description of which it is necessary to use methods of fuzzy mathematics, characterizing it quantitatively with a set of parameters: modal value, membership function, compactness of the uncertainty body. Moreover, this apparatus is invariant with respect to the subject area for which experts are involved and, obviously, more accurate, despite the very concept of fuzziness underlying it.

However, even having quantitative estimates obtained by tools of mathematical statistics or fuzzy mathematics, one should not forget that any expert operates with only a fraction of the input information. Applying his/her knowledge and experience to its processing, s/he forms an opinion that concerns only the local area. To confirm this, it is appropriate to recall the well-known parable of the elephant and the blind men, when the experts involved, who did not have the opportunity to see the elephant and did not imagine it visually, correctly determined what individual parts of the elephant's body looked like but were unable to describe the entire elephant.

All this forms a potentially interesting and invariably relevant scientific topic that could consider the study of expert assessments, methods of their formation, principles of use and selection of the profile of expert groups, as well as their relationship with intelligent decision support systems and, of course, artificial intelligence technologies. It is important to note that this scientific issue itself is multidisciplinary, covering not only borderline scientific areas but also areas that are far from each other in traditional ideas about the classification of sciences. These could be Social and Humanities, Health Sciences, Physics and Engineering, and Life Sciences. In today's global world, there is a need for a broader perception of science as a tool for obtaining practical knowledge. And, given that the proportion of objects of human civilization that are clearly described by fundamental laws is relatively small, the development of the apparatus of expert assessments, regardless of a specific subject area, comes first. Therefore, this topic is inexhaustible, and we consider the proposed monograph as the first step towards broad coverage of topics related to examinations, their impact on risks, safety, and determining their place in decision-making systems in various realms of human activity.

In this monograph, the problem is considered in the following practical domains of knowledge:

– forensic examinations, the quality of which and the correctness of procedures in the context of new technological innovations and new objects of examination directly determine the receipt of objective conclusions by citizens;

– the construction of a decision support system for experts in the field of medical diagnosis of leukemia, with the ability to scale to identify other diseases in which blood cells undergo changes, such as Covid-19;

– use of the Internet of Things (IoT) to formulate solutions regarding ensuring the safety of personnel working in the oil and gas industry, taking into account the human factor;

– intelligent management of the human factor, as an aid in decision-making by experts in addition to knowledge bases about hazards, based on the concept of a human-centered approach, which involves the inclusion of experts in the control loop on oil platforms as objects with an increased level of operating hazard;

– methodology for conducting expert assessment of engineering and planning solutions, organizational and management measures to ensure road safety.

We hope that the solutions proposed in this monograph could be useful not only from a theoretical but also from a practical point of view. I also express the hope that the results of these studies will inspire colleagues, stimulating them to present to the world their developments in this interesting area of knowledge related to expert assessments of objects of any nature operating under conditions of uncertainty.

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CHAPTER 1

An innovative approach to creating a list of types of forensic examinations and expert specialties

Nataliia Martynenko

Abstract

Forensic examination is a rather complex field of activity, characterized by the breadth of specific expertise used and the complexity of research procedures. An accurate "specialty passport" is needed, which describes what this or that examination can do and what it is called. The study uses a system of methods, in particular, general philosophical, general scientific (dialectical, analysis, synthesis, abstraction, analogy), and special legal methods (formal legal, systemic and structural). The methodological basis of the research is the dialectical method of scientific knowledge, which reflects the relationship between theory and practice.

It was found that the existing classification of forensic examinations by the fields of specific expertise used in their conduct is outdated and does not meet the requirements of modernity. This creates difficulties not only for forensic experts and persons who wish to become them, but also for the court, participants in the legal process, and all citizens who are interested in obtaining the opinion of a forensic expert.

It has been established that there is a discrepancy between the types of forensic examination and expert specialties according to which the qualification of a forensic expert is assigned in the departmental lists. This leads to misunderstanding by customers of expert studies of the correspondence of expert specialties and their demarcation.

The appearance as a result of the application of innovative technologies of new objects that did not exist before, or were transformed from already existing ones, contributes to the discovery of new properties and the manifestation of new signs of these properties, which, in turn, leads to the genesis of new expert specialties, species and subspecies, genera, classes of forensic examinations.

It has been proven that the expansion of the sphere of activity of private forensic experts by granting them the right to conduct those forensic examinations, which they do not have the right to conduct today, will allow to create greater competition

 DOI: 10.21303/978-9916-9850-2-1.ch1

between the public and private sectors, improve the quality of expert research, shorten the terms of their conduct, relieving the burden on state forensic expert institutions.

The unification of the interdepartmental approach to the classification of forensic examinations is proposed in order to avoid errors that can cause the issuance of illegal and unfounded court decisions. The issue of unification can be solved by working out a general approach to the classification of kinds and types of forensic examinations with consolidation in an interdepartmental regulatory act, which should be based on the criteria of the general theory of forensic examination. The creation of a unified list by types of forensic examinations and their corresponding expert specialties can be considered a strategic task, which, if successfully implemented, can open up ways to solve many issues facing the expert society.

Taking into account the fact that at the time it is planned to provide opinions by experts in electronic form, the creation of a forensic expert's office and its integration with the Unified Judicial Information and Telecommunication System, the creation of a modern unified list by types of forensic examinations and their corresponding expert specialties is on the agenda.

Keywords

Legal regulation, state specialized institutions, forensic examination, expert specialty, classification of forensic examinations, forensic expert activity, specific expertise.

1.1 Formulation of the problem

Forensic examination is a rather complex field of activity, characterized by the breadth of specialized knowledge used and the complexity of research procedures. This determines the variety of types of forensic examinations, which inevitably raises the question of their classification. Classification is extremely important for forensic examination as a field of practical activity. If in theory we can sometimes afford not to single out separate forensic examinations, then practical activity requires strictness of the name and certainty of the components. A clear "specialty passport" is needed, which describes what this or that examination can do and what it is called.

The classification of forensic examinations as an integrative system structure, which is a complete conceptual formation, all elements of which are in inseparable, interdependent relationships with each other, is required for use both in the development of theoretical provisions and in practical expert activity.

During the period of development of the general theory of forensic examination, which came at the end of the 20th – the beginning of the 21st century, a large amount of empirical material was accumulated in certain kinds (types) of examinations, and on this basis methodological, legal and organizational principles for various types of forensic examinations were developed, common features and signs that should be characteristic of any kind of examination, including newly created ones were determined.

Scientific classifications of forensic examinations have both theoretical and closely related practical significance for the forensic activity itself, as well as for the jurisdictional activity of state bodies and officials. One of the essential grounds for classification is the nature and field of special knowledge, required for conducting an examination of a certain type. Classification of forensic examinations without taking into account such a basis as the nature and field of special knowledge will not be effective enough in modern realities. This is due to the fact that the classification will not be deliberately designed to solve the needs that arise in practice when assigning and conducting a wide variety of forensic examinations. For example, without taking into account the nature and field of special knowledge, it is impossible to determine the competence of an expert who is entrusted with conducting a forensic examination, since it is not known in advance what special knowledge he/she must have to solve the issues before him/her, and, as a result, the correct choice of a forensic institution who has such knowledgeable persons cannot be made.

1.2 Analysis of recent research and publications

The issue of classification of forensic examinations has been considered by scientists for many decades. Practically every scientific study contains various clarifications and details of existing classification structures, or offers completely new ones. Their quality, possibilities of scientific and practical use largely depend on the basic provisions that were used during their development. G. Massonnet, Y. Lim, A. Marolf, N. Estoppey in the field of soil forensics have proposed statistical and probabilistic approaches that help in the determination of relevant variables and subsequently in the construction of various classification models [1]. B. Rappert, H. Wheat, D. Wilson-Kovacs applied rationing classification schemes from health care research to the field of criminology to characterize methods of matching demand with opportunities [2]. V. Fedorenko and L. Tymoschyk offered a classification and general characteristics of the main types of forensic examination on intellectual property [3]. O. Shramko summarized and highlighted various approaches to the classification of examinations in domestic practice [4]. O. Dufenyuk considered the criteria for the classification of forensic examinations in Ukrainian forensic science [5]. A. Polyarush offers criteria for the classification of forensic examinations, which are assigned in the process of investigating crimes related to the illegal circulation of excise goods [6].

1.3 Highlighting previously unresolved parts of the overall problem

At the same time, the increased attention of scientists to the issues of classification constructions in criminology and forensic examination indicates the need for further research and study of existing problems in this field.

1.4 Formulation of the purpose of the article and setting of tasks

A study of the prerequisites, problems and prospects for the creation of a modern unified list of types of forensic examinations and expert specialties, according to which the qualification of a forensic expert is assigned.

The tasks of the research are:

– to find out the classification of forensic examinations on the subject-object-method basis;

– compare the departmental lists of types of forensic examinations and expert specialties, according to which the qualification of a forensic expert is assigned;

– to investigate the differences in the specified lists;

– to propose ways to solve problems in the legal regulation of the classification of forensic examinations.

1.5 Description of the methodology (structure, sequence) of the research

To carry out the research, a system of methods of scientific knowledge was applied, in particular general philosophical, general scientific (dialectical, analysis, synthesis, abstraction, analogy), as well as special legal (formal-logical, formal-legal, comparative-legal, systemic-structural). The methodological basis of the research is the dialectical method of scientific knowledge, which reflects the relationship between theory and practice.

The formal-logical method was applied during the analysis of the content of current domestic legislation in the field of forensic expert activity. Thanks to the comparative legal method, the analysis was carried out and the peculiarities of the normative legal regulation of classification by types of forensic examinations and their corresponding expert specialties were studied.

The theoretical basis of the research is mainly scientific works and conclusions of leading foreign and domestic specialists, devoted to the study of the problems of classification of forensic examinations.

1.6 Presentation of the main material and obtained scientific results

For the purpose of efficient and effective use and application of special knowledge in judicial proceedings, authorized persons, the court, the expert, entrusted with the research, are obliged to adhere to the classification of forensic examinations and distinguish relevant expert specialties. Differences in the nature of research objects and in the tasks of each of the kinds, types and subtypes of examinations should also be taken into account. The name of the forensic examination determines the kind or type of expert examination in accordance with the four-level classification system.

This division of forensic examinations taking into account the tasks they solve (**Table 1.1**) is of significant importance: it helps the person who assigned the examination in the correct choice of the appropriate kind (type) of examination and the addressee of the expert examination; determines the training and retraining of expert personnel, their competence and specialization; helps determine the kinds and types of examinations, the performance of which should be organized in a forensic institution, as well as predict the creation of new ones; facilitates the development of short-term and long-term research plans for the development of the theory and methodology of expert research.

Table 1.1 Classification of forensic examinations on the subject-object-method basis

Examination class	Consists of expert studies, which are united by a community of knowledge, which serve as a source of formation of theoretical and methodical foundations of forensic examinations, and objects, investigated on the basis of this knowledge. The division into classes is carried out according to whether the examination belongs to one or related fields of special knowledge that use similar tools
Examination kind	Is distinguished by subject, objects and, accordingly, methods of expert research
Examination type	Consists of the elements of the kind, which differ in the specificity of the subject in relation to the objects and methods common to the kind
Examination subtype	Component parts of a type, distinguished by a peculiar group of tasks characteristic of the subject of this type of examination, and complexes of research methods of individual objects or their groups

Compiled by the author

The Instructions on the Assignment and Conduct of Forensic Examinations and Expert Research, approved by the Order of the Ministry of Justice of Ukraine dated 08.10.1998 No. 53/5 proposes a unified classifier of the main types (subtypes) of forensic examinations according to a criterion that can be identified as a field of special knowledge.

The following are defined:

1. Forensic: handwriting; linguistic examination of speech; technical examination of documents; examination of weapons and traces and circumstances of their use; traceological (except for studies of traces of clothing damage, associated with the simultaneous infliction of physical injuries, which are carried out in the forensic medical examination office); photo, portrait; examination of holograms; video and sound recording; explosion engineering; man-made explosions; materials, substances and products (paint materials and coatings; polymer materials; fibrous materials; petroleum products and fuel and lubricant materials; glass, ceramics; narcotic drugs, psychotropic substances, their analogues and precursors; alcohol-containing mixtures; soils; metals and alloys and products from them; the presence of harmful substances (pesticides) in the environment; substances of chemical production and special chemicals; food products; potent and poisonous substances); biological.

2. Technical engineering: transport engineering (automotive engineering, traceological, railway); road engineering; construction; construction assessment; land engineering; land assessment; land management; fire engineering; life safety; mining engineering; environmental engineering; electrical engineering; computer; telecommunications, electric transport; examination of the technical condition of elevators; mechanical engineering; water engineering; avia-engineering; heat engineering. Along with the specified types of technical engineering examinations, expert institutions may also conduct other types (subtypes) and complex technical studies with the involvement of relevant specialists in certain fields of knowledge, including aviation and water transport.

3. Economic: accounting and tax accounting; financial and economic activity; financial and credit operations.

4. Merchandising: machinery, equipment, raw materials and consumer goods; transport and commodity science; military property, equipment and weapons.

5. Examination in the field of intellectual property: literary and artistic works; phonograms, videograms, programs (broadcasts) of broadcasting organizations; inventions and utility models; industrial samples; varieties of plants and breeds of animals; commercial (brand) names, trademarks (marks for goods and services), geographical indications; topographies of integrated microcircuits; commercial secrets (know-how) and innovative proposals; economic in the field of intellectual property.

6. Psychological.

7. Art.

8. Ecological.

9. Military.

10. Veterinary.
11. Gemological.
12. Historical and archeological [7].

In order to more fully satisfy the needs of investigative and judicial practice in solving issues that require the application of scientific, technical or other special knowledge, expert institutions organize other types of examinations (except forensic medical and forensic psychiatric), including those that are in the stage of scientific development [7].

There are different points of view regarding the classification of forensic examinations by the fields of special knowledge, used in their conduct (classes, kinds, types and subtypes). Some of the classifications, proposed by domestic and foreign scientists, differ from the unified classifier, given in the mentioned Instruction. Each of the proposed classifications has a certain justification and meets the needs, for which it was developed. However, in the case of engaging an expert and assigning specific expert studies, it is necessary to be guided by the official classifications, set forth in the relevant normative documents that regulate the work procedure of the expert institution or the expert entrusted with conducting the examination.

The classification by types of forensic examinations and their corresponding expert specialties is normatively fixed in:

– the list of types of forensic examinations and expert specialties, according to which the qualification of a forensic expert is assigned to specialists of research institutions of forensic examinations of the Ministry of Justice of Ukraine (hereinafter – the List of MJ of Ukraine);

– the list of types of forensic examinations and expert specialties, according to which the qualification of a forensic expert is assigned to specialists who do not work in state specialized institutions, approved by the order of the Ministry of Justice of Ukraine dated 03.03.2015 No. 301/5 [8];

– the list of types of forensic examination and expert specialties, according to which the qualification of a forensic expert in the Expert Service of the Ministry of Internal Affairs is assigned, approved by the order of the Ministry of Internal Affairs of Ukraine dated 09/21/2020 No. 675 [9] (hereinafter – the List of MIA);

– the list of the main types of forensic examinations and expert specialties, according to which the qualification of a forensic expert is assigned to specialists of expert subdivisions of the SSU, which was approved by the order of the SSU dated 24.12.2014 No. 855 [10] (hereinafter – the List of SSU).

Employees of research institutions of forensic examination of the Ministry of Justice of Ukraine conduct expert research within 41 types (subtypes) of forensic examination in 93 expert specialties, assigned after training and certification [8].

According to the List of MIA, expert studies are conducted within 39 types (subtypes) of forensic examinations in 101 expert specialties, assigned after training and certification [9].

In the List of the Security Service of Ukraine, 51 types (subtypes) of forensic examinations are defined according to a criterion that can be identified as a field of special knowledge, expert studies are carried out in 112 expert specialties, assigned after training and certification [10].

We will compare the types (subtypes) of forensic examinations, indexes and types of expert specialties, according to which the qualifications of a forensic expert are assigned to specialists of state specialized institutions.

The forensic expert qualification is assigned to specialists of state specialized institutions of 39 expert specialties within the scope of forensic examination, according to the List of the Ministry of Justice of Ukraine, the List of the Ministry of Internal Affairs – 50 and the List of the Security Service – 56 (**Table 1.2**). Some expert specialties that are available in the Lists of some departments are not available in others. Thus, according to the type of forensic examination of "Special technical means of secretly obtaining information", expert specialties are assigned only to specialists of expert divisions of the Security Service of Ukraine. Accordingly, the examination of STM of surreptitious audio and video control and surveillance of a person, thing or place; examination of STM of secret removal of information from electronic communication networks, obtaining information about the location of a person or his/her possession, as well as radio equipment (radio-electronic means); examination of STM of secret penetration into an object by unlocking mechanical locking devices, as well as examination of objects; examination of STM of secret removal of information from electronic information systems, penetration into an object by unlocking electronic security devices, as well as examination of software means of surreptitious information acquisition are carried out only by specialists of expert units of the Security Service of Ukraine.

Expert examinations by specialties: 1.3 "Authorship examination of written speech"; 1.4 "Semantic-textual examination of written and oral speech"; 5.3 "Assessment of the possible consequences of the use of explosive devices"; 5.5 "Assessment of the consequences of the influence of technical factors of sabotage (terrorist act), other emergency situations"; 7.4 "Examination of voice and oral speech by technical methods"; 7.5 "Examination of voice and oral speech using linguistic methods" are carried out only by specialists of expert units of the Security Service of Ukraine.

Only the Expert Service of the Ministry of Internal Affairs conducts expert examination in the following specialties: 2.4 “Examination on the documents production age”; 9.7 “Odorological examination”.

Table 1.2 Comparison of types (subtypes) of forensic examinations, indexes and types of expert specialties, according to which the qualification of a forensic expert is assigned to specialists of state specialized institutions, within the framework of forensic examination*

Types (subtypes) of forensic examinations	RIFE of MJ of Ukraine		Expert service of MIA of Ukraine		Expert service of SSU	
	IES**	TES***	IES**	TES***	IES**	TES***
1	2	3	4	5	6	7
Handwriting and linguistics	1.1	Examination of handwriting and signatures	1.1	Examination of handwriting and signatures	1.1	Examination of handwriting and signatures
	1.2	Linguistic examination of speech	1.2	Linguistic examination of written speech		
					1.3	Authorship examination of written speech
					1.4	Semantic-textual examination of written and oral speech
Technical examination of documents	2.1	Examination of document details	2.1	Examination of document details	2.1	Examination of document details
	2.2	Examination of document materials	2.2	Examination of document materials	2.2	Examination of document materials
	2.3	Examination of printing forms and other means of documents production	2.3	Examination of printing forms and other means of documents production	2.3	Examination of printing forms and other means of documents production
			2.4	Examination of documents production age		
Weapon	3.1	Ballistic examination of firearms and ammunition for them	3.1	Ballistic examination of firearms and ammunition for them	3.1	Ballistic examination of firearms and ammunition for them
	3.2	Ballistic examination of firearm marks, shot marks and situational circumstances of the shot	3.2	Ballistic examination of firearm marks, shot marks and situational circumstances of the shot	3.2	Ballistic examination of firearm marks, shot marks and situational circumstances of the shot

Continuation of Table 1.2

1	2	3	4	5	6	7
	3.3	Cold weapon examination	3.3	Cold weapon examination	3.3	Cold weapon examination
	excluded on the basis of the Order of MJ of Ukraine No. 2117/5 dated June 10, 2021		3.4	Examination of weapons with a non-kinetic principle of damage	3.4	Examination of weapons with a non-kinetic principle of damage
	3.5	Examination of grenade launchers	3.5	Examination of grenade launchers	3.5	Examination of grenade aunchers
	3.6	Examination of artillery and missile weapons	3.6	Examination of artillery and missile weapons	3.6	Examination of artillery and missile weapons
Traceological	4.1	Examination of human traces and animal traces	4.1	Examination of human traces and animal traces	4.1	Examination of human traces and animal traces
	4.2	Examination of tools, aggregates, instruments and traces left by them, identification of the whole by parts	4.2	Examination of tools, aggregates, instruments and traces left by them, identification of the whole by parts	4.2	Examination of tools, aggregates, instruments and traces left by them, identification of the whole by parts
	4.3	Forensic examination of vehicles	4.3	Forensic examination of vehicles	4.3	Forensic examination of vehicles
	4.4	Examination of identification numbers and embossed signs	4.4	Examination of identification numbers and embossed signs	4.4	Examination of identification numbers and embossed signs
	4.6	Dactyloscopic examination	4.6	Dactyloscopic examination	4.6	Dactyloscopic examination
Explosion engineering	excluded on the basis of the Order of MJ of Ukraine No. 3819/5 dated September 12, 2022		5.1	Examination of explosives, explosion products and shots	5.1	Examination of explosives, explosion products and shots
	5.2	Examination of explosive devices, traces and circumstances of the explosion	5.2	Examination of explosive devices, traces and circumstances of the explosion	5.2	Examination of explosive devices, traces and circumstances of the explosion
					5.3	Assessment of the possible consequences of the use of explosive devices

Continuation of Table 1.2

1	2	3	4	5	6	7
	5.4	Examination of the circumstances and mechanism of man-made explosions	5.4	Examination of the circumstances and mechanism of man-made explosions	5.4	Examination of the circumstances and mechanism of man-made explosions
					5.5	Assessment of the effects of technical factors of sabotage (terrorist act), other emergency situations
Photo technical, portrait (and holographic images)	6.1	Examination of photographic images and technical means of their production	6.1	Examination of photographic images and technical means of their production	6.1	Examination of photographic images and technical means of their production
	6.2	Identification of a person by appearance based on material images	6.2	Identification of a person by appearance based on material images	6.2	Identification of a person by appearance based on material images
	excluded on the basis of the Order of MJ of Ukraine No. 2117/5 dated June 10, 2021		6.3	Examination of holographic security images and their elements	6.3	Examination of holographic security images and their elements
Video and sound recording	7.1	Technical examination of materials and means of video and sound recording	7.1	Technical examination of materials and means of video and sound recording	7.1	Technical examination of materials and means of video and sound recording
	7.2	Examination of the announcer according to the physical parameters of oral speech, acoustic signals and environments	7.2	Examination of the announcer according to the physical parameters of oral speech, acoustic signals and environments		
	7.3	Linguistic examination of oral speech	7.3	Linguistic examination of oral speech		
					7.4	Examination of voice and oral speech by technical methods
					7.5	Examination of voice and oral speech by linguistic methods

Continuation of Table 1.2

1	2	3	4	5	6	7
Special technical means (hereinafter – STM) of secretly obtaining information					7.6	Examination of STM of surreptitious audio and video control and surveillance of a person, thing or place
					7.7	Examination of STM of covertly removal of information from electronic communication networks, obtaining information about the location of a person or his/her possession, as well as radio equipment (radio-electronic means)
					7.8	Examination of STM of secret penetration into an object by unlocking mechanical locking devices, as well as examination of objects
					7.9	Examination of STM of surreptitious removal of information from electronic information systems, penetration into an object by unlocking electronic security devices, as well as examination of software means of surreptitious information acquisition
Materials, substances and products	8.1	Examination of paint materials and coatings	8.1	Examination of paint materials and coatings	8.1	Examination of paint materials and coatings
	8.2	Examination of polymer materials, plastics and products made from them	8.2	Examination of polymer materials, plastics and products made from them	8.2	Examination of polymer materials, plastics and products made from them

Continuation of Table 1.2

1	2	3	4	5	6	7
	8.3	Examination of fibrous materials and products from them	8.3	Examination of fibrous materials and products from them	8.3	Examination of fibrous materials and products from them
	8.4	Examination of oil products and fuel and lubricants	8.4	Examination of oil products and fuel and lubricants	8.4	Examination of oil products and fuel and lubricants
	8.5	Examination of glass, ceramics and products made from them	8.5	Examination of glass, ceramics and products made from them	8.5	Examination of glass, ceramics and products made from them
	8.6	Examination of narcotic drugs, psychotropic substances, their analogues and precursors	8.6	Examination of narcotic drugs, psychotropic substances, their analogues and precursors	8.6	Examination of narcotic drugs, psychotropic substances, their analogues and precursors
	8.7	Examination of alcohol-containing mixtures	8.7	Examination of alcohol-containing mixtures	8.7	Examination of alcohol-containing mixtures
	8.8	Examination of soils	8.8	Examination of soils	8.8	Examination of soils
	8.9	Examination of metals and alloys and products made from them	8.9	Examination of metals and alloys and products made from them	8.9	Examination of metals and alloys and products made from them
	excluded on the basis of the Order of MJ of Ukraine No. 2117/5 dated June 10, 2021		8.10	Examination of the presence of harmful substances in the environment	8.10	Examination of the presence of harmful substances in the environment
	8.10.1	Examination on the presence of pesticides in the environment			8.10.1	Examination on the presence of pesticides in the environment
	8.11	Examination of substances of chemical production and special chemicals	8.11	Examination of substances of chemical production and special chemicals	8.11	Examination of substances of chemical production and special chemicals
	8.12	Examination of food products	8.12	Examination of food products	8.12	Examination of food products

Continuation of Table 1.2

1	2	3	4	5	6	7
	8.13	Examination of potent and poisonous substances	8.13	Examination of potent and poisonous substances	8.13	Examination of potent and poisonous substances
			8.14	Examination of special chemicals	8.14	Examination of special chemicals
			8.15	Examination of potent and poisonous drugs	8.15	Examination of potent and poisonous drugs
			8.16	Examination of conductors with signs of short circuit	8.16	Examination of conductors with signs of short circuit
			8.17	Examination of the cause of destruction of products made of metals and alloys	8.17	Examination of the cause of destruction of products made of metals and alloys
	8.18	Examination of explosive substances, explosion products (shot)				
Biological	9.1	Examination of objects of plant origin	9.1	Examination of objects of plant origin	9.1	Examination of objects of plant origin
	9.2	Examination of objects of animal origin	9.2	Examination of objects of animal origin	9.2	Examination of objects of animal origin
			9.3	Immunological examination	9.3	Immunological examination
			9.4	Cytological examination	9.4	Cytological examination
	9.5	Molecular-genetic examination	9.5	Molecular-genetic examination	9.5	Molecular-genetic examination
			9.6	Hair examination	9.6	Hair examination
			9.7	Odorological examination		

***IES – indexes of expert specialties, ***TES – types of expert specialties*
**Summarized and systematized by the author using [8–10]*

It should be noted, that under the index of expert specialty 1.2 in the Expert Service of the Ministry of Internal Affairs, the expert specialty “linguistic examination of written speech” is assigned to specialists of research institutions of forensic examinations of the Ministry of Justice of Ukraine, taking into account the order of the Ministry of Justice of Ukraine dated 10.06.2021 No. 2117/5 [11] – “linguistic examination of speech”.

Attention should be paid to the exclusion from the List of the Ministry of Justice of Ukraine of specialties:

– 3.4 "Examination of weapons with a non-kinetic principle of damage" – due to the lack of methods;

– 6.3 "Examination of holographic security images and their elements" – taking into account the lack of orders for this area of research and specialists in the system;

– 8.10 "Examination of the presence of harmful substances in the environment" [11];

– 5.1 "Examination of explosive substances, explosion products and shots" was transferred from explosive technical examination to the examination of materials, substances and products under the expert specialty index 8.18 "Examination of explosive substances, explosion products (shot)" [12].

The aforesaid expert specialties are available in the List of the Ministry of Internal Affairs and the List of the Security Service of Ukraine. In addition, in the specified lists, the type of forensic examination "Photographic, portrait and holographic images" is indicated, according to which, in addition to 6.1 "Examination of photographic images and technical means of their production" and 6.2 "Identification of a person by appearance based on material images", the qualification of a forensic expert is assigned to expert specialty 6.3 "Examination of holographic security images and their elements".

The forensic expert qualification is assigned to specialists of state specialized institutions of 27 expert specialties within the scope of technical engineering examination, according to the List of the Ministry of Justice of Ukraine, the List of the Ministry of Internal Affairs – 26 and the List of the Security Service – 29 (**Table 1.3**). In the technical engineering examination, the expert specialty "Examination of telecommunication systems (equipment) and means" is assigned under the index of expert specialty 10.17 to specialists of research institutions of forensic examinations of the Ministry of Justice of Ukraine and of the Expert Service of the Ministry of Internal Affairs under the type of forensic examination "Telecommunications". At the same time, specialists of the SSU's expert units under the same index are assigned the expert specialty "Examination of electronic communications" (**Table 1.3**) under the type of forensic examination "Electronic Communications".

Table 1.3 Comparison of types (subtypes) of forensic examinations, indexes and types of expert specialties, according to which the qualification of a forensic expert is assigned to specialists of state specialized institutions, within the scope of technical engineering examination*

Types (subtypes) of forensic examinations	RIFE of MJ of Ukraine		Expert service of MIA of Ukraine		Expert service of SSU	
	IES**	TES***	IES**	TES***	IES**	TES***
1	2	3	4	5	6	7
Transport engineering	10.1	Examination of the circumstances and mechanism of traffic accidents	10.1	Examination of the circumstances and mechanism of traffic accidents	10.1	Examination of the circumstances and mechanism of traffic accidents
	10.2	Examination of the technical condition of vehicles	10.2	Examination of the technical condition of vehicles	10.2	Examination of the technical condition of vehicles
	10.3	Examination of vehicle parts	10.3	Examination of vehicle parts	10.3	Examination of vehicle parts
	10.4	Transport and traceological examination	10.4	Transport and traceological examination	10.4	Transport and traceological examination
Life safety	10.5	Examination of the causes and consequences of violation of the requirements of life safety and occupational health and safety	10.5	Examination of the causes and consequences of violation of the requirements of life safety and occupational health and safety	10.5	Examination of the causes and consequences of violation of the requirements of life safety and occupational health and safety
Construction engineering	10.6	Examination of real estate objects, building materials, constructions and relevant documents	10.6	Examination of real estate objects, building materials, constructions and relevant documents	10.6	Examination of real estate objects, building materials, constructions and relevant documents
Land engineering	10.7	Distribution of land and determination of the order of use of land plots	10.7	Distribution of land and determination of the order of use of land plots	10.7	Distribution of land and determination of the order of use of land plots

Continuation of Table 1.3

1	2	3	4	5	6	7
Fire engineering	10.8	Examination of the circumstances of the occurrence and spread of fires and compliance with fire safety requirements	10.8	Examination of the circumstances of the occurrence and spread of fires and compliance with fire safety requirements	10.8	Examination of the circumstances of the occurrence and spread of fires and compliance with fire safety requirements
Computer	10.9	Examination of computer technology and software products	10.9	Examination of computer technology and software products	10.9	Examination of computer technology and software products
Construction assessment	10.10	Determination of the estimated value of construction objects and structures	10.10	Determination of the estimated value of construction objects and structures	10.10	Determination of the estimated value of construction objects and structures
Railway	10.11	Examination of the circumstances and mechanism of the railway accident	10.11	Examination of the circumstances and mechanism of the railway accident	10.11	Examination of the circumstances and mechanism of the railway accident
	10.12	Examination of the technical condition of the rolling stock of railway transport	10.12	Examination of the technical condition of the rolling stock of railway transport	10.12	Examination of the technical condition of the rolling stock of railway transport
	10.13.1	Examination of the engineering equipment of the upper structure of the track	10.13.1	Examination of the engineering equipment of the upper structure of the track	10.13.1	Examination of the engineering equipment of the upper structure of the track
	10.13.2	Examination of the engineering equipment of the lower structure of the track	10.13.2	Examination of the engineering equipment of the lower structure of the track	10.13.2	Examination of the engineering equipment of the lower structure of the track
Land assessment	10.14	Assessment of plots	10.14	Assessment of plots	10.14	Assessment of plots
Mining engineering	10.15	Examination of the causes and consequences of emergencies in the mining industry and in underground conditions	10.15	Examination of the causes and consequences of emergencies in the mining industry and in underground conditions	10.15	Examination of the causes and consequences of emergencies in the mining industry and in underground conditions

Continuation of Table 1.3

1	2	3	4	5	6	7
Road engineering	10.16	Road examination	10.16	Road examination	10.16	Road examination
Telecommunication	10.17	Examination of telecommunication systems (equipment) and means	10.17	Examination of telecommunication systems (equipment) and means		
Electronic communications					10.17	Examination of electronic communications
					10.17.1	Determination of the geolocation of an electronic device
Electric engineering	10.18	Examination of technical operation of electrical equipment	10.18	Examination of technical operation of electrical equipment	10.18	Examination of technical operation of electrical equipment
Environmental engineering	10.19	Examination of the circumstances and organizational and technical causes and consequences of the impact of man-made sources on environmental objects	10.19	Examination of the circumstances and organizational and technical causes and consequences of the impact of man-made sources on environmental objects	10.19	Examination of the circumstances and organizational and technical causes and consequences of the impact of man-made sources on environmental objects
Land management	10.20	Examination on land management issues	10.20	Examination on land management issues	10.20	Examination on land management issues
Electric transport	10.21	Examination of urban electric transport	10.21	Examination of urban electric transport	10.21	Examination of urban electric transport
Technical condition of elevators	10.22	Examination of the technical condition of elevators and the conditions of their safe operation	10.22	Examination of the technical condition of elevators and the conditions of their safe operation	10.22	Examination of the technical condition of elevators and the conditions of their safe operation
Mechanical engineering	10.23	Examination of the technical condition and operating conditions of machines and mechanisms	10.23	Examination of the technical condition and operating conditions of machines and mechanisms	10.23	Examination of the technical condition and operating conditions of machines and mechanisms

Continuation of Table 1.3

1	2	3	4	5	6	7
Water engineering	10.24	Examination of accidents on water transport				
Avia-engineering	10.25	Examination of aviation accidents and incidents				
Radio equipment (radio-electronic means					10.26	Examination of radio equipment (radio-electronic means) of information reception, processing and transmission
Water transport			10.27	Examination of the technical condition of shipping facilities and individual components, crew actions, radar maintenance	10.27	Examination of the technical condition of shipping facilities and individual components, crew actions, radar maintenance
Air transport			10.28	Examination of the technical condition of aircraft and individual components, actions of aviation personnel, aeronautical flight support	10.28	Examination of the technical condition of aircraft and individual components, actions of aviation personnel, aeronautical flight support
Technological engineering of critical infrastructure facilities					10.29	Examination of critical infrastructure facilities
Heat engineering	10.30	Heat engineering examination				

***IES – indexes of expert specialties, ***TES – types of expert specialties*
**Summarized and systematized by the author using [8–10]*

It should be noted, that certain types of forensic examinations are indicated only in the SSU List, namely:

– “Electronic communications”, according to which expert specialties 10.17 “Electronic communications examination” and 10.17.1 “Determination of the geolocation of an electronic device” are assigned;

– “Radio equipment (radio-electronic means)”, according to which the expert specialty “Examination of radio equipment (radio-electronic means) of reception, processing and transmission of information” is assigned under the index 10.26;

– “Technological Engineering of critical infrastructure objects”, according to which the expert specialty “Examination of critical infrastructure objects” is assigned under the index 10.29.

At the same time, some types of examination are mentioned only in the List of the Ministry of Justice of Ukraine, namely:

– "Water engineering", according to which the expert specialty "Examination of accidents on water transport" is assigned under the index 10.24;

– "Avia-engineering", according to which the expert specialty 10.25 "Examination of aviation accidents and incidents" is assigned;

– "Heat engineering" for which the expert specialty 10.30 "Heat engineering examination" is assigned.

So, as regards the "Economic", "Transport and Commodity" examinations, "Military Property" the indexes and types of expert specialties, specified in the investigated Lists for these types of examinations, coincide (**Table 1.4**).

It should be noted, that the expert specialty 12.1.1 "Examination of gaming equipment" is indicated only in the List of the SSU.

The forensic expert qualification is assigned to specialists of state specialized institutions of 9 expert specialties within the scope of examination in the field of intellectual property, according to the List of the Ministry of Justice of Ukraine, the List of the Ministry of Internal Affairs – 11 and the List of the Security Service – 11 (**Table 1.5**). It should be noted, that only in the List of the Ministry of Justice of Ukraine there is no such type of forensic examinations "Topographies of integrated microcircuits".

According to the List of the Security Service of Ukraine and the List of the Ministry of Internal Affairs, the expert specialty 13.7 "Examination related to the topographies of integrated microcircuits" (**Table 1.5)** is assigned to the specified type.

In the List of the Ministry of Justice of Ukraine, unlike the List of the Ministry of Internal Affairs and the List of the Security Service of Ukraine, there is also no expert specialty 13.5.2 "Examination related to animal breeds". As to the "Psychological", "Military", "Historical-archaeological" examination, the indexes and types of expert specialties, indicated in the investigated Lists, coincide (**Table 1.6**).

Table 1.4 Comparison of types (subtypes) of forensic examinations, indexes and types of expert specialties, according to which the qualification of a forensic expert is assigned to specialists of state specialized institutions, within the limits of economic and commodity examination*

Types (subtypes) of forensic examinations	RIFE of MJ of Ukraine		Expert service of MIA of Ukraine		Expert service of SSU	
	IES**	TES***	IES**	TES***	IES**	TES***
Economic	11.1	Examination of accounting, tax accounting and reporting documents	11.1	Examination of accounting, tax accounting and reporting documents	11.1	Examination of accounting, tax accounting and reporting documents
	11.2	Examination of documents on the economic activity of enterprises and organizations	11.2	Examination of documents on the economic activity of enterprises and organizations	11.2	Examination of documents on the economic activity of enterprises and organizations
	11.3	Examination of documents of financial and credit operations	11.3	Examination of documents of financial and credit operations	11.3	Examination of documents of financial and credit operations
Commodity	12.1	Determination of the cost of machines, equipment, raw materials and consumer goods	12.1	Determination of the cost of machines, equipment, raw materials and consumer goods	12.1	Determination of the cost of machines, equipment, raw materials and consumer goods
					12.1.1	Examination of gaming equipment
Transport and commodity	12.2	Determination of the cost of wheeled vehicles and the amount of damage caused to the owner of the vehicle	12.2	Determination of the cost of wheeled vehicles and the amount of damage caused to the owner of the vehicle	12.2	Determination of the cost of wheeled vehicles and the amount of damage caused to the owner of the vehicle
	12.3	Assessment of shipping facilities	12.3	Assessment of shipping facilities	12.3	Assessment of shipping facilities
	12.4	Assessment of aircraft	12.4	Assessment of aircraft	12.4	Assessment of aircraft
Military property	12.5	Assessment of weapons and property and equipment for military purposes	12.5	Assessment of weapons and property and equipment for military purposes	12.5	Assessment of weapons and property and equipment for military purposes

***IES – indexes of expert specialties, ***TES – types of expert specialties*
**Summarized and systematized by the author using [8–10]*

Table 1.5 Comparison of types (subtypes) of forensic examinations, indexes and types of expert specialties, according to which the qualification of a forensic expert is assigned to specialists of state specialized institutions, within the scope of examination in the field of intellectual property*

Types (subtypes) of forensic examinations	RIFE of MJ of Ukraine		Expert service of MIA of Ukraine		Expert service of SSU	
	IES**	TES***	IES**	TES***	IES**	TES***
1	2	3	4	5	6	7
Literary and artistic works	13.1.1	Examination related to literary, artistic works, and others	13.1.1	Examination related to literary, artistic works, and others	13.1.1	Examination related to literary, artistic works, and others
	13.1.2	Examination related to computer programs and data compilations (databases)	13.1.2	Examination related to computer programs and data compilations (databases)	13.1.2	Examination related to computer programs and data compilations (databases)
Phonograms, videograms, programs (broadcasts) of broadcasting organizations	13.2	Examination related to performances, phonograms, videograms, programs (broadcasts) of broadcasting organizations	13.2	Examination related to performances, phonograms, videograms, programs (broadcasts) of broadcasting organizations	13.2	Examination related to performances, phonograms, videograms, programs (broadcasts) of broadcasting organizations
Inventions and utility models	13.3	Examination related to Inventions and utility models	13.3	Examination related to Inventions and utility models	13.3	Examination related to Inventions and utility models
Industrial samples	13.4	Examination related to industrial samples	13.4	Examination related to industrial samples	13.4	Examination related to industrial samples

Continuation of Table 1.5

1	2	3	4	5	6	7
Plant varieties	13.5.1	Examination related to plant varieties	13.5.1	Examination related to plant varieties	13.5.1	Examination related to plant varieties
			13.5.2	Examination related to animal breeds	13.5.2	Examination related to animal breeds
Commercial (brand) names, trademarks (marks for goods and services), geographical indications	13.6	Examination related to commercial (brand) names, trademarks (marks for goods and services), geographical indications	13.6	Examination related to commercial (brand) names, trademarks (marks for goods and services), geographical indications	13.6	Examination related to commercial (brand) names, trademarks (marks for goods and services), geographical indications
Topographies of integrated microcircuits			13.7	Examination related to topographies of integrated microcircuits	13.7	Examination related to topographies of integrated microcircuits
Commercial secrets (know-how) and innovative proposals	13.8	Examination related to commercial secrets (know-how) and innovative proposals	13.8	Examination related to commercial secrets (know-how) and innovative proposals	13.8	Examination related to commercial secrets (know-how) and innovative proposals
Economic in the field of intellectual property	13.9	Economic examination in the field of intellectual property	13.9	Economic examination in the field of intellectual property	13.9	Economic examination in the field of intellectual property

***IES – indexes of expert specialties, ***TES – types of expert specialties*
**Summarized and systematized by the author using [8–10]*

Table 1.6 Comparison of types (subtypes) of forensic examinations, indexes and types of expert specialties, according to which the qualification of a forensic expert is assigned to specialists of state specialized institutions, within the limits of psychological, art, military, gemological, veterinary, historical and archaeological examination*

Types (subtypes) of forensic examinations	RIFE of MJ of Ukraine		Expert service of MIA of Ukraine		Expert service of SSU	
	IES**	TES***	IES**	TES***	IES**	TES***
Psychological	14.1	Psychological examination	14.1	Psychological examination	14.1	Psychological examination
Art	15.1	Art examination	15.1	Art examination	15.1	Art examination
			15.2	Examination in the field of protection of public morals	15.2	Examination in the field of protection of public morals
Military	16.1	Military examination	16.1	Military examination	16.1	Military examination
Gemological	17.1.1	Examination of precious stones	17.1	Examination of precious, semi-precious and decorative stones	17.1	Examination of precious, semi-precious and decorative stones
	17.1.2	Examination of diamonds				
	17.1.3	Examination of precious stones of organogenic origin				
	17.1.4	Examination of semi-precious stones				
	17.1.5	Examination of decorative stones				
Veterinary	18.1	Veterinary examination			18.1	Veterinary examination
Historical and archeological	19.1	Historical and archeological examination of plots	19.1	Historical and archeological examination of plots	19.1	Historical and archeological examination of plots

***IES – indexes of expert specialties, ***TES – types of expert specialties*
**Summarized and systematized by the author using [8–10]*

As for the forensic art examination, the expert specialty 15.2 “Examination in the field of protection of public morals” is mentioned in the List of the Security Service of Ukraine and the List of the Ministry of Internal Affairs. Specialists of research institutes of forensic examinations of the Ministry of Justice of Ukraine do not conduct research in this direction (**Table 1.6**).

The forensic expert qualification is assigned to specialists of state specialized institutions of 5 expert specialties within the limits of gemological examination, according to the List of the Ministry of Justice of Ukraine, the List of the Ministry of Internal Affairs – 1 and the List of the Security Service of Ukraine – 1 (**Table 1.6**). Attention should be paid to such a type of forensic examination as “Gemological”.

According to the List of the Security Service of Ukraine and the List of the Ministry of Internal Affairs, the expert specialty "Examination of precious, semi-precious and decorative stones" is assigned under the index 17.1. Instead, the List of the Ministry of Justice of Ukraine mentions five types of expert specialties under indexes different from the above, namely: 17.1.1 "Examination of precious stones", 17.1.2 "Examination of diamonds", 17.1.3 "Examination of precious stones of organogenic origin", 17.1.4 "Examination of semi-precious stones", 17.1.5 "Examination of decorative stones" (**Table 1.6**).

In the List of the Ministry of Internal Affairs, there is no such type of forensic examinations as "Veterinary". According to the List of the SSU and the List of the Ministry of Justice of Ukraine, the expert specialty 18.1 "Veterinary examination" is assigned to this type (**Table 1.6**).

Forensic experts who do not work in state specialized expert institutions conduct expert research within 26 types (subtypes) of forensic examination (transport engineering; life safety; construction engineering; land engineering; fire engineering; computer; construction assessment; railway; land assessment; mining engineering; road engineering; telecommunications; electrical engineering; environmental engineering; land management; electric transport; technical condition of elevators; economic; commodity science; transport-commodity science; military property; intellectual property (literary and artistic works; phonograms, videograms, programs (broadcasts) of broadcasting organizations; inventions and utility models; industrial samples; plant varieties; commercial (brand) names, trademarks (marks for goods and services), geographical specifications, commercial secrets (know-how) and innovative proposals; economic in the field of intellectual property; psychological; art; gemological; veterinary) according to 48 expert specialties, assigned to them after training and certification in accordance with the Regulation on expert qualification commissions and certification of court experts, approved by order of the Ministry of Justice of Ukraine [8].

Attention should be paid to the fact that the Law stipulates that only state specialized institutions carry out forensic expert activities related to the conduct of forensic, forensic medical and forensic psychiatric examinations [13].

Therefore, in Ukraine, there is a monopoly on conducting forensic, forensic medical and forensic psychiatric examinations only by experts of state specialized institutions, which leads to criticism, since the dependence of expert institutions on the departments, in the structure of which they are located, and in general, in high-profile cases, even on political will of the parliamentary-government majority, results in the fact that judicial practice often received and receives biased opinions of experts, which usually cover up abuse or negligence, which was repeatedly established by the European Court of HR in applications against Ukraine [14].

O. Kaluzhna comes to the conclusion that due to corporate and political interests, not excluding the corruption component and abuse of office, the state judicial expert monopoly needs to be revised [14]. Other scientists also claim similar observations regarding "custom", biased conclusions, which court decisions are based on [15].

The sphere of activity of private forensic experts should be expanded – they should be given the right to conduct forensic examinations, which they do not currently have the right to conduct. This will create greater competition between the public and private sectors, improve the quality of expert examination, reduce the time, needed to conduct it, relieving the burden on state forensic expert institutions.

Thus, the most complete is the List of the main types of forensic examinations and expert specialties, according to which the qualification of a forensic expert is assigned to specialists of the expert units of the SSU (**Fig. 1.1**).

It should also be mentioned the List of the main types of forensic examinations and expert specialties, according to which the qualifications of a forensic expert are assigned to specialists of the Main Expert Forensic Center of the State Border Service of Ukraine [16], which specifies one type of forensic examinations – technical examination of documents and outlines three types of expert specialties:

– examination of document details (expert specialty index 2.1);

– examination of document materials (expert specialty index 2.1);

– examination of printing forms and other means of producing documents (expert specialty index 2.3).

In addition, the qualifications of a forensic expert are assigned to employees of institutions that conduct forensic medical examinations in the following specialties: forensic medical examination, forensic histology, forensic toxicology, forensic immunology, forensic cytology, forensic criminology [17, 18]. The qualification of a forensic expert and qualification classes are also assigned for forensic psychiatric experts [19].

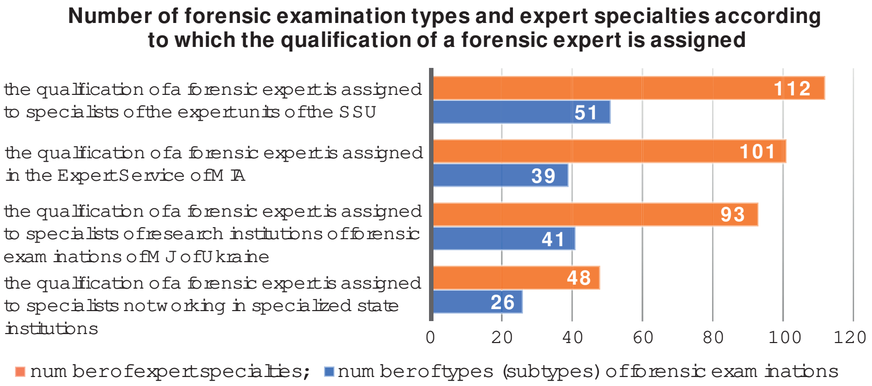

Fig. 1.1 The number of types of forensic examination and expert specialties, according to which the qualification of a forensic expert is assigned [8–10]

The existing classification of forensic examinations by the fields of special knowledge, used in their conduct, is outdated and does not meet modern requirements. This creates difficulties not only for forensic experts and persons who wish to become them, but also for the court, participants in the legal process, and all citizens who are interested in obtaining the opinion of a forensic expert. After all, there is a need to determine the type of expert examination or check the conformity of the type of examination, indicated in the conclusion, with the type that was specified in the decision on the involvement of an expert and the assignment of the examination; compliance of the expert's specialty with the type of forensic examination, conducted by him/her; conformity of the questions, posed to the expert and the conclusions, drawn to the subject of the type of examination that was assigned and conducted, as well as the specialty of the expert; compliance by experts with various specialties of their competence when conducting a comprehensive examination, etc. The classification of forensic examinations is related to cases where an expert goes beyond the limits of his/her specialty.

It is appropriate to pay attention to the fact that currently 17 working groups are working effectively in the European Network of Forensic Science Institutes (hereinafter – ENFSI), consisting of experts of a specific expert specialty: traces of animals, plants and soil; digital image; DNA; documents; drugs; explosive substances; fingerprint; firearms/shot marks; examination of fires and explosions; forensic information technologies; forensic speech examination and audio analysis; handwriting; labels; paint, glass and labels; analysis of traffic accidents; crime scene; textiles and hair [20].

Innovative technologies were of significant importance in the formation and development of forensic expert activity. In order to be adequate to modern risks, challenges and threats in the field of security of citizens, legal entities and the state, forensic expert activity integrates the latest achievements of science and technology. That is why the demarcation of forensic examinations by fields of special knowledge or other criteria cannot be exhaustive in connection with the rapid scientific and technical progress, the constant introduction of innovative technologies in the field of forensic examinations, and the systematic development of new methods and methodologies. This gives reason to predict the emergence of new expert specialties, types and subspecies, kinds, and classes of forensic examinations. The existing classification can be supplemented with new types, kinds and even classes of forensic examinations as new private scientific directions are elaborated and the practice of expert examination develops.

1.7 Conclusions and prospects for further development in this direction

According to the results of the conducted research, it should be noted, that there is a discrepancy between the types of forensic examination and expert specialties according to which the qualification of a forensic expert is assigned in the departmental lists. This leads to misunderstanding of the correspondence of expert specialties and their demarcation by customers of expert examinations.

Without the unification of the interdepartmental approach to the classification of forensic examinations, it is difficult to avoid errors that can cause the issuance of illegal and unfounded court decisions. The problem of unification can be solved by working out a general approach to the classification of kinds and types of forensic examinations with consolidation in an interdepartmental normative act, which should be based on the criteria of the general theory of forensic examination. The creation of a modern unified list of types of forensic examinations and their corresponding expert specialties, according to which the qualification of a forensic expert is assigned, can be considered as a strategic task, which, if successfully implemented, can open the way to solving many issues facing the expert community.

Expanding the sphere of activity of private forensic experts by giving them the right to conduct those forensic examinations, which they do not have the right to conduct today, will allow to create greater competition between the public and private sectors, improve the quality of expert examination, shorten the terms of their conduct, relieving the burden on state forensic expert institutions.

Taking into account the fact that it is currently planned to provide opinions by experts in electronic form, the creation of a forensic expert's office and its integration with the Unified Judicial Information and Telecommunication System (UJITS), the creation of a modern unified list of types of forensic examinations and their corresponding expert specialties, according to which the qualification of a forensic expert is assigned, is on the agenda.

The role of forensic examination continues to grow in the system of legal regulation and law enforcement in society. With the emergence of new social relations, production technologies and spheres of consumption, the informational field of proof for all categories of cases is constantly expanding and becoming more complicated. The level of development of science, engineering and technology in general, the constant exponential growth and complication of scientific information, the processes of integration and differentiation of scientific knowledge are of key importance for forensic expert activity. The appearance of new objects that did not exist before, or were transformed from already existing ones, as a result of the application of innovative technologies, contributes to the discovery of new properties and the manifestation of new signs of these properties, which, in turn, leads to the emergence of new expert specialties, types and subtypes, kinds, classes of forensic examinations.

Conflict of interest statement

The authors declare that there is no conflict of interest in relation to this paper, as well as the published research results, including the financial aspects of conducting the research, obtaining and using its results, as well as any non-financial personal relationships.

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CHAPTER 2

Recognition of images of blood cells using texture and neural networks to diagnose leukemia

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Abstract

Analysis of white blood cells from blood can help to detect Acute Lymphoblastic Leukemia, a potentially fatal blood cancer if left untreated. The morphological analysis of blood cells images is typically performed manually by an expert; however, this method has numerous drawbacks, including slow analysis, low precision, and the results depend on the operator's skill.

We have developed and present here an automated method for the identification and classification of white blood cells using microscopic images of peripheral blood smears. Once the image has been obtained, we propose describing it using brightness, contrast, and micro-contour orientation histograms. Each of these descriptions provides a coding of the image, which in turn provides *n* parameters. The extracted characteristics are presented to an encoder's input. The encoder generates a high-dimensional binary output vector, which is presented to the input of the neural classifier.

This paper presents the performance of one classifier, the Random Threshold Classifier. The classifier's output is the recognized class, which is either a healthy cell or an Acute Lymphoblastic Leukemia-affected cell. As shown below, the proposed neural Random Threshold Classifier achieved a recognition rate of 98.3 % when the data has partitioned on 80 % training set and 20 % testing set for.

Our system of image recognition is evaluated using the public dataset of peripheral blood samples from Acute Lymphoblastic Leukemia Image Database. It is important to mention that our system could be implemented as a computational tool for detection of other diseases, where blood cells undergo alterations, such as Covid-19.

 DOI: 10.21303/978-9916-9850-2-1.ch2

Keywords
Image processing, segmentation of microscopic images, cell analysis, detection of white blood cells, leukemia classification, neural classifiers.

2.1 Introduction

Artificial Intelligence (AI) is currently used in a wide variety of fields, including the medical field. With the aid of various AI techniques, specialized software for the early diagnosis of diseases can be developed [1–3].

In this study AI techniques are applied to analyze and recognize images captured by a microscope of human peripheral blood smear samples. A tool will be developed using computer vision and neural networks to help detect possible changes in the size and shape of the different blood cells, with a focus on lymphocytes, for the detection of Acute Lymphoblastic Leukemia (ALL) [4]. This tool could be used for the detection of other diseases, where there are changes in the morphology of blood cells, for example, the analysis of peripheral blood offers valuable information in the hematology diagnostic process. The morphological assay can add information about the pathophysiology of COVID-19 disease and its progression. In this type of analysis, hematological abnormalities that occur in patients affected by severe viral pneumonia with clinical consequences that can end in multiple organ failure were detected [5–8].

A normal blood consists of three main components: red blood cells (erythrocytes), white blood cells (WBC) or leukocytes, and platelets. Leukocytes are easily distinguishable due to the fact that their nuclei are darker than the background. Granulocytes are leukocytes containing granules, including neutrophils, basophils, and eosinophils. Cells without granules are called mononuclear and include lymphocytes and monocytes, **Fig. 2.1, *a***. The percentage of lymphocytes in human blood ranges from 20 % to 45 %, and their size ranges from 7 to 15 micrometers. They are distinguished by a round nucleus and poor cytoplasm. ALL affects a group of leukocytes called lymphocytes and is caused by the excessive production of immature white blood cells called lymphoblasts (also known as blastic cells), which inhibit the production of normal white blood cells. L1, L2, L3 are three classes of lymphoblasts shown in the **Fig. 2.1, *b***. In detail we will describe this lymphoblasts classification and the image database in paragraph 2.4. ALL lymphoblasts are characterized by additional morphological alterations that exacerbate the severity of the disease. In particular, lymphocytes have a regular shape and a compact nucleus with regular and continuous borders. In contrast, lymphoblasts have an irregular shape and contain small cavities in the cytoplasm, called vacuoles, and spherical particles within the nucleus, called nucleoli [9]. Leucocyte classification for leukemia detection using Image Processing Techniques (IPT) was proposed in [10].

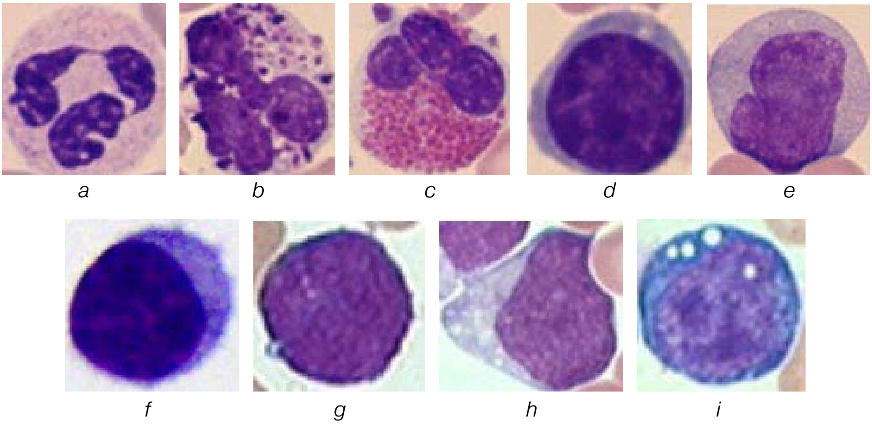

Fig. 2.1 White blood cells (leukocytes): *a*–*e* comparison between various white blood cell types, including neutrophils, basophils, eosinophils, lymphocytes, and monocytes; *f*–*i* comparison between lymphocytes with ALL: a healthy lymphocyte followed by lymphoblasts classified as L1, L2, and L3, respectively [4]

Cells in human blood can be counted using image processing techniques, which at the same time may provide information on cell morphology. A system for the automatic detection of ALL-affected cells is first based on image acquisition using a camera attached to a microscope. Then the image is subjected to preprocessing or image enhancement to eliminate noise or any factor that may interfere with the performance of the subsequent stages. And finally, the segmentation process starts, which consists of dividing an image into its constituent regions or objects. The most challenging task in image processing is the segmentation of complex images, such as blood cells, due to their complex nature and overlapping of these cells. Then from each cellular component, different characteristics, such as shape, color, and/or texture as well as their combinations, most of which are problem-specific, are extracted, and the classifier will detect ALL-affected lymphocytes or not from this data.

Various algorithms have been proposed for separating leukocytes and erythrocytes, as well as their classification as normal or abnormal, based on certain morphological characteristics of the cells, including the analysis of the nucleus in the case of leukocytes. The problem of white blood cell identification and classification is focused in [11]. The proposed system first separates leukocytes from other blood cells in the blood image, then extracts morphological indices, and finally classifies the leukocytes using a neural classifier.

To improve the image, low-pass, and band-pass filters are applied to reduce noise if they do not have good illumination [12]. The authors focus on the segmentation process of blood images to extract significant parts or regions of interest and propose an intuitionistic fuzzy set approach for optimal threshold selection based on histogram calculations. This method is then extended to perform multiple thresholding to account for possible local variations in the image. The proposed method is evaluated on peripheral blood images to subdivide the various image components, where excellent segmentation and speed performance are demonstrated.

Using active contour models that are initialized with morphological operators, cells are segmented in [13]. Functions based on shape and texture are used for classification. Different classifiers are employed, such as K-nearest neighbors, learning vector quantization, multilayer perceptron and support vector machine. This automated differential blood counter system employs statistical and neural network-based classification methods to try to perform Differential Blood Count (DBC) automatically.

An effective technique for automatically segmenting blood cell nuclei is described in [14]. The technique is based on the enhancement and filtering of grayscale contrast. A minimum segment size is implemented to eliminate false objects. The technique is evaluated using 365 blood images. The segmentation performance is evaluated quantitatively as 79.7 % on the test set. Each of the five normal white blood cell types is evaluated individually to compare performance. The lowest segmentation precision is for eosinophils at 69.3 %, and the highest is for monocytes at 86.3 %.

A very detailed review of the different proposals reported in the literature on methods of segmentation, extraction of characteristics, and classification of white blood cells or leukocytes is presented in [15].

There is paper that focuses on white blood cell nucleus segmentation, which separates the nucleus from the cell body by utilizing a combination of automatic contrast stretching supported by arithmetic image operations, minimal filtering, and global thresholding techniques [16].

An image processing technique for automatic blast number counting is proposed in [17]. Using segmentation based on the HSV color space, white blood cells (WBC) are extracted from the background. A simple morphological operator, such as erosion, plays a crucial role, particularly for overlapping cells.

Various segmentation techniques, such as, Hough transform, thresholding techniques, boundary-based segmentation, and region-based segmentation, have been proposed to achieve efficient and accurate results [18–20].

A method for segmenting color images is demonstrated in [21]. Color images provide a more accurate description of a scene than grayscale images because they are a richer source of information.

A system was proposed in which the first separates the leukocytes from the other blood cells was made, then the lymphocytes (cells of interest to detect acute leukemia) were selected, the morphological indices of those cells were evaluated, and the presence of leukemia finally was classified, the morphological indices in three steps: processing first the membrane, then the cytoplasm and finally the nucleus were extracted [22].

An instrument for segmenting and identifying red and white blood cells from an image was provided [23]. This project used color-based segmentation with $L^*a^*b^*$ (CIELAB) color space to perform segmentation. In this work, the accuracy ranges from 64 % to 87 % depending on the type of processing used and the type of cells being extracted.

Tests on public datasets for leukemia detection, SMC-IDB, IUMS-IDB, and ALL-IDB, were conducted and achieved an ALL-classification accuracy of 94.1 % [24]. This research implements image processing techniques to automate the counting and classification of blood cells, specifically white blood cells, as leukemia-affected or not. To better visualize the leukocytes in a blood image, they perform image preprocessing, implement an algorithm that provides useful information about the location of candidate leukocytes, and segment the image into regions of interest using Otsu's algorithm and the watershed algorithm. Then, the characteristics extraction was performed using a convolutional neural network (CNN) that had been pre-trained, followed by binary classification (ALL-affected and unaffected leukocytes) using a linear support vector machine. One of the ways to increase the accuracy and speed of recognition algorithms is to use a convolutional neural network (CNN). It was introduced a CNN in conjunction with a Kohonen network, the first to provide the system with the ability to detect and recognize objects and the second to find areas of interest. The combination of the above methods allows to speed up the process of searching and recognizing objects in images [25, 26].

There are different proposals to detect ALL using different artificial intelligence methodologies. They use the ALL-IDB database [27]. This database is popular to compare different methods and algorithms. We will analyze the results that were obtained with this image database.

There was proposed and developed the algorithms using image segmentation and data mining algorithms and showed the classification of the acute lymphoblastic leukemia into its three respective categories namely: L1, L2, L3, achieved an overall accuracy of 98.6 % [28]. The segmentation process is automatic using K-medoids algorithm, they extracted the cytoplasm from the images without involving manual cropping procedure. Their approach is based on extracting shape, visual and texture features like area cytoplasm, area nucleus, nucleus-cytoplasm relation, size of the blast, vacuoles, entropy and contrast of the image, among others. For classification and prediction, the Random Forest (RF) algorithm presented the best results [28].

It was used fuzzy c-means (FCM) clustering for nuclei segmentation [29]. They extracted, five geometrical features (area, perimeter, solidity, eccentricity and extent) and, 36 statistical features (mean, standard deviation, energy, entropy, skewness and kurtosis) are calculated from the image histogram of the red, green and blue, plus the hue, saturation and enhanced value channels from the pixels located in nuclei, respectively. In this way they obtained 41 components and selected 13 of the best features. For the classification of L1, L2, L3, normal, reactive and atypical cells, RF classifier was applied and result was in 98 % accuracy. They propose in the future, in addition of nuclei, segmentation of cytoplasm and extraction its features to improve accuracy of their system [29].

It was proposed a hybrid model based on deep convolutional neural networks (CNNs) and a deep residual network named ResNet-50 V2 [30], to predict ALL. They trained the deep residual network using the optimized hyperparameters by genetic algorithms (GA), reaching higher performance against approaches without optimization and optimization using random search and Bayesian algorithms [31]. The results show that the GA optimization improves the accuracy of the classifier, obtaining 98.46 %.

A novel deep learning framework (DLF) based on convolution neural network was proposed [32]. The authors did two experiments: in one of them they obtained 98.62 % when the data has been partitioned on training and testing sets as 80 % and 20 %, and in the second experiment they obtained 97.73 % when the data has been partitioned as training and testing images as 60 % and 40 %.

It was proposed an improved Adaptive Network-Based Fuzzy Inference Systems (ANFIS) model to predict leukemia data using an Euclidean distance to measure between the trained feature data and the test feature data [33]. An Improved Adaptive Neuro-Fuzzy Neural Network (ANFNN) is also introduced, which helps the input space be partitioned into many local regions by the fuzzy clustering, in which the computation complexity is decreased and, based on both the separation and the compactness among the clusters, the fuzzy rule number is determined by the validity function. Improved ANFIS obtained the best accuracy of 97.14 %.

Classification of white blood cells into healthy and unhealthy using Support Vector Machine (SVM) learning model was presented in [34]. Image features are extracted with transfer learning approach of deep convolutional neural network using AlexNet pretrained model. AlexNet is an eight layered convolutional neural network. This model is introduced by Alex Krizhevsky at University of Toronto in 2010 [35]. This approach validates the process of discriminating white blood cells into healthy and acute lymphoblastic leukemia affected unhealthy cells with 96.15 % of accuracy.

A computer-aided automated diagnosis system for detection of acute lymphoblastic leukemia (ALL) using deep-learning models is discussed in [36]. A pretrained AlexNet model is deployed for performing this task. The work implemented in this paper does not require any preprocessing, the raw image is fed in this model for performing both feature extraction and classification task. This proposed method achieves an accuracy of 98 %.

A micro-pattern descriptor, called Local Directional Number Pattern (LDNP) along with Multi-scale Weber Local Descriptor (MWDT) for feature extraction task to determine cancerous and noncancerous blood cells are discussed and presented in [37].

It was applied different individual and combined feature extraction methods, and fed into the machine learning classifiers (Decision Tree, Ensemble, K-Nearest Neighbors, Naive Bayes, and RF) and presented an average classification accuracy 97.69 % using Ensemble classifier.

We can summarize the introduction with a conclusion regarding the relevance of this issue, based on a review of tasks, approaches and methods for medical image recognition and classification. The task of medical images recognition is actual and important.

2.2 Materials and methods

Currently, there are various approaches and methods to solve the task of medical images recognition which are closer to our approach.

The k-means clustering algorithm for segment the images. Based on the colour, texture and shape the image pixels are grouped as three clusters. The texture features were extracted as Grey Level Co-Occurrence Matrix (GLCM) and Local Binary Pattern (LBP) are used in [38]. Support vector machine (SVM) with Gaussian radial basis function (RBF) as kernel is used for classification. They obtained an accuracy of 95.3 % for ALL-IDB2 database.

So, last years' active attention of scientists and engineers is attracted to the problem of automatic recognition and classification of blood cells for different types of diseases. Analysis of WBC from blood can help to detect ALL, COVID-19 disease or other illness.

We have proposed an automated method for the identification and classification of white blood cells using microscopic images of peripheral blood smears and neural Random Threshold Classifier (RTC).

The first application of the RTC for medical image recognition was realized for Chagas recognition [1, 39]. Chagas disease is caused by the *Trypanosoma cruzi* parasite and affects both humans and domestic animals, and the vector for introduction into the human body is a bedbug. This insect usually lives in gardens, jungles and especially on thatched roofs and dirt floors. In **Fig. 2.2, *a*** we present the sample of infected tissue.

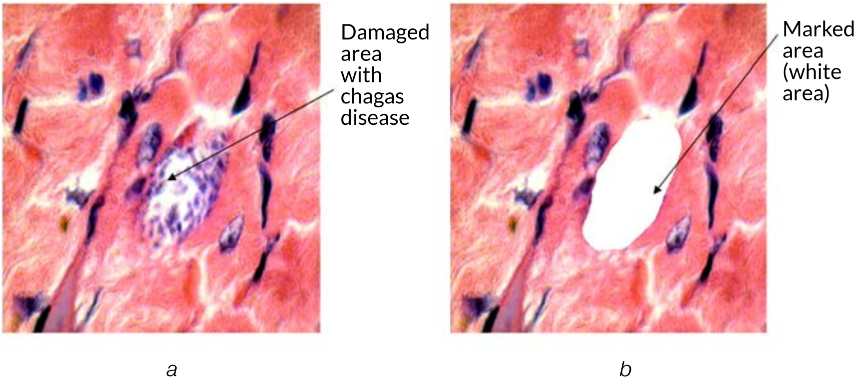

Fig. 2.2 Tissue with Chagas: *a* – infected tissue; *b* – marked image

At our disposal we have a set of 10 images with tissue damaged by Chagas disease in BMP format (Bitmap) with a resolution of 533×400 pixels and a size of 625 KB.

As inputs for our neural RTC classifier we used texture features. Texture features algorithm was developed on the base of calculation of histograms of brightness (analysis of every pixel), contrast (analysis of two adjacent horizontal or vertical pixels and calculation of their brightness differences), and contour orientations (analysis of four, 9 or 16 adjacent pixels). The orientation of contours on the image can be calculated with help of Schwartz (Paragraph 2.2.1), Sobel, or Roberts algorithms [40, 41]. On the base of these results, we can calculate histograms of contour orientations.

The training and validation of the system was carried out using a base of 10 images: 5 of which were used for training and 5 were used for recognition. The best recognition percentage was 97.54 %.

2.2.1 Calculation of the contour orientation on an image

To calculate the orientation of contours in the image, we used the algorithm, based on Schwartz's [40] patent for analogous electronic schematics. We have adapted his proposal for computer calculations.

This algorithm works on square arrays of four adjacent pixels whose brightness is known (**Fig. 2.3**).

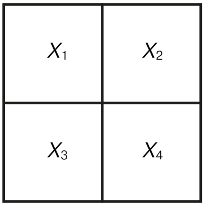

Fig. 2.3 Four pixels for analysis

The algorithm has several steps:

1. We choose four pixels. Each value from $X1$ to $X4$ corresponds to a brightness value, this value can go from 0 to 255 (in case eight bits are used for encoding).

2. Two new variables of $Y1$ and $Y2$ are used; these values correspond to the sum of the brightness values diagonally (**Fig. 2.4**).

Therefore, the following equations are obtained:

$$Y_1 = X_1 + X_4, \tag{2.1}$$

$$Y_2 = X_2 + X_3.$$

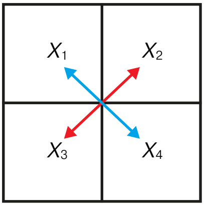

Fig. 2.4 Diagonal elements

3. Additionally, a value for a constant C is chosen (for this task a constant value of 10 is used).

This value is experimental and the one that will work as an indicator of whether or not there is any contour in this place.

If $Y_1-Y_2>C$, outline does not exist and we have to analyze the next four pixels (step 1).

If $Y_1-Y_2\approx C$, the contour can exist and we have to calculate the angle of its orientation (step 4).

4. Now the difference between the values of the pixels is calculated diagonally, and they are assigned to the variables δ_1 and δ_2:

$$\delta_1=X_1-X_4, \quad (2.2)$$

$$\delta_2=X_2-X_3.$$

5. Now the minimum value and the maximum value of the absolute values of the variables δ_1 and δ_2 are established and are assigned to variables θ_1 and θ_2, respectively:

$$\theta_1=\min(|\delta_1|, |\delta_2|), \quad (2.3)$$

$$\theta_2=\max(|\delta_1|, |\delta_2|).$$

6. From the absolute values of these differences, the maximum and minimum are obtained and we make the quotient:

$$Y=\frac{\theta_1}{\theta_2}. \quad (2.4)$$

Value of Y will always be less than 1.

7. **Table 2.1** indicates eight octants. According to the signs of the parameters δ_1, δ_2, and $|\delta_1|-|\delta_2|$. **Table 2.1** is established, which will indicate the interval in which the contour orientation angle is found.

Table 2.1 Calculations of angle orientations

φ	$\left(0, \frac{\pi}{4}\right)$	$\left(\frac{\pi}{4}, \frac{\pi}{2}\right)$	$\left(\frac{\pi}{2}, \frac{3\pi}{4}\right)$	$\left(\frac{3\pi}{4}, \pi\right)$	$\left(\pi, \frac{5\pi}{4}\right)$	$\left(\frac{5\pi}{4}, \frac{3\pi}{2}\right)$	$\left(\frac{3\pi}{2}, \frac{7\pi}{4}\right)$	$\left(\frac{7\pi}{4}, 2\pi\right)$
				Y				
δ_1	+	+	+	–	–	–	–	+
δ_2	–	+	+	+	+	–	–	–
$\lvert\delta_1\rvert-\lvert\delta_2\rvert$	+	+	–	–	+	+	–	–

Depending on the combination of signs, the value of Y will be added or subtracted from the dividing line corresponding to $\pi/4$, $3\pi/4$, $5\pi/4$ or $7\pi/45$, depending on the case indicated in the **Table 2.1**.

Example:

1) adjacent pixels:

4	3
2	1

Therefore:

$X_1=4, X_2=3$ and $X_3=2, X_4=1$;

2) it is calculated $Y_1=X_1+X_4= 4+1=5$, $Y_2=X_2+X_3=3+2=5$;

3) it is compared with the value of the constant C (for this case it is 10). In this case the values of $Y_1=5$ and $Y_2=5$ show that the contour exists;

4) the values of δ_1 and δ_2:

$\delta_1=X_1-X_4=4-1=3$, $\delta_2=X_2-X_3=3-2=1$;

5) the maximum and minimum of δ_1 and δ_2 are θ_1 and θ_2:

$\theta_1=3$; $\theta_2=1$;

6) The value of Y is calculated:

$Y=1/3$.

By using **Table 2.1** and based on the conditions obtained, that is, the signs of δ_1, δ_2, and $|\delta_1|-|\delta_2|$, that all three have "+" we are in the second octant. In this case, since all the signs of our variables are positive, we can deduce that the orientation of the contour is between $\pi/4$ and $\pi/2$. The actual value is calculated as $\pi/4+Y=0.785+0.33=1.115$ radians.

2.2.2 Other algorithms of texture recognition

Other algorithms were developed for calculating texture characteristics on the image and tested [42]. It was proposed an algorithm for finding a set of texture features characterizing the most homogeneous texture area of an input image. The found set of features was intended for extraction of this segment. The algorithm, developed by A. Goltsev, processed any input images in the absence of any preliminary information about the images and, accordingly, without any learning.

The essence of the algorithm is as follows. The image is covered with a number of test windows. In each of them, a degree of texture homogeneity is measured. The test window with maximal degree of homogeneity is determined and a representative patch of pixels is detected. The texture features extracted from the detected representative patch is considered as those that best characterize the most homogeneous texture segment. The example of work of the developed algorithm is presented in **Fig. 2.5**.

a *b* *c*

Fig. 2.5 Textures of black cat and tree:
a – original image; *b* – cat texture; *c* – tree texture [42]

The proposed algorithm facilitated solution of the texture segmentation task by providing a segmentation technique with helpful additional information about the analyzed image. The computer program was tested on natural grayscale images.

The other texture algorithm was developed on the base of calculation of histograms of brightness, contrast, and contour orientations. We calculated the brightness, contrast, and contour orientation histograms of the images and use them as features and inputs to the Random Subspace Classifier (RSC) neural classifier. Our recognition system is based on a special neural network, the RSC that is the version of RTC. The only difference of the RSC from the RTC is that not all input parameters are involved in the operation of the system. From the entire set of input parameters, a subset is selected for each block.

This study was to develop and test a recognition system for the Colorado potato beetles (example is presented in **Fig. 2.6**) on the plants [43]. This task is very important for localizing the beetles and reducing the pesticide volume used to protect the harvest. We employ a beetle image dataset representing different beetle positions and varying numbers of beetles. These images were collected from the Internet. We obtained the best recognition rate of 85 %.

a *b*

Fig. 2.6 Examples of Colorado beetle images: *a* – original images; *b* – marked images for RSC

This investigation was continuing for Mexican beetles' recognition [44].

The aim of this study is to develop a method for automated classification of blood cell images for the diagnosis of various diseases, which allows increasing the recognition rate in the diagnosis of diseases. To achieve the goal, the following tasks are required:

– development of algorithms of feature extraction from images;

– development of neural networks as element of decision making;

– programming of the algorithms of feature extraction from images and neural network method;

– testing them on selected image database.

The main hypothesis of the study is based on our experience in development of neural classifiers.

We developed different types of neural classifiers as RTC, Limited Receptive Area Classifier (LIRA), Permutation Coding Neural Classifier (PCNC).

Assumptions accepted in the work are the following:

– we can extract different features of the images of the blood as from patients with diseases and from images of healthy persons;

– neural network can be trained and after that can be used to recognize new images of blood cells.

2.3 Methodology

2.3.1 Texture recognition in blood smear images

The task of image recognition of lymphocytes affected by ALL consisted from several steps. The first step requires selecting the cells that are affected by the disease. A typical blood image consists of three components: red blood cells (erythrocytes), leukocytes, and platelets. Therefore, we will focus on leukocytes, specifically lymphocytes. **Fig. 2.7** depicts a sample image from the ALL-IDB2 database [27] containing four healthy cells from patients without ALL and four probable blast cells. The second step includes the calculation of texture features. The third step includes the training of neural classifier.

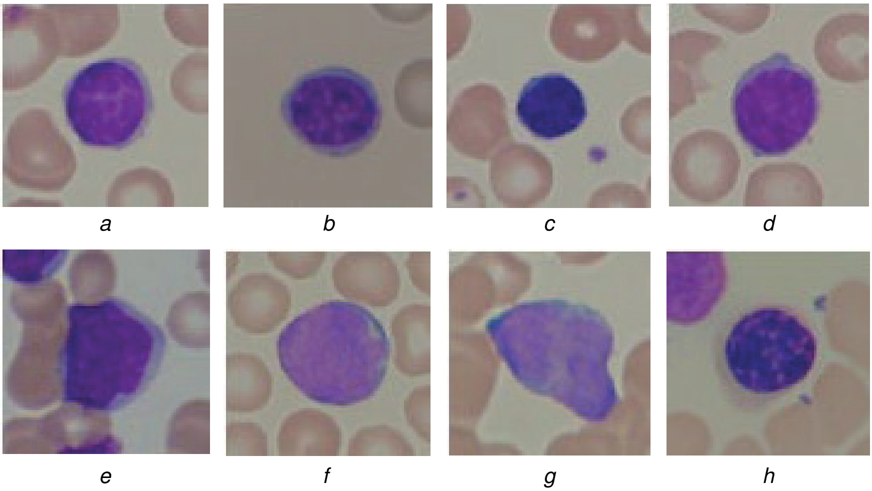

Fig. 2.7 Images from the ALL-IDB2 database: *a–d* present healthy cells from patients without ALL; *e–h* present probable lymphoblasts from patients with ALL [27]

The method of French-American-British co-operative group (FAB) is used in medicine for a long time to classify a cell as a blast or normal [45]. The FAB classification for acute lymphoblastic leukemia is divided into three categories:

L1: Lymphoblasts are small and homogeneous. The nuclei are round and regular with little cleavage and discrete nucleoli. The cytoplasm is scant and usually without vacuole.

L2: Lymphoblasts are massive and diverse. The nuclei are irregular and frequently cleft. Nucleoli are present. The cytoplasm may contain vacuoles, and its volume is variable but typically abundant.

L3: Lymphoblasts range in size from moderate to large and are homogeneous. One or more prominent nucleoli are present. The shape of the nuclei is regular and round-oval. The cytoplasm is moderate in volume and contains numerous prominent vacuoles.

Some characteristics of lymphocytes and lymphoblasts are as follows:

– a lymphoblast is approximately 10–18 μm in size, while a mature lymphocyte is about 17–20 μm;

– a lymphoblasts have a nuclear-to-cytoplasmic ratio of 4:1, while lymphocytes have a ratio of 2:1;

– a lymphoblasts contain 1–2 nucleoli, whereas mature lymphocytes lack nucleoli;

– in contrast to lymphoblasts, the chromatin of lymphocytes is dense and clustered;

– a lymphoblast cytoplasm is devoid of granules, whereas few azurophilic granules are present in lymphocytes;

– the stained lymphoblast cytoplasm turns medium blue with a dark blue border, whereas the stained lymphocyte cytoplasm turns light blue.

In terms of area, perimeter, texture, circularity, and nucleus-cytoplasm ratio, **Table 2.2** depicts the morphological characteristics of affected and normal cells for diagnosing ALL [9].

Therefore, the local characteristics of the blood images are extracted first in terms of texture. For this purpose, the following structure of the proposed texture recognition system is presented in **Fig. 2.8**.

Table 2.2 Morphological characteristics for ALL diagnostic [9]

Characteristic	L1	L2	L3	Normal	Mathematical relation
Cell size	Small	Large	Large	17–20 μm	Area and perimeter
Cell chromatin	Fine or grume	Fine	Fine	Dense and clumped	Texture from histograms
Nucleus shape	Regular, may have indentations	Irregular, may have indentations	Regular, oval or round	Regular without indentations	Area, circularity and nucleus-cytoplasm relation
Nucleolus	Does not distinguish	One or more, big prominent	One or more, big prominent	Without nucleolus	Texture from histograms
Cytoplasm	Scarce	Moderately abundant	Abundant	Normal	Area and nucleus-cytoplasm relation

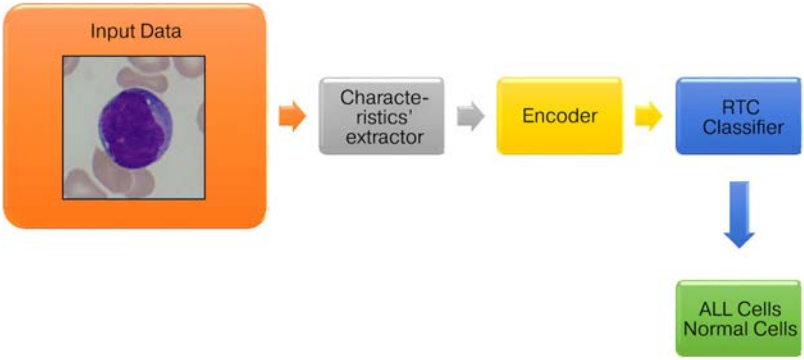

Fig. 2.8 RTC classifier's structure

The extracted characteristics are presented to the input of the encoder. The encoder generates the output binary vector, which is then presented to the input of the single-layer neural classifier, and, finally, the classifier's output provides the recognized class, which in this case consists of two classes, healthy cell, and affected cell [37, 38, 45]. In **Table 2.2** the morphological characteristics for ALL diagnostic are presented [9].

2.3.2 Characteristic extractor

This module is based on the image processing procedure. It will provide us with the necessary information to distinguish a leukocyte from the other cells in the peripheral blood image, as well as the characteristics that distinguish a lymphocyte from a lymphoblast. This system includes color, texture, and border characteristics represented through their histograms, and these characteristics are obtained from the nucleus of every lymphocyte or lymphoblast discovered by the system. To achieve this, an initial image is scanned by moving a (20×20)-pixel window with a 10-pixel step. Three brightness, contrast, and contour orientation histograms were calculated for each window. Each histogram consists of 16 components, for a total of 48 components or features that will comprise the input vector ($X_1, \ldots, X_n$) for the RTC classifier.

2.3.3 Characteristic encoder

The characteristic encoder converts the extracted properties given by the property or characteristics extractor into a binary vector. Encoding then creates a binary vector (b_1, ..., b_s) for each characteristic vector (X_1, ..., X_n). This vector is presented to the classifier's next layer. The proposed neural classifier has the Hebbian training rule as a one-layer perceptron.

2.3.4 Random Threshold Classifier (RTC)

It is proposed a neural classifier with high performance both in training and processing. Random Threshold Classifier (RTC) is the name of this classifier [46–48]. The basic idea is to create multilayer perceptrons with a single layer of training connections, which allows a rapid training rate. Placing additional non-modifiable layers of connections and binary neurons that allow nonlinear transformations of spatial input parameters to binary spatial parameters with extremely high dimensions improves image recognition accuracy.

The RTC structure is depicted in **Fig. 2.9**. The network structure is comprised by s similar blocks with a neural output in each (b_1, ..., b_s) block. A complete set of (X_1, ..., X_n) characteristics supplies each block's inputs.

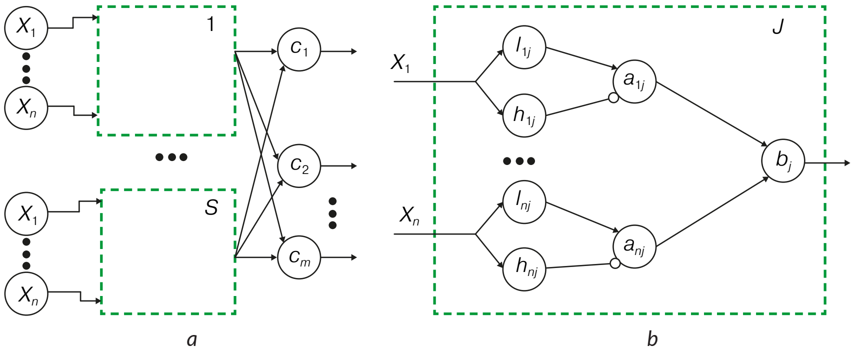

Fig. 2.9 RTC neural classifier: *a* – the whole structure; *b* – structure of one block

Each X_i characteristic feeds two neurons, h_{ij} and l_{ij}, where i ($i = 1, 2, ..., n$) represents the input features for neurons in every block j. The threshold value of l_{ij} falls below the threshold value of h_{ij}. A unique random procedure determines these values. The output of the l_{ij} neuron is connected to the excited input of the next a_{ij} neuron, and the output of the h_{ij} neuron is connected to the inhibited input of a a_{ij} neuron. At the output of a a_{ij} neuron, the signal only occurs when the signal X_i is between l_{ij} and h_{ij}.

All outputs of *a* neurons within a *j* block are connected to the excited inputs of a b_i neuron, which represents the whole neural block output.

The threshold value of the b_j neuron equals the number of a_{ij} neurons, i.e., in the b_j neural output, the signal is generated when all a_{ij} neurons within the block are excited. The neural output for each block is connected to all the neural inputs of the (c_i) classifier through trainable connections (w_{ij}), which are modified at each training stage. Each neuron in this layer represents a classification response of the system, and the neuron with the greatest excitation value is chosen. The classifier works in two ways: training and recognition. For training connections, Hebbian rule is applied:

$$w_{jc}(t+1) = w_{jc}(t)+a; \quad (2.5)$$

$$w_{ji}(t+1) = w_{ji}(t)-a, \quad (2.6)$$

in which the *c* index represents the correct class, and the index *i* represents the incorrect class.

The neural network undergoes a training phase whose objective is to correctly recognize as many patterns as possible. The training consists of decreasing all the weights of the connections of the incorrect class and increasing those of the correct class, which leads us to supervised or master training.

In order to understand the principles mentioned above, we will interpret them geometrically, as shown in **Fig. 2.10**, for a case with three input features X_1, X_2, and X_3, so for three-dimension task instead of *n* dimension as presented in **Fig. 2.9, *a***.

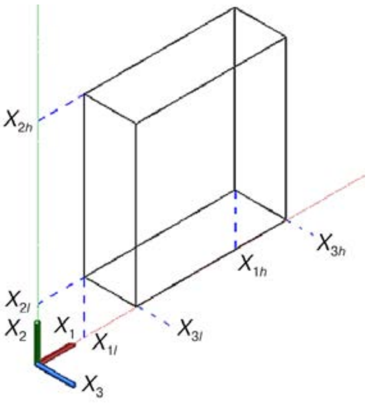

Fig. 2.10 Geometric identification of the neuron

When the point representing the feature vector is inside the represented rectangle, the output neuron that is corresponded to the block output will be stimulated or active. Since the classifier contains a sufficient number of blocks with similar (neurons with thresholds) but different characteristics (different values of thresholds), all spatial features appear in a sufficient number of multidimensional parallelepipeds located on random planes and having random sizes. We demonstrate the geometrical interpretation only for three input parameters.

The number of parallelepipeds is equal to the number of blocks ($b_1, \dots, b_s$). We can analyze the point in space $\left(X_1^*,\ X_2^*,\ X_3^*\right)$ shown in **Fig. 2.11** where numerous (V) parallelepipeds have been covered. With the training process and definition of weights between penultimate and last layers (w_{ij}) the neural classifier can divide the parametric space on different classes.

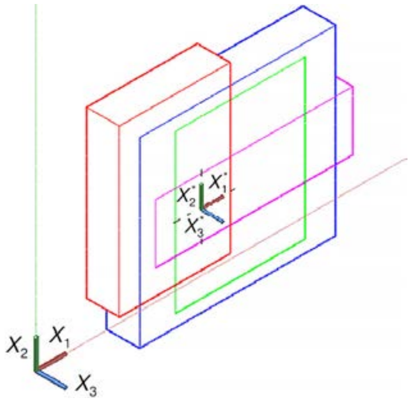

Fig. 2.11 A geometric representation of the classifier

V is the random value for different points in space, and typically classifier parameters are chosen to obtain an average value V.

Taking into account the need to distinguish three classes, let the point $\left(X_1^*,\ X_2^*,\ X_3^*\right)$ belong to the second class. If the point is far from the class boundary, it is covered by parallelepipeds whose volumes lie within the class boundary of the second class. This implies that during the training process, the weights of the connections between neurons belonging to b_i and the neural outputs of the second class will be greater than the weights of the connections of b_i neurons with first-class neurons. Therefore, the point $\left(X_1^*,\ X_2^*,\ X_3^*\right)$ will be recognized as belonging to the second class.

2.3.5 Database description: ALL-IDB

ALL-IDB [27] is a public imaging database of peripheral blood samples from healthy individuals and leukemia patients. These samples were gathered by professionals at the M. Tettamanti Research Center for Childhood Leukemia and Hematological Diseases in Monza, Italy. The ALL-IDB database is comprised of two different versions, ALL-IDB1 and ALL-IDB2, and its images are in JPG format with 24-bit color depth. ALL-IDB1 is comprised of 108 original RGB images captured with a laboratory optical microscope and an Olympus Optical C2500L camera or a Canon Power Shot G5 camera. The resolution of the first 33 images is 1712×1368, while the remaining images have a resolution of 2592×1944.

The images were taken at different microscope magnifications, ranging from 300 to 500, which brought the differences in color and brightness. ALL-IDB1 provides complete images containing cells and agglomerates; thus, it can be used to evaluate the segmentation capabilities of algorithms, as well as the image preprocessing techniques or the classification systems. ALL-IDB2 is a collection of clipped areas of interest from blastic and healthy cells extracted from ALL-IDB1. It consists of 260 images, with 50 % of these depicting lymphoblasts.

2.4 Results, experiments and discussion

To present the results obtained by the RTC neural classifier, the aforementioned ALL-IDB2 database was employed, along with 100 images, of which 60 were used for training and the remaining 40 for testing. To calculate the recognition error percentage, the total number of windows is first obtained using the following equation:

$$NTV = \left(\frac{W}{\frac{w}{2}} - 1\right) \times \left(\frac{H}{\frac{h}{2}} - 1\right) \times NIB, \tag{2.7}$$

where *NTV* is a total number of windows; *W* is an image width; *H* is an image height; *w* is a window width; *h* is a window height; *NIB* is a number of images stored in the database.

The percentage error is computed by the following equation:

$$x = \frac{100 \times N_{error}}{NTV} \%, \tag{2.8}$$

where N_{error} is the number of windows that the system did not recognize correctly in the recognition stage.

Before presenting the results of calculations, we want to describe in detail the algorithms of the system.

The graphical user interface is comprised of a menu with the following options (**Fig. 2.12**): Mask generation, Open Image-Coding, Training, and Recognition.

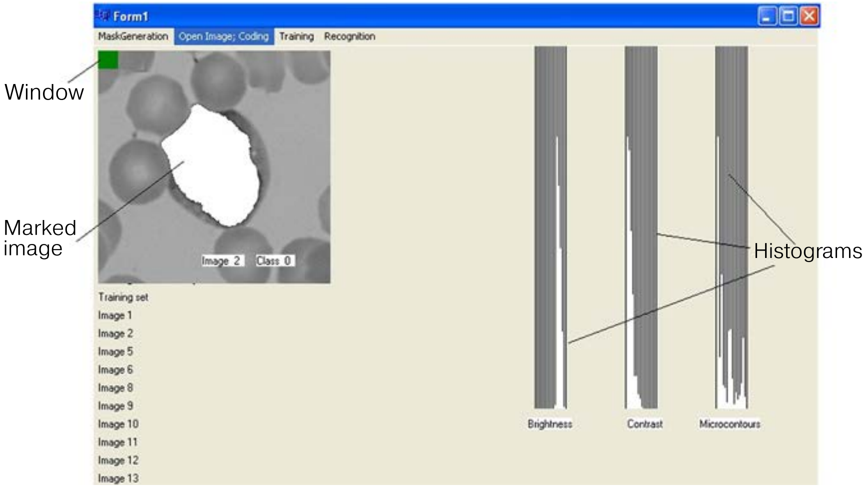

Fig. 2.12 Program system

In the first option, "Mask generation" is the first part of the RTC classifier structure. In this stage all *S* blocks were generated with neurons with random thresholds (**Fig. 2.9, *b***) and they were saved and used in work process. In the case that we analyze in this work $S = 64000$ (**Fig. 2.9, *a***). In the first menu item (in the process of system preparation) the program randomly selects images from the ALL-IDB database for the training and test phases, where half of the images are selected for training and the other half for testing.

The following option – "Open Image-Coding" – is where the 100 images in the database are opened and encoded. It is performed a scan of the whole image with a (20×20 pixels) window (in **Fig. 2.12** the window is presented with green colour). The step of scanning corresponds to the half of the window size. Every window is a sample for the neural network. For every window we calculate three histograms that are presented in **Fig. 2.12**. These are the histogram of brightness, histogram of contrast and histogram of micro contours orientations. So, we have three groups of features. Every group has 16 features. So, in total we have 48 input features for every block. In our case, $n=48$ (**Fig. 2.9, *a***).

In our task there are three classes, $m=3$ (**Fig. 2.9, *a***). One of them corresponds to class zero (0), which helps us identify the background of the image; the next class (1) for the case where there are no cells affected by the ALL disease, i.e., healthy cells, and finally, class two (2) where there are cells affected by the ALL disease (lymphoblasts). For each window (input sample) the histograms of brightness, contrast, and micro-contour orientation are computed, after the work of blocks (**Fig. 2.9, *a***) the system has a neural output in each (b_1, ..., b_s) block. The vector (b_1, ..., b_s) is a binary vector that is a code of window for the network structure.

Once this process is finished, the “Training” option will begin, which, as mentioned above, consists of decreasing all the connections weights of the incorrect class and increasing those of the correct class. The objective of the training is to correctly recognize the most significant number of patterns. The training process is a supervised training (training with a teacher). For this reason, we marked all images that participate in our experiments for the process of training (**Fig. 2.12**). The system has information about which class the considered window belongs to. If the window falls on the image area where two or three classes have their representation, then choose the class that has the largest number of pixels.

Finally, there is the “Recognition” option in which the remaining half of the images, which were not used in the training phase, is used. At this stage, we can obtain the number of errors, and with these, we can calculate the percentage of recognition rate of our system.

It is worth mentioning that we obtain 48 texture characteristics. In **Fig. 2.13** one example of the results of RTC work are demonstrated. The image is green because it was scanned with window of green colour.

We investigated the influence of the window size to the recognition rate. To obtain statistically stable and confident results we did with every window size five experiments and calculated the average error number. The results are presented in **Table 2.3**.

Five experiments for each window size help us to decrease the influence of the randomly selected parameter values.

The best results were obtained for window sizes\ (20×20) and (40×40) pixels. Trend of this investigation demonstrates that with large window we can obtain the better results.

Table 2.4 shows a comparison of the different methods employed by various authors, as well as the results obtained using our proposed RTC method.

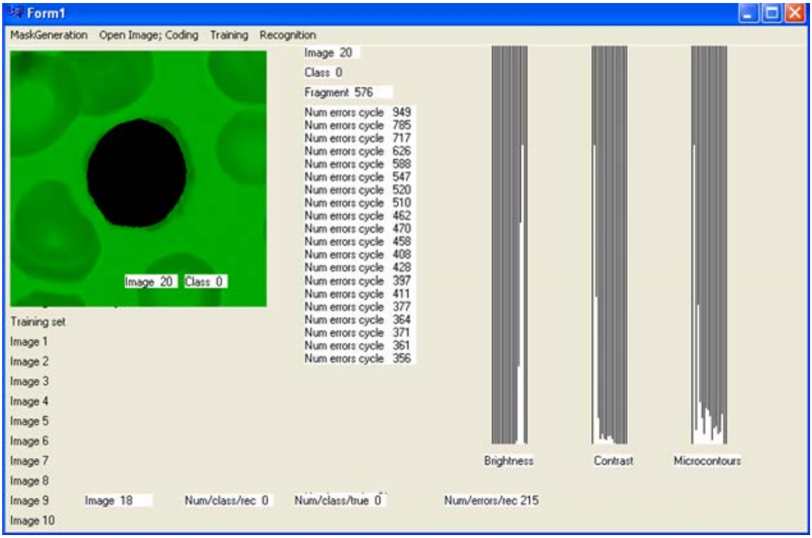

Fig. 2.13 Development environment

Table 2.3 Experiments with different window size

Window size	**10×10**		**20×20**		**30×30**		**40×40**	
	Errors	**Recog-nition Rate (%)**	**Errors**	**Recog-nition Rate (%)**	**Errors**	**Recog-nition Rate (%)**	**Errors**	**Recog-nition Rate (%)**
Run								
1	7048	86.13	215	98.24	347	93.33	88	96.87
2	7040	86.14	205	98.32	371	92.87	79	97.19
3	6090	88.01	235	98.07	261	94.98	108	96.15
4	7030	86.16	195	98.4	325	93.75	90	96.79
5	7050	86.12	183	98.5	355	93.18	110	96.08
Average		**86.512**		**98.306**		**93.622**		**96.616**

Experiments with RTC demonstrate that the results were superior to the best result obtained in [37] and significantly superior to those obtained using SVM-G in [38]. It should be noted that all mentioned methods utilize the ALL-IDB database. A detailed description of these methods is beyond the scope of this paper; instead, we will compare our outcomes to theirs.

Table 2.4 The average recognition rate for the ALL-IDB database (%)

Authors	Gayathri & Jyothi [49]	Putzu, Caocci, Di Ruberto [10]	Di Ruberto, Loddo, Puglisis [24]	Shakhawan Hares Wady [37]	Alagu & Bagan [38]	Curtidor, Kussul, Baydyk, Mammadova [50]
Methods	CNN	IPT	Deep Learning	LDNP+M-WDT	SVM-G	RTC
Recognition (%)	93	93.2	94.1	97.69	95.3	98.3

As shortcomings of this study we can noted that we used only one image database. For effective application of neural classifiers, it is very important to increase the number of images for training process. The time of training may demand hours or days. But it is possible to use pre-trained neural networks.

In the future we can use other image databases for diagnostic not only ALL but other diseases where image analysis is important for doctors and they need assistance by computer systems.

It will be interested to add to texture characteristics the other features, for example, the form parameter that can be calculated as perimeter of the cell divided to the area of the cell.

To our opinion the difficulties that we may encounter in future are connected with quality of images. Image set quality may include, for example, excessively noisy images, mislabeled duplicate images, uneven image resolution, varying class sample sizes that can demand special preliminary preparation of image dataset.

2.5 Conclusions

The neural classifier with the title the Random Threshold Classifier (RTC) was used to recognize the texture of human blood cells images, with a focus on white blood cells (leukocytes). The classification of healthy lymphocytes and diseased lymphocytes, also known as lymphoblasts was selected as test task. At the input of the RTC classifier, brightness histograms, contrast histograms, and micro-contour orientation histograms were calculated for each image from the ALL-IDB database, generating a characteristics vector that would be the input of the neural classifier. We developed the specialized program using C++ to extract the characteristics of interest and to train and test the images with RTC neural classifier. The program system permits us to recognize where the healthy or diseased cells are detected.

The RTC neural classifier demonstrated a higher recognition percentage of 98.3 % compared with 95.3 % of the SVM-G and of 97.69 %. So, our neural classifier may be used to identify the lymphoblasts using images of the healthy or diseased cells.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

Acknowledgment

The authors would like to thank Labati et al for sharing the Acute Lymphoblastic Leukemia image database (ALL-IDB).

We thank the Regional Center of Investigations Dr. Hideyo Noguchi, from the Autonomous University of Yucatán, for the tissue image database.

The special acknowledgment from Dra. Airam Curtidor for poststudent grant del CONAHCYT, Mexico.

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CHAPTER 3

Analysis of the Internet of Things capabilities in monitoring the physiological state and location of personnel on an offshore oil platform

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Abstract

This chapter explores the opportunities of using the Internet of Things (IoT) to ensure the safety of personnel on offshore oil platform. To this end, the IoT applications and technologies are analyzed for the monitoring of the physiological state and location of personnel. The chapter presents the opportunities of using IoT with cloud technologies, Big Data technologies, and artificial intelligence for system development which enables to monitor and, if necessary, to make appropriate decisions through systematic monitoring of the state of personnel based on expert assessment of deviation of real time parameters' values from the norm. The practical tasks related to the application of IoT technology in various fields of healthcare are explored. IoT Services and IoT Applications used in e-health are analyzed and classified. The risks and challenges arising from the implementation of IoT solutions in healthcare and posing a threat to both the physical safety of patients and the confidentiality of their personal data are identified.

Keywords

Offshore oil platform, expert assessment, IoT technology, IoT Applications, smart wearable sensors, Wireless Sensor Networks, e-health, IoT Services.

3.1 Introduction

In accordance with the thesis of the Concept of Human Development, "people are the real wealth of every state, and the development policy conducted in any field should serve them precisely", the protection and provision of health of human resources

 DOI: 10.21303/978-9916-9850-2-1.ch3

is among the priorities in all facilities [1]. Offshore oil platform (OOP) is a complex engineering facility designed for excavation of deposits in the seabed, and in the depth of ocean or other water basin and for the extraction of hydrocarbon raw materials [2].

Noticeably, the work of oil workers and gas producers is related to health risks. Early Preventive Medical checkup, Evaluation, Inspection and Review System is designed to minimize the risks. However, medical examination does not always guarantee that employees will be able to perform their professional activities during their shift (usually within two weeks in OOP). Analysis of emergency situations on oil platforms shows that most of them occur due to unexpected deterioration of health, critical fatigue and loss of consciousness of employees. In this regard, monitoring of employees, their health status (temperature, pressure and other physical controls), and location (space) are currently of great importance.

There are two main aspects of reducing the number of emergency situations (accidents, injuries, etc.), i.e., reducing the gravity center of the complications on the oil platform. The first aspect involves the development and perfection of technical tools and the support of the working environment, the prevention of their wear and, thus, the prevention of accidents on OOP. The second aspect is directly related to the safety of personnel, especially its physiological and psychological condition, behavior, performance on OOP and their geographical position, and professional activity. This means that, in addition to registering the equipment, raw materials and environmental parameters, it is important to ensure the proper evaluation of safety of the personnel. Despite the close interrelation between them, both aspects have their own scientific and technical specifications.

The subject matter of this chapter is the personnel and its physiological safety on OOP. The key point here is related to the human factor, the main reason for the tragedy is the personnel's insufficient instruction on emergency situations on the platform [3]. One of the chief ways to prevent the "dangerous behavior" of a personnel, or more precisely, the human factor on OOP, is a systematic monitoring of the physiological and psychological state of an employee and his/her geographical position at the place. With real time information, the level of risk and safety of each employee's health and psychological condition can be determined based on expert assessment. The Internet of Things, modern mobile technologies, the Internet of Medical things and numerous ICT technologies open up wide opportunities to strengthen security measures through the real-time monitoring of the health of personnel on OOP and systematic monitoring of the location of each employee.

The exploration of the possibilities of the Internet of Things to ensure the safety of staff on OOP requires first of all the study of the concept and the essence of the "Internet of Things".

3.2 The concept of "The Internet of Things"

The concept of the "Internet of Things" was first used by the English innovator in the field of technology Kevin Ashton in 1999 for the description of the system in which the objects of the physical world were connected to the Internet through transmitters. In the same year, the Massachusetts Institute of Technology established the Radio Frequency Identification (RFID) and Auto-ID Center, and respectively, the concept of IoT has gained a wide range.

The simple idea of the Internet is that surrounding objects or things (such as tablets, smartphones, fitness equipment, home appliances, clothes, cars, manufacturing equipment, medical equipment, medicines, etc.) can be equipped with miniature identifiers and sensors (sensitive devices) and can be connected to the Internet and to each other via wired and wireless (satellite, mobile, Wi-Fi and Bluetooth) connections [4, 5]. Availability of the necessary channels allows not only to identify and monitor the parameters of these objects by space and time, but also to manage them. Thus, the "Internet of Things" can be viewed as a global network infrastructure consisting of a large number of devices, interconnected through sensors, communication, networking and information technology [6].

From the information-communication point of view, the Internet of things can be typically written as a symbolic formula as follows [7]:

IoT=Sensors (Transmitters)+Data+Network+Services.

3.3 Definition of "The Internet of Things"

At present, the term "Internet of Things" does not have a single universally accepted definition in literature. Many definitions of IoT focus of its various aspects and features [7–9]. Some of them are listed below:

1. The Gartner analytical company interprets the "Internet of Things" as a network of physical objects based on technology that allows measuring the parameters representing the position of the physical objects as well as their environment, and using and transferring this data. The main aspect of this interpretation is that, despite the notion of "the Internet of Things", the things are often linked via the M2M (machine-to-machine) protocols rather than the Internet. In this case, it is focused on decisions based on the interactions of transmitters, sensors and other "iron" things without the participation of people [8].

2. The Internet of Things – Physical devices connected to the Internet – a global network of "things" equipped with data transmission facilities that enable sensors,

transmitters and data collection and share ("communicate" with each other). These facilities are connected with data management, control and processing center access tools [10].

3. The International Telecommunication Union defines the Internet for Thing as a global infrastructure for the information society, providing the opportunity to deliver more complex services by connecting physical and virtual objects based on existing and emerging ICTs [11].

Due to the rapid development of technology, various interpretations of IoT are given, however they are all based on the same concept. According to this concept, IoT is referred to the group of non-computerized devices, equipment, transmitters, and routine tools with computing ability and network access. Most of these devices usually referred to as "smart or intelligent devices" can process and utilize, analyze and share data with the minimal interference of human.

These things interacting and communicating with each other, and sharing information about the environment and responding to environmental processes without human intervention are predicted to be the most active participants of business, information and social processes in the future [12, 13].

3.4 Smart wearable IoT devices

At present, the continuously expanding market of health Internet of things have been applied in many healthcare sectors. Thus, many health centers around the world have been using smart clothes, gadgets for sensing data on key health parameters, climate control platforms in hospitals, applications for transferring health data to physician, and so forth. For interconnection of different devices with different applications, they are combined with different types of networks over the Internet.

Let's note that various types of health Internet of things are referred to the large number of intellectual devices that are easily accessible in our daily lives. They are smart wearable Internet of things.

Today, there are numerous body-worn wearable devices that measure human physiological parameters [14]. Wearable biomedical transmitters are the subset of devices measuring human biological parameters. Wearable IoT technologies are typically rigid or flexible, based on ordinary electronics, and are designed for low power consumption. They are able to control the patient's parameters in a natural environment and an arbitrary environment, and to transmit signals and information.

In the market of the health Internet of things presents various wearable technologies installed on the transmitters that are categorized as "smart clothes" (head covers, space suits, helmets, jackets, trousers, coats, socks, etc.) and "smart things" (glasses, watches, rings, bracelets, sticks, bandages, lens etc.) [15].

"Smart Clothes" can be used to sense and analyze the data related to the physical activity of a person, to control vital health indicators. They can control the state of people working in hazardous conditions, and monitor the location of the patients and their place of residence in emergency situations, and to observe fatigue levels of an oil man, pilot, driver, etc.

"Intelligent things" (gadgets or devices) may include body-worn transmitters, the objects to monitor vital health indicators, to track the location of the staff on SP, and the applications or objects (e.g. smart box for ampule/pills) reminding the stuff, as well as the healthcare personnel observing their physical state (both physicians), smart devices for real-time monitoring of critical health status, transmitters for tracking and transmitting geolocation data.

Let's note that each wearable smart gadget has certain functional capabilities and is intended to address specific issues.

This allows classifying the wearable IoT for their functional capabilities and relevant applications.

Essentially, wearable medical IoT can be grouped as follows:

1) IoT for monitoring, diagnostics, treatment, care and rehabilitation of personnel;

2) IoT for supporting healthy lifestyle of staff, including their daily physical activity and physical condition;

3) transmitters for tracking staff displacement.

First-group devices include measuring and analyzing one or more vital indicators and parameters (cardiac frequency, ECG, arterial pressure (smart tonometer), sugar rate (smart glucometers), respiratory rate) characterizing the functioning of the cardiovascular system, and the transmitters for drug control.

Second-class wearable devices are designed for continuous monitoring of the level of human agility (SP employee), and shows the data, pulse rate, distance traveled, calories consumed, and so forth sensed from accelerometers. The sensed data can be transmitted to the employee's smartphone or computer as well as to the medical personnel (physicians) who treat them. The applications specifically designed for the calculation of various human health indicators provide advice to users when they detect abnormalities in these indicators, and notify the healthcare personnel in critical situations (insult, heart attack, epilepsy, etc.) and for emergency medical intervention.

Third-class mobile devices can be used successfully for tracking the location of people at high-risk areas, including people from vulnerable categories (elderly, children, people with psychological illnesses).

3.5 Smart IoT Applications

Success of IoT depends on the applications that improve the daily life of a person. The requirement for the use of certain applications is the presence of transmitters for the transmission of the relevant data set. IoT applications are software applications or software systems designed to handle specific issues [16].

IoT applications play an important role in e-health and are directly used by users and patients. In addition, they enable tracking and monitoring the health of people working in other areas, including those of specific risks. IoT applications supporting one or more health indicators at the same time are shown below.

Glucose level sensing. Blood sugar monitoring enables detecting blood glucose level and nutrition plan, activity, and the time to take medication [17].

At present, IoT-based health monitoring systems are being successfully implemented. However, modern IoT-based continuous monitoring systems for sugar levels are not numerous and existing systems also have some restrictions. In [18], using IoT, the architecture for glucose level monitoring system is developed. The system provides actual information about the amount of glucose in blood, including body temperature and contextual data (e.g. environmental temperature) in realtime mode in a timely or affordable format to the users (patients and physicians).

The authors of the article [19] offer the configuration for *Internet of m-health (m-IoT)* for non-invasive real-time monitoring of glucose providing IPv6-connectivity with medical service providers (physicians) based on the transmitters mounted on the patient's devices (gadgets).

The article [20] introduces a model for sugar monitoring system based on IoT networks comprising the devices for blood collection and glucose level measurement modules, including mobile phones or computers for data transfer.

Electrocardiogram monitoring (ECG). ECG is one of the methods of simple, palliative and informative diagnostics of heart disease. The method is based on the recording of electrical impulses that occur in the heart and its graphic writing in the form of extensions on the special paper film. ECG reflects numerous variations of the certain parts of heart in the form of extensions [21].

In recent years, various studies have focused on the use of IoT in ECG monitoring. IoT technologies are now thought to be quite promising for the acquisition of maximum amount of information related to the activities of cardiovascular system, including ECG monitoring [22, 23]. The article [24] offers IoT-based system for real-time authentication of heart function. The system records the electrical activity of the heart and sends this data to the data analysis center, which detects ECG errors and evaluates the patient's condition. Another article [25] develops a complex of algorithm for practical detection of ECG signals in IoT environment for continuous monitoring of ECG. In [26], IoT-based applications are developed to write and monitor of ECG, to measure heart rate and provide the graphical description of the heart rhythm, and then to send these data to the databases and web servers. ECG collecting devices cover the transmission of data on the frequency of heart attacks and *Arduino* microcontrollers. The software is written in MATLAB and C^{++} programming languages in order to process and analyze ECG and download it into the database and Web servers.

A new generation *Nuubo*, offering a wireless and remote platform for heart monitoring, is of great interest. This Spanish company produces, manufactures and sells a wearable medical technology portfolio for the diagnosis and rehabilitation of cardiovascular diseases. These tools are based on the ECG wireless remote monitoring platform and incorporate patented biomedical electronic tissue technology (electronic smart tissues), which uses digital technology called **BlendFix Sensor** [27].

The advantage of *Nuubo* series transmitters is that they can be installed on a daily basis. Smart *Nuubo* shirt is equipped with special devices that control the vital condition of the patient and his/her movements. The shirt records ECG, transmits the sensed data through wireless network to the server for analysis, where special software can define the abnormal parameters. The transmitters installed in the shirt regularly collect parameters such as heart rate, arterial pressure, and body temperature. Shirt-mounted transmitters use a GPS network for connectivity and ensure recording of people on the move (moving throughout the OOP) [27].

Heart rate. The frequency of heart rates is characterized by the number of rates in the same time and measured in bits per minute. The frequency of heart rates is substantially dependent on context, i.e., it increases after physical exercises and can change due to stress, insomnia, illness and drug intake. The frequency of heart rates is also affected by age and genetics. IoT-based ECG monitoring systems incorporate the measurement of heart rate and pulse rate, as well as the diagnostics of multichannel arrhythmias, myocardial infarction, and so forth. In healthy people, the frequency of heart rates and pulse are equal [24, 25].

Blood pressure monitoring. Blood pressure is referred to the Withings in the arterial vessels. The blood pressure in arteries, veins and capillaries differs and is one of the main indicators of the functional status of an organism.

High blood pressure is a risk factor for the development of insidious, cardiovascular, and chronic renal failure; thus, it is important to systematically monitor and check the effects of treatment. At present, there are a large number of different devices, including mobile devices, to measure blood pressure.

The relevance of the problem is that blood pressure-measuring devices and a set of mobile phones supported by NFC (Near Field Communication) have to be related so that they will make up a part of blood pressure monitoring on IoT networks. Performance of the blood pressure measuring devices depends on the model connecting them with a mobile computing device (for example, *Apple*), which realizes wireless data transmission [28]. The article [29] proposes a device equipped with the apparatus for blood pressure measuring with communication modules for collecting and transmitting blood pressure data in IoT networks. The article [30] offers IoT-based Intelligent Terminal, which identifies the location of the wearable apparatus for blood pressure monitoring.

Body temperature monitoring. Body temperature monitoring is an integral part of health care. This indicator is a vital parameter for homeostasis support [31].

Traditional method of temperature measurement through mercury thermometers has been recently replaced by more reliable and inexpensive wire and wireless sensor transmitters for the determination of health status. To determine body temperature, the article [19] provides an example of the realization of m-IoT concept, which uses transmitters installed on *TelosB Mote* platform. Another article presents IoT-based architecture for temperature control system [32]. FID module and body temperature control module are the key components of the system responsible for the temperature recording and its transmission in the system.

Smartphones for the development of IoT Solutions in healthcare. Recently, smartphone-driven transmitters have been developed. This enhances the essence of smartphones in the development of IoT technologies. Various hardware and software products that transform smartphones into a universal health device have been developed [33]. Modern smartphones support a large number of health applications (diagnostic, reference, commentary, analytical, etc.) [34]. Health applications also use numerous wireless transmitters running on algorithms to analyze images [35].

Smartphones include effective diagnostics of asthma, cystic fibrosis, allergic rhinitis, as well as monitoring of vital indicators as heart rate, blood pressure, respiratory rate, and so on [34]. Health applications for smartphones offer solutions that are not too expensive for both the patient and the wide user audience. Today, there is a tendency of using multifunctional applications to interact with several sensor devices as of *ZephyrLIFT* series, while the first health applications were designed to interact with one transmitter.

Applications for geographical location tracking. At present, there is a growing need for solutions that enable each person to track the trajectory of traffic and notify the emergency response service immediately about hazardous situations. Modern mobile devices are equipped with information on their geographical location. For example, *Corvus-Tracker* for *Android* operating system is designed to track users' mobile devices. This application sends information about users' geographic location to the monitoring system server. The system is also capable to send SOS signals to the specified phone numbers. The complementary function of the system is to create a geographic area, run within a given time, combine several users in one group, and visualize the system data for the user [36]. Applications for "smart" items' tracking are also widespread. Thus, applications supporting Global Positioning System (GPS) provides operational information to the relevant medical personnel about the location of the users (including those with special risks, as objects, children, elderly people, mentally handicapped people, etc.) through pre-installed sim-cards.

Nowadays, modern systems providing the identification of real-time location system (RTLS) are available. Actually, GPS is considered to be the most important RTLS. This satellite-connected navigation system is able to find objects anywhere on the Earth in different weather conditions. The basic principle of the system is to determine the geographical location by measuring the time of receipt of synchronized signals from antenna satellite navigation in any point of the Earth and of the space. This feature of the GPS can be used for the identification of the location of medical part of the ambulance, patients, physicians, as well as the staff on OOP, and for the acquisition of the information on the location [37].

3.6 Technologies used in Medical IoT

The IoT concept for healthcare is realized through a range of technologies. A brief description of these technologies is shown below.

The instruments that constitute the basis of IoT and allow the integration of physical devices into the digital world include *RFID* technologies and *Wireless Sensor Networks (WSN)*.

RFID technologies are based on the use of microcircuits that collect information from the devices mounted on the machine or chips installed on the devices. RFID technology enables the transmission of identifiable information wirelessly to the meters via microchips. RFID meters allow identification, monitoring and control of any object automatically integrated with RFID [38].

RFID technologies can be used in IoT to track the movement of staff on OOP. By integrating IoT technologies with e-Health solutions, it is possible to assign RFID to each staff member on OOP and to send data to the center. This allows the staff to access electronic health records, and the sent data is stored on the Health Center database. The physician gets access to health records of a specific person by scanning the RFID tag [39, 40]. RFID tag can register any person on OOP or the specific business areas of the platform. This is especially important in extreme situations to get accurate information about people on OOP and their location.

Wireless Sensor Networks *(WSN)* or *Ubiquitous Sensor Networks (USN)* constitute a technological basis for the realization of the concept of the Internet of things [41]. *Wireless Personal Area Network (WPAN)* is a distributed network of unserved miniature electronic devices (sensor nodes) that provides collection of data about external environment parameters and transfer them to the processing center based on retranslating them from node to node. All transmitters are linked with interconnected radio-channels located in the air, water and water surface, and inside the body.

Wireless Body Area Network *(WBAN)* is a wireless computer network which is wearable and wearable on body. These devices can be mounted and implanted into the body, mounted to the body in certain conditions, or installed in clothing (e.g. in a pocket) and carried items (e.g., in a bag) that people wear in different places. *WBAN* system can use wireless network as a gateway to reach greater distances. The wearable devices can be interconnected through the Internet via the gateways. Thus, health workers can access the information online regardless of the patient's location [42].

3.7 IoT based medical data transfer technologies

At present, networking combinations with different forms and able to operate from different distances, and requiring different powers open wide possibilities for IoT. They may include wireless personal area networks (WPAN), Wi-Fi networks, wireless mesh networks, cellular networks, extremely broad-band networks, and satellite-connected networks.

IoT are grouped into near and remote activity segments. The near business segment mainly covers the devices linked with connection channels through the use of unlicensed radio communication technologies (Wi-Fi, ZigBee, Bluetooth) covering 100 meters or fixed as a local area network (LAN), PLC (Power Line Communication). The remote activity segment covers the devices connected through cellular networks, unlicensed low-band radio communications technologies (such as *LoRa*, *Sigfox*) or satellite technologies.

IoT are assembled into two groups for distant and remote data transfer. Today there are various wearable devices that support medical sensors to collect data. Most of these devices provide connection at a near distance. This can be a link between nodes or sensor nodes, or a gateway aggregating the data from sensors.

If the data is required to be transmitted to the nearest distance, the device can use a Personal Area Network (PAN), as well as wired USB interface presented with wireless data transmission technologies such as *BLE (Bluetooth Low Energy)*, *ZigBee*, and *6LoWPAN*.

LAN can be used when the data is partially transmitted at a far distance (e.g., within a clinic or hospital). Wired local networks are often built on *Ethernet* and optical fiber technologies, while the wireless ones are built on *Wi-Fi* technology. *WiMax*, *LTE*, etc. are used for the organization of a global network (Wide Area Network, WAN) [43].

Over the past two years, the technology has been developed to connect low-powered devices to *LPWAN* [44].

Data transmission speed and energy consumption are the key factors for the choice of cellular technology in specific cases. *BLE*, *ZigBee*, *Z-Wave* are used in limited-powered devices and comprises the use of gateways for data aggregation and sending them in IP-network [5].

IoT uses the BLE and ZigBee technologies for data transfer at a close distance.

Bluetooth LE technologies. *Bluetooth* is a wireless technology that provides the data transmission between the devices that are not too far away from each other. This technology allows the communication between the devices within the coverage of 10 m. One of the significant advantages of *Bluetooth LE* is its low power consumption and extreme low power consumption in sleep mode. In other words, the device "sleeps" at 99 % of the time and "awakes" for a short period of time, shares data and "re-sleeps" again. In general, *BLE* is very advantageous in medical applications. It is safe and has low bandwidth, low latency, low power consumption and resistant to hindrances. This standard is recommended for the design of wearable healthcare systems.

Bluetooth 5.0 is the newest generation of *Bluetooth*, allowing for data sharing between devices at a distance of up to 200 meters and at a rate of 4–12 megabytes/s [45].

Wi-Fi technologies are designed to provide access to wireless broadband networks for high-speed data transfer. The networks can be expanded without interlayers and wire through *Wi-Fi*, with access to network and mobile devices. Within the Wi-Fi zone, several users can access the Internet on a computer, laptop, tablet, phone, etc. may be included in [46].

ZigBee (6LoWPAN) technologies. *ZigBee* is designed to create wireless personal networks (WPANs) using small-size radio transmitters with little power. *ZigBee* technology is oriented at the applications capable to operate separately and securely for a long time during high-speed data transmission [47, 48].

ZigBee is used in bio-transmitters for medical diagnostic devices, medical equipment, and for the monitoring of the condition of athletes, including the personnel operating at high-risk sites. In this case the maximum transmission speed accounts for 250 kb/s. *ZigBee* consumes low power operating in sleep mode. Devices can be enabled by pressing the button, working with the timer, and so on. "Sleeping" devices switch back to "sleep" mode as soon as the data is transmitted and they get the confirmation on the receipt of the package by the main line. The disadvantage of *ZigBee* technology is often due to the fact that it is not used on smartphones, although *BLE* is used. Therefore, the use of ZigBee technologies in fixed locations is recommended.

ANT+technology is a wireless communication standard designed to transmit information between ANT+ supported devices [7]. This standard uses the frequency used by Bluetooth, supports up to 30 meters distance, and is implemented through special chips allowing the data transmission between devices. The standard is intended for house use and medical application. This standard is used by *Philips*, *Samsung*, *Sony*, *HbbTV*, *France Televisions*. Its main advantages include low energy consumption, thus the ANT+ connection uses 70 % less energy than *Bluetooth*.

3G/4G LTE (Long Term Evolution) and 5G technologies. 3G is a third-generation mobile communication technology, providing a set of services combining both high-speed mobile access technologies with data transmission channels, as well as Internet-based services. 3G networks work within the range of decimeters and centimeters, and transmit data at speeds of up to 3.6 mbit/s.

4G LTE is a fourth-generation mobile communication technology, designed for high-speed wireless data transmissions in data-driven mobile devices and other equipment. The objective of 4G LTE is to increase speed and transmission capabilities using modulation methods and digital signal processing, as well as the reconstruction and simplification of IP-based network architecture, which will significantly reduce delays in data transmission in regard to 3G-architecture networks.

5G is the next generation mobile communication technologies, which involves the creation of a network that practically enables connecting almost everything. The transition to global standard 5G NR (*New Radio*) will ensure a new mobile broadband connection for smartphones (tablets) in 2019. These devices sense the information from transmitters in the human body and send them to the network for general use [42, 49].

NFC technologies *(Near Field Communication, NFC)*. In recent years, near field high-speed wireless technology has also improved significantly and allows data exchange between devices at a distance of about 10 centimeters. NFC technologies were primarily intended for the use on digital mobile devices. This technology is a simple expansion of contactless standards that connect interface smart cards considering it a single device. The NFC device supports the communication with a smart card and other NFC devices, which can work with existing contactless card infrastructures [8].

NB-IoT technologies *(Narrow Band IoT)* is a new generation of cellular connection standards for telemetry devices for low-scale data exchange (2016), designed to connect a wide spectrum of autonomous devices, including medical devices to digital network connections [50]. Since NB-IoT is protected and supports a large number of devices and transmission at a great distance, it is very convenient for healthcare applications.

Transmitters. The development of transmitters is one of the main incentives for the expansion of the ICT application. Transmitters measure the physical data and convert them into raw information. This information is then stored digitally, and useful for analysis and processing.

Miniaturization of sensors has allowed them to integrate into "smart" devices, with the latter being able to record data, analyze the data, and allowing them to be transmitted over the Internet. The size of modern transmitters can range from one millimeter to tens of centimeters. At present, the work is underway to further reduce the dimensions of transmitters to ensure high comfort within the human body. Transmitters are fastened to the body in a variety of ways, and combined with the basic headset (often with a smartphone) via wireless technology, such as via *Bluetooth*, *ANT+*, *ZigBee*, etc.

Transmitters have to work perfectly and autonomously for the full realization of IoT capabilities, i.e., transmitters must be systematically fed. Solution of the problem should be sought from the environment: the methods of generating electricity from vibration, light and air flow [51]. Many achievements have already been done in this area. Scientists have announced the utilization of commercial nanogenerators – the chips that transform the movement of the human body (even one finger) into electrical energy, which avoids the use of battery and electrical sockets [52].

IoT platforms. An IoT device is interconnected via the Internet protocols for data transmission between each other. IoT-platforms provide bridge services between sensors and data transmission networks.

The most popular companies in the IoT platform market may include:

– Amazon Web Services;
– Microsoft Azure;
– ThingWorx IoT Platform;
– IBM's Watson;
– Cisco IoT Cloud Connect;
– Salesforce IoT Cloud;
– Oracle Integrated Cloud;
– GE Predix.

3.8 IoT and other technologies

The development and use of IoT potential will be possible in its interaction with other technologies.

Cloud technologies, Big Data tools and techniques, artificial intelligence technologies should be mentioned here first.

Cloud technologies. The IoT system generates a large amount of data to be stored, processed and shared. Clouds in the universal architecture of IoT have three main functions:

– data collection and storage (transmitters' indicators), and their accessibility. The devices with transmitters collect giant volumes of data; the latter ones are stored in the clouds for further processing and analysis;

– data analysis. Cloud services provide data review, cross-connections detection, and important data extraction, including transformation of transmitters' indicators for remote data exchange and decision-making. Real-time analytics (analytic processing), including the analytics implemented after packet mode data collection in wide intervals. In this case, machine learning and data acquisition algorithm and technology play an important role;

– providing execution commands: IoT systems refer to data in different directions, along with transmitting the transmitters' indicators, and ensuring that the commands are securely activated from the cloud.

In addition, cloud solutions perform administrative functions such as managing the records of device and users' logs, performing the protocols of use, monitoring of server status and reporting [53].

Big Data is one of the most important technologies that complements IoT and provides tools and techniques for large, diverse, different sized and unstructured data processing. The use of IoT also increases the number of large data in e-health [54]. Anyone in need of regular medical supervision and wearing a transmitter is the generator of infinite large numbers of digital anamnesis. Thus, one of the most important issues for the development of new medical technologies is the solution of large data generated by IoT transmitters. Modern medical technology allows scanning a body for only a second, whereas the whole human body is scanned for 60 seconds. This means that after appropriate examination, 10 GB of data will be sent to disease archive in the form of unprocessed images and electronic reports. Moreover, the volume of data on the electronic health record (EHR) of an adult patient will account for more than 2 TB.

The development of specific analytical tools aimed at working with medical data is very important for the solution of big data problem in medical IoT. Today *Hitachi Clinical Repository's* solutions are very successful in the market [55], these solutions allow processing the results of the examination and the raw medical data from various sources, and obtaining the necessary information.

Artificial intelligence technologies. Several researchers and developers offer creating "sensitive Internet objects" by transferring artificial intelligence to the "objects" and communications networks. They state that IoT system should have the features of "self-configuration, self-optimization, self-protection and self-healing" in the future [56]. The "smart" things are estimated to be "smarter" due to context dependence, large memory, and extensive processing capabilities, as well as ability to think [57].

The Internet of Things generates a huge amount of data; however, the real problem is the timely and precise processing and analysis of this data. The analytical capabilities of artificial intelligence applications on servers that handle data obtained or served to the IoT networks can provide fast and adaptive data collection. The combination of IoT and artificial intelligence technologies will enable the development of "smart" and "connected" machines to interact with each other and to make decision with the without or minimized participation of a human in general.

3.9 The Internet of medical Things

One of the most important areas where IoT technologies can significantly benefit society is e-medicine. Special terms as "the Internet of medical things" (IoMT) or "the Internet of things in medicine" are already used for this field. Almost all segments of medicine have recently been in the focus of IoT researchers and creators, and these technologies are being applied in solving a number of practical issues. As a result, many applications and service areas have emerged.

Large-scale research and experiments on the integration of IoT innovations into medical practice demonstrate the wide potential of this technology in the field of healthcare. Undoubtedly, the prospects for the expansion of the IoT segment are currently determined by the needs of the medical field. The main reason for this is the possibility for mass and direct interactions between people and electronic devices. Consequently, according to *Allied Market Research* forecasts, the market for medical *IoT* devices (gadgets) and *IoT* applications is estimated to grow to 136.8 billion USD in 2021 [58, 59]. Currently, the average annual growth rate of the IoT market is 12.5 %, and the number of high-tech services, applications and systems in the field of healthcare is predicted to increase in the near future. Market development is also driven by increasing availability of medical gadgets and increasing user awareness of medical innovations.

IoT technologies allow medical institutions to increase the efficiency of work, reduce the time of stay in the stationary mode, monitor the patients' health by providing new services, receive and analyze additional information about the course of treatment, and get consultations from the best doctors. Remote health monitoring provides prompt control of medical indicators, reduces the cost of medical care and simplifies the relationship between the doctor and the patient.

IoT devices, various sensors and analytical applications working with them are involved in solving a number of administrative management, logistics and treatment-diagnostic issues. The global connectivity of the Internet of Things allows collecting, processing and effective use of various types of medical data related to security, diagnostics, therapy, treatment, medicine, management, finance, daily activities, and etc. [60, 61].

Below are some practical issues successfully solved in a number of medical spheres with the use of IoT technologies [62–65].

Administrative management. IoT technologies have great potential in solving the following problems in the administrative management segment of e-medicine:

– patient control and monitoring of his/her health condition (temperature, pressure and other physical indicators);

– real-time monitoring of the location of doctors and patients in a medical institution (this allows for their urgent call in emergency situations, i.e., an operation or a procedure);

– monitoring of environmental parameters, climate control in the medical institution and wards, monitoring of internal climate conditions in the medical institution to warn about exceeding the limits of certain indicators (for example, temperature, humidity, oxygen concentration, etc.);

– management, monitoring of the status and condition of medical equipment, drug stock, used materials, etc. in medical institutions and pharmacies;

– automation of inventory work, automatic reporting on the intensity of use of medical equipment and information technology equipment.

The IoT devices used in solving the problems under consideration are deployed in hospital refrigerators, ice chambers, wards, corridors or other places of the medical facility.

Medical diagnosis. Medical diagnostics involves various measuring instruments as the potential of IoT in this field is infinite. Currently, in addition to the "traditional" visualization (for example, ultrasound, magnetic resonance and computer tomography) and laboratory diagnostic methods, the field of clinical diagnostics is widely applying transmitters for measuring many clinical indicators (for example, heart rate, arterial pressure, pulse, brain activity), as well as micro-transducers and nano-sensors for the assessment of clinical biomarkers. Today, nano-sized biochips are already being used in laboratory conditions, which allow ultra-sensitive analysis *in vivo* (*lat. "in living"*), or rather, "inside a living organism or inside a cell" [66]. Significant progress identifies cancer biomarkers and infectious microorganisms through molecular diagnostics. For example, a unique biosensor developed by Swiss researchers, which is only one centimeter long, is implanted under the skin and measures glucose, cholesterol, toxins, etc. in the blood. By transmitting the information about the amount of above listed to the patient's phone, it allows patient to monitor this amount continuously. The device is charged with a special patch attached to the patient's skin. Wearable, implantable and absorbable sensors monitoring various vital signs are connected to the patient's smartphones and can also directly "communicate" with the treating physician.

Remote monitoring. Remote monitoring through IoT is an integral component of modern telemedicine systems and telemetry. Thus, wearable transmitters allow doctors to remotely monitor the patient's important vital functions, analyze the real time data and predict changes in their health conditions. At present, diagnostic complexes are available with transmitters for remote monitoring of heart rate, body temperature, blood pressure, blood sugar level in diabetics, and for real time processing of breathing functions.

The signals from the transmitters are sent to the patient's mobile device, to the monitors of the staff and treating doctors. The analysis is performed and conditions related to life-threatening situations are formed being supervised by a doctor. The patient himself/herself can send an alarm signal about his/her condition to the server from the phone interface [67].

The use of IoT technologies enables remote monitoring of the physical condition of workers in hazardous facilities and making decision regarding the provision of appropriate and immediate medical assistance. Vests with a set of transmitters already recording the electrocardiogram (ECG), arterial pressure and a number of other parameters, with the ability to record the ECG and transmit it to the medical center using *General Packet Radio Service* (GPRS), as well as diagnostic complexes composed of mobile phones identifying the coordinates of the employee (patient) in a life-threatening situation have already been developed and tested [68]. The processing of received data by specialists enables the real time monitoring the situation of workers in dangerous zones, assessing the situation and responding to it immediately. Radio Frequency Identification (RFID) technologies, RFID tags track the movement of employees, determine their location in special risk facilities and warn about entering a prohibited zone.

Drug therapy. Drug therapy is one of the medical spheres where the use of IoT will bring great benefits. Today, micro-transmitters embedded in pills have already proven themselves to be effective in the monitoring of medication intake, helping to control medication intake and compliance with the prescribed schedule. Such implants can "connect directly" to both the patient's smartphone and the treating doctor. Currently, devices monitoring the correct use of drugs and making reminders about their regular intake are widespread in the market.

Proteus Biomedical (USA) develops miniature microchips that are part of the pill [69]. When the pill is swallowed, the microchip entering the body creates enough potential to transmit the signals of the person's movement to the ECG and through radio channels to a small receiver attached to the abdominal wall.

The receiver collects the signals from the swallowed pills and then transmits them to the server or the doctor's computer. Detailed information on the use of such a chip-pill is provided in [70].

Philips develops an "intelligent pill" (*iPill*), which is a tiny device composed of a microprocessor, battery, radio receiver, pump, and a container for medicines [35, 71]. This device "releases" the drug exactly where it is required.

When an "intelligent pill" enters a human body, it determines the necessary dose by minimizing the harmful effects of the drug. The "electronic brain" in the *iPill* consists of control chips and transmitters, as well as a tiny pump regulating the temperature and acidity. The microprocessor processes the sensed data and transmits a voltage to the "pump" releasing the necessary amount of medicine at the current moment. The *iPill* can be programmed to deliver medication at set intervals.

Treatment and care. *IoT* has a great potential in treating and caring for patients both in the healthcare facility and at home. The expansion of the IoT segment in healthcare, and regularly sending the patient's health indicators to the treating physician responsible for the monitoring the patient's health status through transmitters, has made it possible for many people to live more comfortably. The clinic's staff analyzes each patient's health based on the requirements of the relevant technology, determines his/her needs and teaches him/her how to use IoT-enabled devices. The application of IoT in the field of patient monitoring in operating rooms, other emergency rooms, separate intensive care and post-operative care units has a great potential. In this case, transmitters can be used to measure a wide range of clinical indicators (heart rate, arterial pressure, pulse, brain activity, etc.). Customized IoT platforms with health data analytics enable medical personnel to monitor the condition and alert them to the need for medical intervention.

IoT solutions focus more on preventative care at home rather than emergency care. The use of appropriate technologies reduces the cost of medical services by reducing the demand for emergency services and visits to hospitals.

3.10 IoT Services and Applications in medicine

Currently, IoT technologies open up wide opportunities for the development of the following services and applications in the medical segment:

1) to increase the quality and efficiency of medical assistance service;

2) to perform collection, analysis and interpretation of various types of data;

3) to improve real-time decision-making;

4) to constantly monitor the health status of patients with dementia and chronic diseases or preventive intervention;

5) to create favorable conditions for the development of customized and personalized medicine, etc.

Research shows that there is no standard definition of an IoT service in the medical context. IoT technologies are expected to proliferate, each providing a large number of medical solutions, providing a variety of medical services. However, in exceptional cases, the service may be objectively separated from a specific solution or application [72]. In addition, it should be noted that the common services and protocols essential to the IoT infrastructure may require minor changes in the functionalization of the healthcare scenarios which they belong to. These include alerting service, shared resource access service, Internet service, cross-switching protocols for heterogeneous devices, and aggregation protocols for basic connectivity. Note that services are aimed at their creators, whereas the applications are used directly by users and patients.

Fig. 3.1 presents IoT-based medical services and applications that are currently more available and widespread.

IoT services in medicine are defined by:

1. Public healthcare. The rapid growth of healthcare expenditure has been a challenge for most countries of the world. In many developed and developing countries, the trend of population aging, "lifestyle diseases" (obesity and diabetes, memory problems, arthritis, etc.), a significant increase in patients with chronic diseases are considered the main factors of the extensive development of the medical care system [73].

Because of the policy in the field of public health, i.e., the traditional reactive health care model is now giving way to a preventive one. The latter involves monitoring the health status of people and predicting its change, preventing the development of diseases. The e-medicine technologies referred to in this model, especially IoT-based technological solutions, provide remote diagnosis, remote monitoring of chronic patients, monitoring of health status and, as a whole, achieve cost reduction in the healthcare system [20].

2. Mobile healthcare Internet. The mobile health (*m-Health*) industry comprises the medical data generation, collection and sharing through mobile and wireless devices.

According to [72, 74], *m-Health* consists of mobile computing complex, wearable transmitters and communication technologies for providing medical services. The theoretical foundation of the mobile Internet of Things (*m-IoT*) is a new model of healthcare connectivity. According to this model, *6LoWPAN* will be integrated into the advanced *4G* network for future *m-Health* Internet services. At this time, attention should be paid to the specific aspects determining the importance of direct interaction with people in the course of monitoring, diagnosis and treatment of *m-IoT*. These aspects should be considered in *m-IoT* architecture designing for e-medicine, solving context-dependent problems and ecosystems.

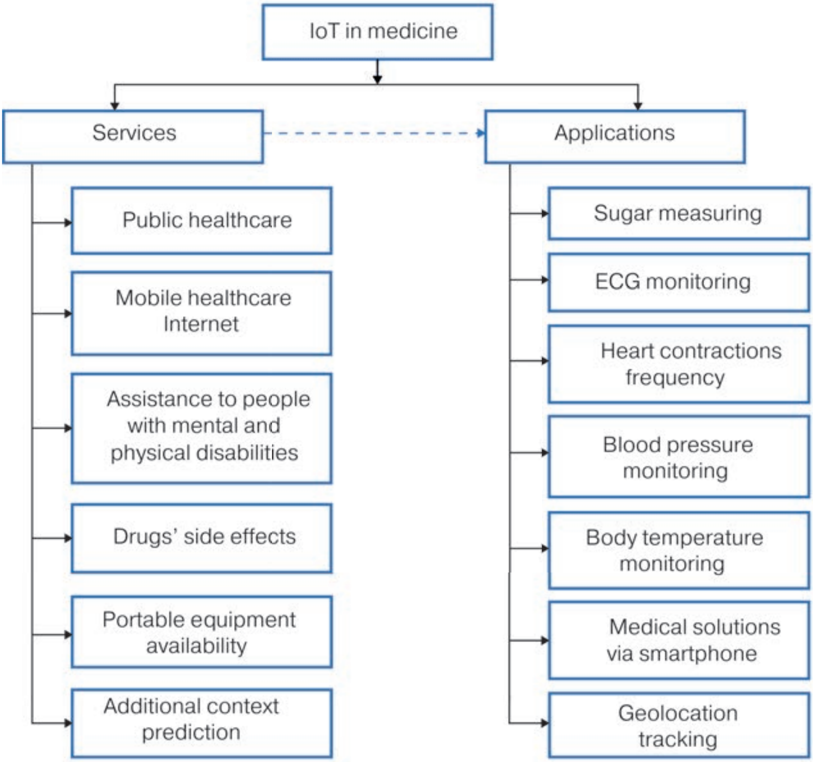

Fig. 3.1 IoT services and applications in e-medicine

3. IoT technologies for supporting the elderly. IoT technologies supporting the living environment it covers are designed to provide special services to the elderly and disabled. The essence of this technology is to ensure the independent life of the relevant category of people through modern technologies, especially IoT. Remote monitoring systems and transmission of alarms are designed to prevent potential dangers as falls, illness, etc. *GPS* transmitters installed in "smart" vehicles track the movement route of patients with limited mobility, activate the warning system in case of falls and exceeding the location boundaries, and the information panel shows their location. An open, secure and flexible platform based on IoT and cloud computing, which supports the surrounding environment, is described in [75].

4. Drugs' side effects. The World Health Organization concludes that the side effects of drugs are harmful to the body, dangerous, unintended reactions when taking certain doses of drugs used by a person for the prevention, diagnosis and (or) treatment of a disease, as well as for the correction and modification of physiological functions [76].

Side effects of drugs are revealed in the following cases:

1) after taking the first drug;

2) as a result of long-term drug intake;

3) in the process of taking two or more drugs together – in this case, the relevance of the effects of each drug to specific clinical situations should be evaluated.

A personalized system for drug availability verification using IoT is proposed in [23]. Mobile devices identify medications directly through contactless connections or barcodes. The suitability of the drug for the patient is checked with the help of an intelligent pharmaceutical information system organized from a database (description of drugs, active ingredients, side effects) and a knowledge base (rules for detecting allergies or adverse reactions to the drug).

This system checks the drug compatibility with the patient's electronic medical history, in particular with the allergic profiles of certain drugs. The use of such system in special risk facilities, including OOP, is of great importance for checking whether the drugs to be taken by the employees during the early elimination of health problems are useful or not.

5. Availability of wearable facilities. Ensuring IoT excellence is a complex task. Thus, its solution practically requires a revision of all issues, from the general architectural principles of the existing identification technologies that make up the modern Internet, the management of networks, to the provision of human rights and security. Today, a large number of different wearable transmitters have been developed for a wide range of medical applications, especially medical care based on wireless sensor networks. These transmitters are promising enough to provide relevant services in the IoT environment. Wearable devices can provide a set of functions realized based on the architectural principles of IoT. This necessitates the integration of existing transmitters into wearable IoT products. Researchers and developers dealing with the integration problem face many challenges related to the heterogeneous character of medical transmitters. In this context, mobile devices require a special service called accessibility. Already today, due to such a service, there are many applications for IoT based on wireless sensor networks scenarios. Thus, the IoT environment proposes solutions based on the use of mobile and wearable devices such as smartphones, tablets, smart-watches, wristbands to monitor a person's physiological state, systematically control the physical activity, etc. [77, 78]. The listed aspects make it necessary to use the latter on OOP.

6. Context recognition. One of the ways to improve the efficiency of IoT applications is to implement a context recognition service. The device's knowledge of its environment, its users, as well as the application context (for example, generating a location map to automatically display the user's current location) filter data and adapt to the application. The more contextual information an IoT device has, the more probably the necessary information will be automatically presented to the user.

When collecting contextual data through clinical transmitters, it is important to consider relevant temporal and spatial characteristics. If these characteristics do not coincide, the data reading can be confusing. Context can also play an important role in determining the security, confidentiality, performance, and availability requirements of transmitters' networks. This continues to be an area of active research [79].

Over time, the Internet of Things will enable us to receive more information from web services and nearby physical transmitters and share them with other devices. Consequently, the accuracy of received data and made decisions will increase. Future devices will be "smarter". The development of context-dependent systems, which operate in different ways depending on the context, provides an opportunity to respond adequately to the situation [80]. Developers of context-dependent medical systems in the IoT network base require the context prediction service to provide possible contexts. A predictive context framework for providing medical services is developed in [80], and an application of predictive context for remote medical monitoring in the IoT environment is presented in [81].

7. IoT Applications in medicine. The success of IoT depends on applications improving people's daily lives. A prerequisite for the processing of certain applications is the availability of transmitters for sending the appropriate data set. IoT applications are the programs or software systems designed to solve a specific problem [17].

IoT applications play an important role in e-medicine, directly used by users and patients. They track the location and health of people in other spheres, including special risk facilities. Below are the IoT applications supporting the vital medical indicators of a person, in this regard, to monitor the health status of employees on OOP, to detect their health problems up to the point of "emergency care" and to eliminate them by providing early assistance:

– *determining the amount of sugar*. Blood sugar monitoring detects the patterns of blood level changes and planning nutrition, activity, and medication timing [18];

– *ECG monitoring*. By recording the electrical activity of the heart in real time, an IoT-based system for identifying the heart's activity is proposed, which assesses the patient's condition in time and transmits the detected ECG errors to the data analysis center [25]. An algorithm complex for detecting ECG signals at a practical level for continuous ECG monitoring in the IoT environment is developed in [26]. Applications designed for ECG recording and monitoring, heart rate measurement and heart rhythm graphic representation, and subsequent data transfer to databases and web servers are proposed in [27];

– *heart rate*. Heart rate is characterized and measured by the number of heart beats per minute. The frequency of heart contractions depends significantly on the context, i.e., it increases after physical exercises, and changes by stress, lack of sleep, illness and drug intake [25, 26];

– *arterial pressure monitoring*. Arterial pressure is a blood pressure measured in the arteries. The threshold of blood pressure in arteries, veins and capillaries is different and one of the main indicators of the functional state of the body;

– *body temperature monitoring*. Body temperature monitoring is an integral part of medical care. This indicator is a vital parameter for maintaining homeostasis [32];

– *smartphones in the development of IoT solutions in medicine*. Transmitters controlled by smartphones have appeared in recent years. This increases the importance of smartphones in the development of IoT technologies. Medical applications for smartphones offer inexpensive solutions for both patients and a wide user audience. Early medical applications were developed for interaction with one transmitter, whereas now, there is a trend to develop multifunctional applications interacting with several sensor devices.

Smartphones are a successful tool for monitoring the health status and location tracking of employees on OOP and transmitting alert information to the employees and relevant officials on OOP.

8. Applications for geolocation tracking. Currently, there are mobile devices that monitor the patient's movement trajectory and alerting the emergency response service in case of dangerous situations, and they are equipped with information about their geolocation. For example, *Corvus-Tracker* application of the *Android* operating system, designed for tracking users' mobile devices. Applications for tracking "smart" things are becoming more widespread.

Modern systems for real time reporting geographic location in make it possible to find relevant objects. This feature necessitates the use of those systems to locate personnel on OOP and to alert people when they enter (or attempt to enter) restricted facilities.

3.11 IoT in medicine: risks and challenges

Analysts believe that medicine and healthcare will be the most widespread segment of *IoT* in the following five years. The main demand factor for this technology is the ability to establish direct contact with patients in the process of diagnosis and treatment. However, this factor directly connecting the *IoT* to the human body creates threats to his/her health, sometimes even fatal consequences, and conditions specific risks. On the other hand, the global connection, which collects, processes and automatically links a large amount of personal information, makes high demands on data security and protection of personal data, confidentiality [82–84].

Below are some of the risks and challenges arising during the implementation of medical IoT, which pose a threat to both the physical safety of patients and the confidentiality of their personal information:

– the risk of breaking the system delivering drugs installed in the human body, injecting a fatal dose for the patient into the system, not introducing the drug into the body in time;

– attacks on the transmission of the patient's vital health data collected on the monitor to the doctor's office via the network, the risks of system hacking, information theft;

– attacks on personal gadgets connected to IoT (remote control of cardiac pacemakers, diabetes support system, contact lenses supporting infrared vision, etc.);

– the problem of protecting data security and confidentiality as a result of the mobility and complexity of IoT;

– problems and requirements of personal data protection in the IoT environment capable of tracking and automatically linking a large amount of personal and individual data;

– high requirements for the guarantee of information security and confidentiality of patient data for IoT solution providers in healthcare (this leads to the increase in the price of IoT products and a decrease in their availability in the market);

– importance of identifying research on the security and confidentiality of IoT solutions for healthcare and proposing a more reliable security model;

– necessity of careful analysis of encryption technologies before using information received from wireless sensor networks or other networks in order to protect information during IoT implementation;

– uncertainty of data security and confidentiality issues in IoT, their legal interpretations;

– lack of unique standards and protocols of data transfer, which complicates the integration and cooperation of devices of different manufacturers in the IoT industry;

– technological challenges related to the transition to the *IPv6* protocol in the development of IoT and the energy supply of billions of new transmitters;

– presence of a psychological barrier such as patients, doctors and other medical professionals not trusting the machine providing IoT services in making important decisions;

– generation of the huge volume of data in the base of IoT solutions exceeding the volume characteristic of big data;

– traditional conservatism of patients and medical professionals, which is one of the main obstacles for the application of modern technologies.

These risks and challenges make it necessary to adopt appropriate programs and develop procedural rules and take security measures for the implementation of IoT solutions.

3.12 Conclusion

IoT technologies allow collecting and processing relevant data, analyzing them, and detecting potential problems along with the monitoring of the health and location of the personnel on OOP. Thus, the data received from smart devices during a certain period of time allows building the behavioral patterns of the personnel on OOP and providing the staff with clinical information based on the discrepancies recorded through expert assessment by the health monitoring results. One of the trends promoting the realization of these capabilities is the gradual reduction of the size of the connecting devices, which enhances the capability of wearable devices to be implanted to the human body. In this case, microscopic transmitters installed in the human body (inside) and body-worn devices allow the collection of objective information and the control of the treatment process (at any point of the world). This increases the probability of the provision of medical care before undesirable and unpleasant situations occur.

Today, many countries recognize that IoT is capable to radically change human resources management in the world as a whole, as well as in certain areas, particularly those at risky sites. Unquestionably, many countries are developing the strategies and guidelines for installing IoT technologies at special risk sites (coal mines, mines, oil platforms, etc.), and conducting research on different segments of IoT. Based on IoT applications and services, monitoring the health of people on OOP and tracking their location will detect the problems arisen in their condition before "emergency care", eliminate them with early medical intervention, and prevent undesirable situations that may occur due to the human factor. Therefore, the use of IoT to protect the health of employees on OOP requires a deep understanding of the essence of these technologies, changing the views of consumers, relevant officials, and medical professionals regarding its benefits, and preventing their traditional conservatism, and the presented article will be beneficial in this field.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

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CHAPTER 4

Methodological approaches to the intelligent human factor management on an offshore oil and gas platforms

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Abstract

This chapter overviews the problems of increasing the efficiency of safety and health management of shift workers in offshore oil and gas industry through the prism of the human factor. It studies the specific features of the environment, hazards and risks, working conditions and professional activities in the offshore sector. The fields of safety and health management of personnel employed on offshore oil platforms are highlighted. It is shown that, despite the sufficient elaboration of the knowledge base on health hazards and mechanisms for their elimination in the traditional system of occupational safety and health protection, the safety and health issues related directly to the human factor have not explored so far. The state-of-the-art of the problem of personnel safety and health in the context of the human factor is investigated. The concept of a human-centered approach to personnel safety and health management is proposed, implying the inclusion of employees in the control loop as the main component in their contextual environment. This involves continuous remote monitoring of vital health indicators of employees and, at the same time, parameters of the context-dependent environment of each of them, and an expert assessment of the deviation of these parameters from the norm. Based on IoT technologies and e-health solutions, a functional model of a system for continuous remote monitoring of the health of workers during the period of their shift on offshore oil platforms is developed. The architecture and principles of functioning of a distributed intelligent health management system for shift workers in the offshore industry are proposed.

Keywords

Offshore oil and gas industry, human-centered approach, IoT, continuous remote monitoring, expert assessment, intelligent health management system.

 DOI: 10.21303/978-9916-9850-2-1.ch4

4.1 Introduction

The offshore oil and gas industry is one of the leading sectors in the industry and plays a key role in the global oil and gas supply. The growing demand for oil amongst the depletion of onshore hydrocarbon reserves has contributed to the intensification of work on the exploration of hydrocarbon deposits and their production on sea shelf. Currently, offshore fields produce about 40 % of oil and 30 % of gas. According to the agreed experts' estimates, in the next 20–30 years, the deepwater fields (from 400 m to 1.5 km) and ultra-deepwater (from 1.5 km and more) fields will become the main source of expansion of hydrocarbon production [1]. Oil and gas corporations are interested in the development of such fields. It increases the relevance of the task of implementing deep-water projects for the exploration and production of hydrocarbons on a global scale [2].

Meanwhile, as the depth of production increases, the distance of the offshore structure from the coast, the hardness and thickness of the rock, the exploration and development of new oil and gas fields are becoming more capital-intensive and science-intensive processes. A steady trend towards the development of hydrocarbon resources in more "difficult" conditions requires the use of high-tech equipment, new innovative methods for collecting, transmitting and processing a large amount of information received from geographically distributed offshore objects [3, 4]. The use of Internet of Things (IoT) solutions can contribute to the formation of effective strategies for the development of offshore fields for reducing operating costs and increasing the level of hydrocarbon production. Currently, large oil and gas corporations are beginning to implement IoT for continuous monitoring and control of exploration, production and transportation of hydrocarbons, ensuring the safety of special offshore drilling facilities [5, 6].

However, achieving production efficiency only on the basis of digitalization of various operational processes does not seem realistic. Today, a large number of skilled workers and specialists are involved in many of the operational processes of the oil and gas industry, whose functional duties and work activities are associated with potential hazards and health risks. Therefore, the task of improving the efficiency of management of safety and health of workers is an essential part of the oil and gas industry at all stages of the life cycle of the oil and gas business. At the same time, the problem of health management of workers is becoming especially relevant in the offshore oil and gas industry, which is classified as a segment of increased danger to the health of workers [7, 8].

According to experts, the use of IoT technology is one of the challenges for the future development of the offshore oil and gas industry [5]. Moreover, the concept and tools of Industry 4.0 provide an opportunity for the development of IoT-based cyber-physical systems [9], allowing in the future to partially or completely depersonalize the operational processes implemented in the offshore oil and gas segment (OOGS) of the industry [6]. Moreover, we share the opinion of the authors who believe that a person will be present in the management circuit of the oil and gas industry for a long time, and, in particular, in the OOGS. Therefore, digital transformation, first of all, should be aimed at creating an Ambient intelligence for the professional activities and daily life of oil workers [10, 11].

This chapter explores the problems of managing the safety and health of workers employed on offshore oil platforms, based on modern digital technologies.

4.2 Problem statement

Currently, there is a tendency towards wide digitalization of the oil and gas industry. The digital transformation of the industry is stimulated by the emergence of such technological innovations as communication networks for the machine-to-machine (M2M) data sharing [12], wireless sensor networks (WSN), IoT technologies [13–17], as well as a large number of IoT applications and industrial services (Industrial IoT, IIoT) [18]. Moreover, many types of equipment in the oil and gas industry are already supplied with smart sensors for various purposes, which, at various stages of the development of oil and gas fields, collect large amounts of previously inaccessible information online, share the collected data and transmit it for processing [12–20]. Expanding the capabilities of IoT and its scope through integration with WSN, modern storage tools, analytical processing of a large amount of heterogeneous data (cloud computing, big data, real-time decision support systems) allows data acquisition to support informed decisions [21–25].

Analysis of electronic sources demonstrates a significant increase in the interest of researchers and developers in solving industrial safety problems in the oil and gas industry using the potential of IoT. The growing awareness of oil companies about the wide possibilities of the IoT in supporting industrial safety and decision-making in the processes of search, exploration and development of fields, production activities, asset management and remote monitoring have stimulated large-scale investments in this sector [26–31]. In 2019, total IoT investment and funding in the oil and gas industry accounted for 284 million USD, with a particular focus on the development of IoT analytic platforms and cloud services for oil and gas supply chain applications. According to experts, by 2024 investments in the global IoT in the oil and gas market are estimated to account for 43.48 billion USD, increasing by an average of 21.86 % annually over the period 2019–2024 [32, 33].

However, it should be noted that the development and application of IoT solutions to support the safety and health of workers (personnel) are not discussed sufficiently [34–39]. At the same time, the development of technologies and the emergence of intelligent wearable, body-worn and implant sensors (smart watches, bracelets, bandages, patches, sensors placed under the skin or inside body), Wireless Body Area Networks (WBAN) [40–43], GPS and mobile devices (smartphones, tablets) [44–46] have opened up unprecedented opportunities for remote monitoring of the health status of workers, including those employed in industries with an increased health risk for a long time without restrictions on their professional activity [47–49].

The relevance of the problem is confirmed by statistical data, according to which the workers in the oil and gas industry are 8 times more likely to be injured [50, 51]. Thus, according to the US Bureau of Labor Statistics, in 2016, 300 fatal and more than 410 thousand non-fatal industrial injuries were registered in the private sector of the oil refining industry [52]. According to the statistics from the UK Health and Safety Executive (HSE), in 2016–2017, 19 fatal and 60 thousand non-fatal accidents were registered. Moreover, the total cost of payments accounted for more than 700 million USD [53]. According to the statistics provided by the Centers for Disease Control and Prevention (CDC), from January 2015 to January 2017, oil and gas workers were involved in 602 incidents, 481 hospitalizations and 166 amputations [54]. According to the statistics of the State Oil Company of the Azerbaijan Republic (SOCAR) [55], in 2016–2018, 32 accidents were registered, 12 out of which were fatal.

The above data on incidents (fatal incidents and accidents) confirm the need to develop an effective safety and health management system for human resources in the oil and gas industry [51, 56, 57].

4.3 The human factor in the offshore oil and gas segment

The oil and gas industry is inherently hazardous to the health and safety of workers. OOGS of the industry refers to the objects of increased danger.

Obviously, oil extraction from offshore fields is performed using various types of special oil drilling facilities. These structures represent a complex oil and gas field engineering and technical complex designed for drilling and development of wells, oil and gas production, lying in the depth of the sea, ocean or other water environment. At the same time, one platform can accommodate up to 80 wells and, as a rule, is attached to the bottom with tons of tethered cables. To date, a significant part of offshore oil facilities (hereinafter we will use the term “offshore oil platforms”) are equipped for the residence and work of personnel [58]. The technological cycle of work on offshore oil platforms (OOP), associated with drilling, production, transportation, storage of oil and oil products, repair and maintenance of equipment and pumps, is rather complicated and fire hazardous [59, 60].

4.3.1 Specific features of OOP through the prism of human factor

Offshore development and operation of oil and gas fields takes place in difficult and often extreme working and living conditions. Analysis of literary sources through the prism of the human factor allows to identify the following specific factors:

1. Attracting a significant number of human resources to various operations and production processes at geographically distributed offshore facilities and structures of OOP [34, 60, 61].
2. Complexity of exploration and production of new hydrocarbon reserves in offshore zone, which are implemented in hazardous and hard-to-reach places [7, 8].
3. Exposure of human resources to risk factors of various nature, affecting their physiological state and behavior, increasing the probability of making mistakes and involvement in emergency situations [48, 50, 51].
4. Risks of release of radioactive substances, the presence in crude oil of hazardous contaminants that pose a threat to life and health of human resources employed in offshore oil and gas industry [50, 51].
5. Deterioration of equipment, oil and gas leaks during their development, transportation and processing, endangering the safety and health of workers.
6. Serious consequences of accidents (death and injury of people, damage to environment, etc.), necessitating the need to improve monitoring and control methods for the safety and health of workers [62, 63].

4.3.2 Features of working conditions and professional activities of workers at OOP

The study of the activities of shift workers engaged in offshore development and operation of oil and gas fields, through the prism of the impact of working conditions, daily life and external factors on their health, makes it possible to systematize following features:

1. Work and living in confined spaces and polluted environments that increase the risk of infectious diseases and the danger to the life of workers [64].

2. A twelve-hour shift work schedule during a certain time interval (often two weeks), which is a source of psychosocial risks, stress [65], depression [66].

3. Fatigue of employees as a result of irregular working hours and stressful working conditions, assessed as one of the most dangerous risks of making mistakes and accidents [67–69].

4. Exposure of employees to hazardous and harmful factors (industrial noise, vibration, exposure to oil and its components) that threaten health and life [4, 70].

5. Unfavorable external factors (cold, wind, fog, dust, rain, storm) that affect the physical condition, work capacity and labor productivity [69].

"Unsafe" behavior of offshore workers, which is one of the main causes of emergencies [71].

6. Leading positions in the structure of occupational diseases of oil workers, which are diseases of the cardiovascular system, disorders of the musculoskeletal system, hypertension, diabetes, skin problems, hearing loss due to industrial noise [70, 72–74].

4.3.3 Safety and health management of human resources employed in public health services

The management of safety and health of human resources in the oil and gas industry is implemented in two interrelated and interdependent areas:

1) safety of working conditions, workplaces and the environment associated with the elimination of hazards and risks to the health of personnel;

2) health protection and elimination of dangers of diseases [50, 51]. Likewise, the safety and health issues of shift workers employed by OOP can also be considered in two main ways.

The first area involves reducing the risks to health of employees by:

a) preventing potential hazards and minimizing the risks to life and health of personnel;

b) improving the working conditions and safety of workplaces by tracking the parameters of raw materials and the environment (exceeded temperatures, noise and dust, hazardous chemicals, etc.);

c) developing the methods for increasing the reliability of equipment and safety of traumatic agents (machines, mechanisms, devices, etc.);

d) systematic training of personnel in mastering new technologies, labor safety rules and regulations, etc.

Today, relatively stable knowledge basis has been formed about health hazards in the oil and gas industry, including on the shelf [4, 50, 51, 63, 75].

Traditionally, experienced specialists (experts) are involved in oil and gas production to prevent emergency situations and minimize hazards. However, against the background of a shortage of qualified workers, aging processes and a natural outflow of experienced specialists, the constant complication of technologies, keeping experts at each local site becomes an almost impossible task for companies [76–78]. At the same time, existing rules and standards of labor safety, fixed in regulatory documents, mainly represent the requirements for the safety of workplaces, the environment, and equipment. However, despite the constant improvement of regulatory documents that take into account technological innovations, the number of incidents caused by the human factor remains quite high (more than 70 % of crashes and accidents in the oil and gas industry). This fact, recognized in recent years by large oil and gas companies, prompts those companies to pay more attention to the role of the human component in ensuring safety and health at all stages of the life cycle of industry:

1. Upstream – Exploration and Production.
2. Midstream – Transportation, Storage and Marketing.
3. Downstream – Refining, Sales and Distribution [35, 50, 51, 56, 57, 60].

To date, the issues of the manifestation of the human factor in the system of safety and health of workers of OOGS are not given sufficient attention in the scientific literature. This determines the relevance of the choice and research of the second area.

The second area is directly related to a person who is the most important participant in production processes in the oil and gas complex. The multifaceted nature of the representation of the human factor, the serious and often unforeseen consequences of human erroneous decisions at high-risk facilities, as well as poor knowledge of the nature and causes of this phenomenon predetermine the need to develop new approaches to its study.

Scientific studies [7, 34, 35, 39, 51, 61] do not include unambiguous interpretation of the concept of "human factor". Analysis of the existing definitions of this phrase shows that the content of each of them is attributed to the characteristics of the object under study, the role of a person in hazardous production, the goal and the tasks to be solved.

In this case, the specific *object of research* is shift workers, whose activities are associated with various production processes on OOP, equipped for human living and work. The *task of research* is the development of modern technologies for managing the health and safety of shift workers, allowing to minimize the impact of the human factor. The *human factor* on OOP is referred to the possibility of committing erroneous actions by a person under current circumstances, i.e. making wrong decisions that caused this or that incident.

Let's assume that the probability of making erroneous decisions by any member of the personnel directly depends on the psychophysiological state of its health, which determines its behavior, activity during the shift on OOP. Therefore, the state of health, as the most important characteristic and the main component of human resources, directly affects all its professional activities [79]. Thus, analysis of the causes of accidents on offshore oil platforms shows that most of them are associated with an unforeseen deterioration of the health of employees, loss of consciousness, exhaustion, "unsafe" behavior, inadequate response and making wrong decisions in emergency situations, etc. The deterioration of the health of employees in the period they perform their functional duties and reside on OOP can affect their actions and decisions made, cause a violation of standards of conduct and safety measures, and lead to incidents. Therefore, the preservation and strengthening of health at the workplace, the timely identification of the reasons for the deterioration of the state of health make it possible to successfully cope with physiological, psychological and social stress and improve the functional capabilities of workers [80].

This actualizes the need for systematic remote monitoring of the health and safety of workers in the environment of their work and life. Continuous remote monitoring of the health and safety of workers during the shift, will allow timely identification of the causes of deterioration in health of workers on OOP and elimination of the impact of human factor [40, 81].

Despite the close interaction of the above two areas for ensuring the safety and health of workers, each of them has its own scientific and methodological specifics. However, with the development and implementation of modern intelligent technologies in the processes of ensuring safety and health, and, in particular, the IoT and supporting technologies, there is a gradual integration of these two areas within the concept of a "connected" worker. For example, the introduction of appropriate IoT solutions can provide continuous remote access of OOP personnel (authorized persons, individual employees) to the knowledge and advice of experienced specialists (supervisors, drilling engineers, labor safety inspectors, medical workers, etc.). Moreover, through feedback received from OOP, IoT technology will provide experts with real information about the current situation, specific workplaces, location and health status of workers in various geo-zones of OOP, the dynamics of the development of a particular hazard, etc. Collection and mining of the data continuously generated by sensors installed in wells, equipment and other oil and gas fields can play an important role in improving models for supporting workplace safety. Sensors designed for continuous monitoring of personnel health indicators in their contextual environment, i.e. position of posture, availability of personal protective equipment taking into account the location, will help reduce the risk of accidents and industrial injuries [37, 38, 81].

4.4 Digital transformation of the oil and gas industry as a key factor in improving the safety and health of personnel on OOP

Currently, the work on the implementation of IoT, wireless technologies and intelligent analytical tools in a wide range of production processes and operations of the oil and gas industry and its offshore segment have not been widely implemented yet [82–84]. The main reason for this is the lack of sufficient data, which is associated with barriers of a technological and infrastructural, as well as managerial and financial nature. For example, sensors and measuring instruments that record diagnostic and operational information are connected by cable wires mainly with the dispatch center on OOP. As a result of the lack of the necessary infrastructure, the information recorded by the sensors cannot be transferred to the shore to the situational centers responsible for the safety and health of personnel on OOGS facilities. This is due to both the specificity of the standards of incoming signals and the inability of traditional cable technologies to remote data transmission. Meanwhile, modern infrastructure for collecting, transferring and processing large amounts of data through digital technologies of Industry 4.0 (IoT, cloud computing, artificial intelligence, Big Data, blockchain, etc.) requires significant financial and temporary resources. New data governance models are needed to create effective tools for data handling and generating value from it.

Today, digital transformation is taking place in oil and gas companies located on almost all continents of the world. The portfolio of many leading oil and gas companies has not only strategies or programs, but specific digital services have already been created and are being implemented to solve some production and operational problems of oil and gas. These companies aim at full coverage of all links of the value chain (exploration and production, transportation and storage, processing and marketing) [26–28].

Let's note that the decline in oil prices has contributed to traditionally conservative oil and gas companies to perform more moderate assessment of the possibilities of new digital technologies in increasing the efficiency of basic processes and decision-making. This has led to a significant growth of companies that have recently begun to develop strategies and programs for the development of the industry and carry out reforms in the framework of pilot projects [30, 31, 78, 85–87].

The analysis of electronic sources shows that today the human factor in the system of ensuring the health of workers in the oil and gas industry and, in particular, shift workers on OOP, have been poorly studied. The development of technologies and the complication of production processes determine the multidimensional nature of possible representation of human factor in the emergence of the threat of incidents. This, in turn, causes an urgent need to develop new approaches to prevent or minimize the impact of human factor at high-risk facilities and, in particular, on OOP [31, 88, 89]. From our point of view, continuous remote monitoring of health of OOP personnel through IoT solutions can be an effective solution to minimize the human factor. In this case, remote monitoring of the health of OOP personnel involves (**Fig. 4.1**):

– continuous tracking of vital indicators of the physiological state of workers during the shift on OOP;

– real-time tracking of activity (movement) of individuals, identification of each employee and determination of its exact location (geolocation) on OOP, including in dangerous, obscure and prohibited areas;

– remote control of the use of mandatory personal protective equipment by each employee, as well as continuous monitoring of the state of environment surrounding an individual employee;

– online collection, transmission and operational processing of information about the physical condition (position) of workers (falling, loss of consciousness, etc.), their behavior (actions), ensuring timely decision-making to eliminate dangerous situation;

– systematic collection and accumulation of data on the dynamics of vital indicators of the health of employees, necessary for a systematic analysis of the state of health taking into account the demographic parameters and the prognosis of early symptoms of a particular disease;

– formation of a data base containing retrospective information on the dynamics of vital health indicators of personnel during the shift, data on the results of regular pre-shift examinations and appointments, information on adopted medical and diagnostic decisions, prescribed medications, updated with current data from systematically conducted monitoring, etc.;

– access to data about the health of each employee using electronic health cards, which are regularly updated electronic analogues of the medical history of certain individuals, containing demographic indicators (age, gender, residential information, education, professional skills, etc.) and data collected from all medical organizations that the employee has contacted throughout its life [90–92];

– development of a single digital integration platform, which could:

1) consolidate a set of isolated heterogeneous data characterizing safety and health taking into account the demographic parameters;

2) identify threats and risks of incidents and injuries associated with the human factor;

3) conduct a comprehensive analysis of all monitored data to generate reliable analytics that support operational decisions on the management of safety and health of workers, which track the health status of personnel and their environment during the work shift on OOP.

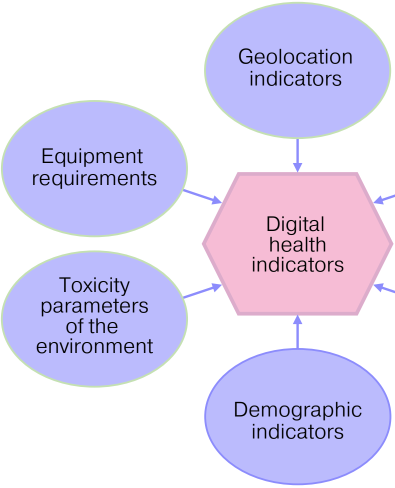

Fig. 4.1 Human-centered approach to health and safety management

The lack of reliable information about the health status of workers in the context-related environment of the latter (geolocation, activity, behavior, level of gas pollution) makes it difficult to make informed expert decisions on taking measures to prevent incidents on OOP adequate to the current situation. The development of IoT solutions for continuous remote monitoring of the health status of personnel and context-dependent parameters and characteristics that directly affect vital health indicators during the shift work on OOP can reduce the risks of emergency situations associated with the human factor.

Taking into account the above, the goal of this study is to develop IoT-based concept and methodological approaches to the synthesis of architecture of an intelligent health management system for shift workers employed in OOGS.

4.5 Conceptual problem statement

The main idea of the proposed concept is a human-centered approach to personnel safety and health management, which implies inclusion of employees themselves as one of the most important components in the management loop. In this case, a human-centered approach to safety and health management involves continuous remote monitoring of vital health indicators of workers and, at the same time, the parameters of context-dependent environment of each of them. Address geolocation coordinates, behavioral models (including those related to the observance of labor safety standards by each employee), activity, state of posture, gas pollution of the environment, etc., can be taken as the parameters of the context-dependent environment. At its core, the IoT platform in the personnel safety and health management system as a tool for continuous remote monitoring of various context-dependent parameters, which directly or indirectly affect the values of vital physiological indicators of workers, provides a “snapshot” of the health status of the latter in their immediate surroundings.

IoT system detects the facts of deviation of certain indicators and parameters from the norm and, in typical situations, automatically develops solutions that exclude human factor. In non-standard situations, all relevant information and real-time solutions offered by IoT system are provided to interested services and their authorized persons (supervisors, doctors, occupational safety specialists, experts), enable the latter to find out the reasons for deviations of indicators from standard values and make appropriate decisions.

The concept of a human-centered approach to the synthesis of an intelligent health management system for shift workers in OOGS involves the development of:

1) methodological approaches to continuous remote monitoring of the physiological state of shift workers based on IoT technologies and e-health solutions, taking into account context-related information;

2) architecture of the intelligent health management system for shift workers;

3) network architecture that supports the processes of remote monitoring and control of the safety and health of personnel during the shift on OOP.

The strategic goal of continuous monitoring of the health and safety of personnel working on OOP is the interaction with each employee, the systematic collection and accumulation of personalized information, the formation of a sufficiently representative and regularly updated database on the dynamics of their health status after a certain time. Embedding this base into the architecture of an intelligent personnel health management system as a module of a dynamic database and joint analytical processing of current and retrospective data will allow to objectively assess the trends of changes in the health status of each employee, make informed and objective decisions to eliminate problems that adversely affect the health of personnel in a short, medium and long term.

IoT technologies, as the basis for a personalized remote monitoring system, will enable to:

1) collect up-to-date information about vital health indicators of personnel and parameters of surrounding environment;

2) identify the deviation of the monitored indicators and parameters from the typical values and standards;

3) create a dynamic database on deviations of health status and context-dependent parameters from norms and standards during the entire shift on OOP;

4) identify the correlation between the state of health, "unsafe" behavior of employee and production factors on the basis of analytical processing of the accumulated information.

Conceptually, a human-centered approach to the management of the health of shift workers on OOP can be divided into three main stages (subtasks) (**Fig. 4.2**).

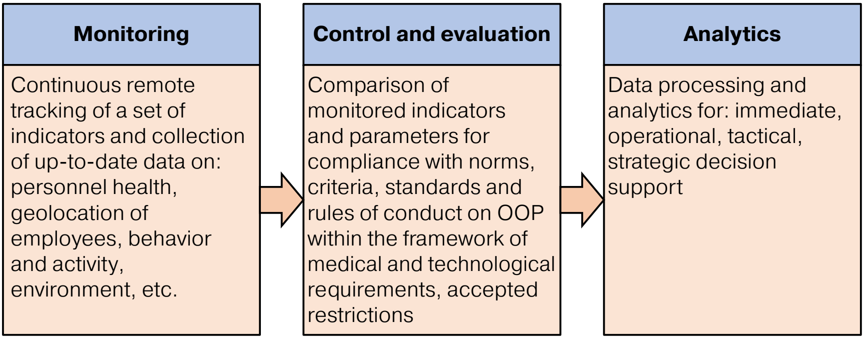

Fig. 4.2 Functional model of health management of OOP personnel

Based on a three-stage functional model of the personnel health management process, the architecture of the "Digital Health" system is developed, which is a multilevel intelligent information system for the health management of OOP personnel.

4.6 Architecture and principles of functioning of intelligent health management system

Before proceeding to the exploration of IoT possibilities in ensuring the safety and health of personnel employed in the oil and gas industry, and in particular in the offshore oil and gas sector, let's briefly outline the essence of the concept of this technology.

4.6.1 IoT architecture

IoT is a network of physical devices with built-in sensors, detectors, electronics, which are uniquely identified, are capable to connect to the network, collect and share data via wired and wireless networks without human intervention [19]. The IoT platform operates on three levels [18, 93–96]:

1. Sensor level represents various objects, extended by embedded systems and smart sensors. The purpose of the sensor level is to collect the necessary data through sensors, process it and transfer it to the network level.

2. Network layer is intended for routing, receives information from sensors and transfers it to IoT devices or applications through data transmission channels without human intervention [18]. Physical objects and devices (things) connect to each other, to the Internet (cloud) through *Gateways* using wireless communication (*Wi-Fi*, *Bluetooth*, *LPWAN*, etc.).

3. Application level (control center) receives data from the network level (from gateways), stores, processes and accumulates it to search for knowledge and then form decisions on its basis. Control Center consists of only two levels, i.e. network and application levels. Technically, application layer is a server with software that analyzes different data sets based on special algorithms for decisions. This level contains many different applications that are activated depending on the tasks assigned [93].

4.6.2 Architecture of shift worker health management system

In accordance with the conceptual approach and functional model described above, the architecture of an intelligent health management system for shift workers in OOGS, which we call "Digital Health", is proposed. The system has a hierarchical structure, in which each of the three levels is geographically distributed, is a target intelligent information system with its own purpose and functions. At the same time, each of the systems is integrated into a single decision process for managing the health of shift workers in OOGS. In this case, OOP personnel acts as a biological object, which is equipped with body-worn and/or wearable devices that generate different data varying for purposes. Body-worn and wearable devices (mono- and multi-functional gadgets in the form of bracelets or watches, bandages, etc.) are personal portable electronic devices (biosensors, trackers) with built-in wireless communication elements that can interact with the environment and the user, record, accumulate, process and transmit data. Smart sensors, RFID-tags (issued to each employee), GPS-trackers built into wearable devices continuously monitor physiological health indicators (temperature, heart rate, blood pressure, etc.), parameters, characteristics and coordinates of geolocation, activity and behavior of each employee. Additionally, special sensors can be attached to the personnel's clothing to detect gas concentration in the air. The use of IoT technology based on wearable technologies and address identification of the necessary parameters allows to actually obtain context-related information about the health status of each employee taking into account the demographic parameters and referring to a specific object, date and time. This information is reliably and securely transmitted in real time to appropriate services, from the position of geographical location and environmental condition (dispatch center on OOP, doctors and security specialists onshore).

The configuration of sensors and settings in IoT platform can be changed and expanded depending on the specific tasks and needs of user. **Table 4.1** shows a set of most informative tracked parameters included in the functionality configuration of Industrial IoT applications. **Table 4.1** presents the types of the most informative monitored parameters.

IoT system is capable of simultaneously transmitting sensed data to various control centers (servers) located both in the horizontal plane (at one level) and hierarchically distributed over many levels.

Table 4.1 Types of monitored parameters

Parameters	Component
Vital health indicators	– temperature; – pulse; – pressure; – heart rate (based on cardiogram recording); – complete blood count; – blood oxygen level; – blood sugar level; – galvanic skin reaction, etc.
Geolocation, activity, behavior	– location determination (using GPS and RFID systems) on platform; – being in a recreation area, incl. rest control; – being in the working area, incl. control of working hours and compliance with labor safety; – monitoring the approach to the energized zone/equipment; – control of going beyond the perimeter and entering prohibited, blind areas (danger of falling overboard), etc.
Condition and posture	– control of the availability of personal protective equipment and the necessary portable equipment; – control of falls/slips (with the provision of automatic signals about an employee's falling); – personal identification; – alarm button; – (SOS); – alarm signaling (warning); – presence of voice communication and instant messages; – video surveillance (photo/video camera) capable to interpret collected indicators for a quick assessment of the general condition

Fig. 4.3 shows the architecture of the intelligent health management system "Digital Health" for shift workers.

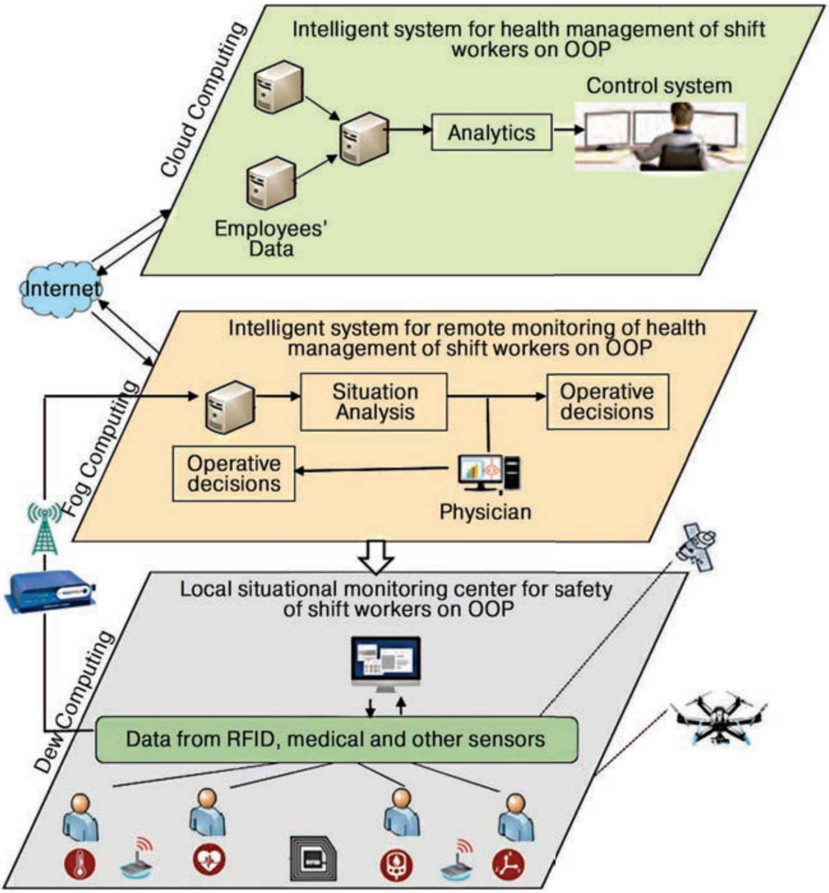

Fig. 4.3 Conceptual model of the "Digital Health" intelligent system

As **the first level** of "Digital Health" system, an IoT solution implemented at the place of residence of the staff, i.e. on OOP, is proposed. When it is possible to include the proposed health management system of shift workers of separate level on OOP into the architecture, we were guided by the consideration that, first of all, urgent decisions related to the elimination of health hazards and the provision of immediate first aid have to be supported at the place of accident. Data collection, processing and analysis is implemented through Dew computing, which provides real-time decision making ensuring low latency in data processing. Targeted data of workers recorded by sensors and RFID through wearable device and smartphone used as a gateway is transmitted via wireless or wired communication to the Local Situation Center for Emergency Response (LSCER) on OOP. LSCER is a computerized workplace of persons responsible for health and safety of workers on OOP. Physically, this is a local computer (Dew data center) designed to receive and analyze incoming data streams on health and safety of workers during the shift. IoT continuously compares the normative (reference), initial (pre-shift) and current (real) values of monitored health indicators and parameters of the contextual environment of workers. As long as all data of workers and their environments is within acceptable limits, nothing is transferred to local computer (Dew data center). As soon as the values of any health indicators and/or coordinates and parameters recorded by sensors go beyond the typical range, these data are sent to local IoT application for processing, analysis and decision-making. IoT application (IIS), equipped with special analytical tools and intelligent algorithms, identifies changes in the health of each employee and deviations of environmental parameters from standards and offers solutions for their elimination.

The second level of the structure of “Digital Health” system supports the remote monitoring management processes in the onshore Specialized Medical Unit through IoT solutions. The need for continuous remote monitoring is due to a number of significant factors. Thus, the personnel work on OOP, which are located at a distance from several hundred meters to several tens of kilometers from specialized medical services. Often, in the event of critical situations related to the health of workers, decision makers responsible for making immediate decisions on OOP do not have sufficient knowledge and qualifications both to interpret and implement the recommendations generated by the IoT system on OOP, and to provide adequate medical assistance to the current situation. Therefore, communication with “onshore” team of medical and safety specialists is a prerequisite for timely qualified medical intervention and taking control actions. However, in this case, medical specialists must have real and reliable information about the dynamics of the vital health indicators of the victims and the circumstances that provoked the deterioration of their condition.

The third level of the architecture of “Digital Health” system is designed to manage the personal health trajectory of shift workers based on IoT solutions. The importance of this module lies in the fact that the results of processing of continuously recorded data on the current state of health of shift workers in long term, systematically accumulated in the database, will make it possible to trace change trends in the state of health of shift workers. The obtained analytical data as an evidence base will make it possible to make informed strategic decisions to improve the management of health, safety and career paths of each employee.

In the proposed architecture of the personnel health management system, all the working functions of the IoT system (data collection, processing, solution synthesis, data storage) are integrated into the following hierarchically distributed computing levels:

1. ***Dew computing*** is intended for continuous data recording by sensors, processing of the latter, and synthesis of local solutions, primarily in the smallest local network (*Dew*), i.e. the data is processed and analyzed offline where it is collected. This allows for data processing with low latency and making urgent decisions (almost in real-time) to ensure the crew safety on OOP (for example, identification of an employee approaching a prohibited zone, fixing a fall, voice communication or a signal to immediately withdraw from a dangerous zone, emergency decisions to eliminate critical situation or provide medical assistance at place). At the same time, it opens up an opportunity for more efficient use of local devices, through which *Dew computing* can provide services and functions on OOP in online and offline modes. *Dew Computing* makes up for the main disadvantage of cloud computing that is the requirement for a stable Internet connection, which is not always possible to ensure on remote OOP. However, in the latter case, the length of time increases during which the cloud will be unavailable and there will be a need to provide qualified medical support and decision-making at a higher level. To overcome this problem, an additional layer – fog computing is introduced, which is a layer between cloud and dew computing [95].

2. ***Fog computing*** is designed for making operational decisions synthesized by an IoT application in specialized data centers and directed both to the lower computing level (*Dew*) to take operational control actions, and to the upper level (*Cloud*) for more detailed analysis. The main advantage of *Fog computing* is data processing without the need to transfer it to large *Cloud* data centers, which reduces the load on the latter. Further, mobility of *Fog* technologies and possibility of geographic location of data centers (*Fog* servers) in the most convenient locations close to the user accelerates the processing and analysis of data from wearable sensors and making operational decisions in accordance with the current situation at *Dew level*. *Fog computing* is often performed on low-power and dispersed computers that do not unnecessarily communicate with cloud. The integration of *Fog computing* into IoT applications contributes to the efficiency of remote health monitoring [96].

3. ***Cloud computing*** intended for a thorough and comprehensive analysis of:

a) data accumulated from the Fog level (IoT gateway), recorded on the fact of deviations of various health indicators, context-related information and decisions made;

b) targeted retrospective, pre-shift, initial and starting medical data of workers;

c) electronic medical records of workers using powerful modern analytical tools (Big Data, ML, Soft computing, etc.).

The purpose of such a comprehensive coverage of employee data for analysis is to increase the validity of decisions made, to reveal hidden dependencies between different indicators for the synthesis of decisions in critical situations. They are delivered to the lower levels of *Fog* and *Dew* computing (for example, making decisions about the urgent evacuation of an injured employee).

4.6.3 Principles of functioning of distributed intelligent system Digital Health

The general principles of functioning of DIS Digital Health in the context of structural layers, proposed in the work, are as follows:

1. All three layers of DIS Digital Health along with many specific applications are equipped with a unique IoT application (software) for each of them. This application is an intelligent information system (IIS) based on a functional model of health management of personnel employed on OOP (**Fig. 4.3**).

2. Modules of IIS database include digitized ranges of changes in normative, edge and critical values of each health indicator (temperature, pulse, pressure, heart rate, etc.), information on standards (reference images) of activity and behavior within the framework of technological requirements and restrictions, authorized and prohibited formats and coordinates of access to hazardous geo-zones (in accordance with the map of drilling rig, working and residential sites, explosive zones on OOP, etc.), permissible limits and level of excess environmental toxicity.

3. IIS knowledge base contains cognitive information linking the expert assessments and decisions with granules of possible values of various indicators and parameters, including critical ones, provoking the emergency situations on OOP.

4. The process of continuous health and safety monitoring of workers employed on OOP generates a huge amount of data, which is problematic to analyze through traditional methods. This leads to the inclusion of high-performance algorithms and analytical tools into the analytical unit of computing platforms DIS Digital Health.

5. IoT monitors in parallel the streams of sensed data of all workers on OOP, compares them with the normative (reference) health status templates, behavioral patterns, geolocation and environmental parameters pre-recorded in IIS databases and knowledge bases, and identifies the deviation rate of a particular indicator and parameter in real time.

6. IoT, instantly analyzing the current situation, reveals the deviation of certain indicators and parameters from the norm and analyzes the current situation. Depending on the criticality of the situation, the degree of its compliance with already known (typical) models, or the identification of new patterns, decision can be made according to two scenarios:

1) automatic formation of a control action by the system;

2) real time data redirecting to emergency response services to make an operational decision.

4.6.4 Scenario for implementing a distributed intelligent system for managing the personnel's health on OOP

An IoT system based on intelligent algorithms automatically (without human intervention) analyzes data and synthesizes a diagnostic solution that can be implemented in accordance with two scenarios (**Fig. 4.3**).

Scenario 1: a decision automatically made by the IoT system as a response to a critical situation instantly acts as a control effect in the local situational center for emergency response (LSCER) on OOP. In this scenario, an IoT system for continuous remote monitoring of the health status of personnel employed on OOP can be considered as a platform that ensures the integration of the real physical world with the virtual world of computing processes, i.e., as a cyber-physical system (CPS), functioning without human intervention in the control loop (human out of loop) [97]. In this case, the connected object is an employee equipped with unique identifiers and sensors to track the health status of the latter in their environment. Sensors interact with the virtual world, i.e., transmit collected data wirelessly online to a computer (Fog and Cloud data centers) for analysis and development of analytics. Automatically made decisions to eliminate health risks based on the analytics results are sent for execution to the LSCER on OOP.

Scenario 2: the decision automatically synthesized by the IoT system is transferred to the responsible clinician (expert) for evaluation and confirmation. The doctor evaluates the results of the data analysis, involving, if necessary, specialists in the field, and makes a final decision, which, within a given period of time, is transferred to OOP for execution. The cyber-physical model of this scenario assumes maintaining a human expert (clinician, supervisor, safety engineer, etc.) in the control loop for remote monitoring of the health and safety of employees on OOP (human in the loop) [12, 98].

Currently, the designed IoT platforms mainly provide the stage of redirecting electronic diagnostic data by a "smart" system to the responsible clinician for a final decision. This is due to the specifics of the monitoring object (person), the high cost of an error (threat to human health and life), as well as the psychological factor. Moreover, the system provides clinicians with the necessary contextual and background information to reduce diagnostic errors and quickly make informed decisions [99]. The results of real-time remote data analysis enable specialists to identify early symptoms of certain pathologies and risks in the nearest onshore Fog data center and warn employees and decision-makers on OOP about this.

4.7 Discussion

The issues of increasing the level of industrial safety, improving working conditions aimed at reducing the rate of accidents, industrial injuries and occupational diseases of employees are the main priorities of companies producing oil and gas onshore and offshore. These issues are associated, first of all, with the complexity of technical devices and technological processes, the danger of oil and gas operations, and the specifics of professional activities on OOP especially in offshore segment. As shown above, when solving the problems of supporting labor safety and health protection of workers on OOP, it is also possible to take into account the physical nature of workers and the multifaceted manifestations of human factor, which in extreme situations can cause incidents. Today, oil and gas companies are experiencing an acute need for technologies that could provide them with real-time complete and correct information about the actual state of safety and health of personnel working on remote OOPs. The availability of such information will allow them to get a holistic picture of the situation on OOP and control it by making timely decisions to eliminate potential threats, including those related to human factor. The digital transformation of the industry, including the offshore segment, allows oil and gas companies to create a fundamentally new IoT-based infrastructure for collecting, remote transmission and processing of heterogeneous data on the safety and health of workers during the shift on OOP. The proposed concept of a person-centered approach to industrial safety, which implies the inclusion of an employee (person) in the control loop as the main component in the environment of its professional and daily activities on OOP, can contribute to improving the management of safety and health of employees. In accordance with the concept, the possibility of making erroneous decisions by an individual employee directly depends on the physiological state of health and determines the behavior and activity of the latter during the shift on OOP. Thus, the deterioration of the health status of workers during the period of their functional duties and residence on OOP can affect their actions and decisions made, cause a violation of standards of behavior and safety measures, and lead to incidents. IoT solutions take into account human nature in hazardous production. Continuous remote tracking of workers' health and context-dependent information, instant advanced analytical processing of a huge stream of consolidated real data provide an opportunity to timely identify changes in the health status of workers, establish the reasons provoking unsafe behavior, make timely informed decisions in emergency situations that eliminate or minimize the human factor.

Based on the proposed concept and functional model of the personnel health management process, we develop architecture and principles of functioning of an intelligent health management system for shift workers in OOGS based on IoT infrastructure and e-health solutions. Geographically distributed over three layers, IoT monitoring system based on wearable devices and smart sensors constantly monitors an individual worker and its surroundings. Moreover, each level in the management hierarchy is an intelligent information decision support system that has its own purpose and functions. At the same time, all three systems are logically integrated into a single decision support process for managing the health of shift workers in OOGS.

4.8 Conclusions

A human being is the most valuable and at the same time the most vulnerable link in the chain of the life cycle of the oil and gas industry, which is fraught with danger to the health and safety of workers. The challenge of continuously improving the efficiency of employee's safety and health management, particularly in offshore industry, is a critical part of the oil and gas industry. The study of the specifics of professional activity shows that offshore development and operation of oil and gas fields occur in difficult and often extreme working and living conditions. This often leads to an unforeseen deterioration of the health of employees, fatigue, "unsafe" behavior and actions that provoke the emergency situations which require the immediate intervention of decision maker. However, the lack of real and reliable information about both the health status of workers and the situation at places, the collection and analysis of which takes some time, makes it difficult to take acceptable measures to prevent an incident.

In this article, as an effective solution to this problem, we proposed conceptual approaches to the development of a system for continuous remote monitoring of the health status of personnel working on OOP in its immediate contextual environment based on IoT and e-health solutions. Immediate analytical processing of constantly generated data on vital health indicators of workers and context-dependent information referred to a specific date and time will reduce the risks of emergency situations associated with the human factor.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

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CHAPTER 5

Decision support in a remote health monitoring system for shift workers on an offshore oil platform

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Abstract

This chapter proposes a methodological approach for the decision synthesis in a geographically distributed intelligent health management system for oil workers working in offshore industry. The decision-making methodology is based on the concept of a person-centered approach to managing the health and safety of personnel, which implies the inclusion of employees as the main component in the control loop. In this chapter, a functional model of the health management system for workers employed on offshore oil platforms id developed and implemented through three phased operations that is monitoring and assessing the health indicators and environmental parameters of each employee, and making decisions. These interacting operations combine the levels of a distributed intelligent health management system. The paper offers the general principles of functioning of a distributed intelligent system for managing the health of workers in the context of structural components and computing platforms. It presents appropriate approaches to the implementation of decision support processes and describes one of the possible methods for evaluating the generated data and making decisions using fuzzy pattern recognition. The models of a fuzzy ideal image and fuzzy real images of the health status of an employee are developed and an algorithm is described for expert assessment of the deviation of generated medical parameters from the norm. The chapter also compiles the rules to form the knowledge bases of a distributed intelligent system for remote continuous monitoring. It is assumed that embedding this base into the intelligent system architecture will objectively assess the trends in the health status of workers and make informed decisions to eliminate certain problems.

Keywords

Offshore oil platforms, Internet of things, distributed intelligent health management system, expert assessment, decision making.

 DOI: 10.21303/978-9916-9850-2-1.ch5

5.1 Introduction

The oil and gas companies are interested in developing technologies and tools to monitor the health status and environment of employees during their work [1, 2]. Acquiring and evaluating real time information on the health status of each employee and making automatic decisions according to the critical situation and providing prompt feedback will allow for more effective management of each employee's health, as well as the prevention of accidents due to the human factor, and these are currently possible with the application of digital technologies, especially IoT technologies [3, 4]. However, it should be noted that the development and application of IoT solutions to eliminate possible representation of the human factor and to support the health and safety of workers in oil and gas industry and, particularly, the offshore industry has been poorly studied yet [5, 6], although in a number of increased risk facilities, such studies are already being carried out. Thus, [7] highlights the possibilities of modern network platforms and applications for solving healthcare problems based on IoT. The approach to remote health monitoring proposed in [8] based on non-invasive and wearable sensors and modern information and communication technologies is an effective solution to support the elderly living in comfortable home conditions. These systems allow medical staff to monitor important physiological signs of their patients in real time, assess health status and provide feedback from remote facilities. The paper [9] shows the possibilities of using IoT applications in healthcare, in particular for the physiological monitoring of personnel involved in firefighting. [10] reviews published research related to the implementation of IoT in high-risk industries focusing on various areas of healthcare, food logistics (FSC), mining and energy industries.

In paper [11], the authors highlight the problem of effective management of the health and safety of shift workers on an offshore oil platform (OOP) from the perspective of human factors. The specific aspects of the environment, dangers and risks, labor and professional activity conditions On the OOP are studied, and the possibilities of applying IoT to ensure the health and safety of employees are analyzed in detail. The possibilities of integrating IoTs with cloud, Big Data, artificial intelligence technologies for the systematic monitoring of the health status of employees, monitoring their safety, and making appropriate decisions if necessary are shown. In the following research of the authors, a new conceptual approach is proposed for the development of a continuous remote monitoring system of the health status of employees working on the OOP in the environmental context based on the Internet of Things ecosystem and smart medicine (e-medicine) solutions for the prevention of accidents caused by the human factor. According to this concept, the architecture-technological and functionalization principles of the geographically distributed multi-level intelligent system are developed for the management of the workers' health and safety [12, 13]. The main idea of the concept is to improve the safety of oil workers through the introduction of a human-centered approach to managing their health. This approach implies the inclusion of worker themselves in the management loop as the main component. "Placing" people (workers) at the center of the personnel health and safety management system enables linking the vital health indicators of each employee with the context of the environment and reasonably assessing the criticality of current situation.

In paper [14, 15], based on informative parameters of health status of workers employed in OOP, a decision-making technique is proposed to identify the current health status of workers using fuzzy pattern recognition methods.

5.2 Materials and methods

An analysis of the professional activities of workers involved in the offshore development and operation of oil and gas fields, through the prism of the impact of working conditions, everyday life and external factors on their health, shows that offshore development and operation of oil and gas fields take place in difficult and often extreme working and living conditions [5–7]. An analysis of the causes of accidents shows that many of them are associated with an unforeseen health deterioration of workers [11, 16]. Available rules and standards of labor safety fixed in regulatory documents mainly include the requirements for the safety of workplaces, the environment, and equipment. However, despite the constant improvement of regulatory documents considering technological innovations, the number of incidents caused by the human factor remains quite high (more than 70 % of accidents and incidents in the oil and gas industry) [17, 18].

Human factor on OOP refers to the possibility of person committing erroneous actions under certain conditions or making wrong decisions caused an incident. In such situations, the subjectivity of nature and the psychophysiological characteristics of a person are manifested [12]. Therefore, the human factor in hazardous production begins to pose danger rather than the production itself. Based on this, let's assume that the likelihood of making erroneous decisions by any employees directly depends on the state of health affects his/her behavior, as well as on the nature of his/her actions and activity during the shift on platform. This actualizes the need for systematic remote monitoring of health and safety of workers in their working and living environment.

Basing on IoT and e-health solutions, the works [12, 13] develop architecture of a distributed intelligent system (DIS) for managing the health and safety of workers employed in OOPs. Architecture of intelligent health management system for shift workers in OOS has a hierarchical structure, in which each of the three geographically distributed layers is a target intelligent information system (IIS) with particular purpose and functions (**Fig. 5.1**). All three layers are integrated into a single decision support process and ensure the functioning of system as a whole.

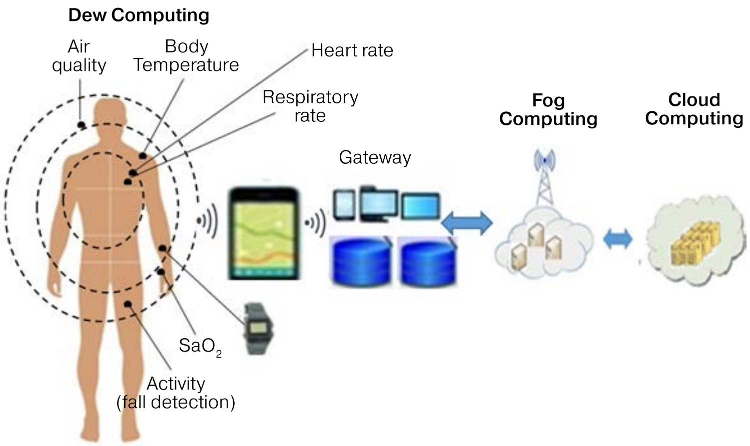

Fig. 5.1 The architecture of an intelligent health management system for workers employed on OOP

At this stage of research [12, 13], we review the mechanism for remote monitoring of the health and safety of OOP personnel at the methodological and architectural and technological levels.

A human-centered approach to health and safety managing involves continuous remote monitoring of the workers' vital health indicators and, at the same time, the parameters of the context-sensitive environment of each of them.

The current (actual) situation here refers to a model (image) of the real health status of an employee, which is shaped upon the fact of deviation of continuously sensed health indicators and relevant context-sensitive information from regulations, accepted restrictions, standards, safety rules, etc.

Smart sensors, GPS trackers built into wearable devices and active RFID tags issued to each employee continuously monitor the physiological health indicators of workers on OOP (temperature, pulse, blood pressure, etc.), parameters, geolocation characteristics and coordinates, activity, and employee's behavior through the prism of compliance with labor safety standards and rules.

In the course of continuous monitoring of the workers' health and safety, a large amount of data on the workers' health status is generated, which complicates analysis through traditional methods. This leads to the development of intelligent algorithms for automatic (without human intervention) data analysis and synthesis of diagnostic decision.

Thus, the aim of this research is in development decision-making technique is proposed to identify the current health status of workers. To achieve this aim, the following problems are stated:

– to develop the principles of functioning of distributed intelligent system determining the approaches to the implementation of decision-making processes;

– to develop an algorithm for assessing the current situation on the health status of an employee;

– to make decisions on the health status of an employee.

This chapter proposes one of the possible options for the analytical implementation of the functioning of the DIS for managing the health and safety of workers employed on OOP, including tools for assessing and analyzing data and making decisions.

5.3 Results

5.3.1 Principles of functioning of distributed intelligent system determining approaches to the implementation of decision-making processes

The functional model of the health management system of OOP personnel is implemented by tracking vital indicators of the physiological state and parameters of the environment of the following stages:

– tracking, i.e., continuous remote monitoring of vital health status indicators of the personnel and environment settings;

– monitoring and evaluation, i.e., comparison of monitored health indicators for compliance with standards in terms of medical requirements and specified restrictions;

– decision making, i.e., data processing and analytics to support decision making.

These interacting operations distributed across the DIS levels, are the links in decision-making process. The principle of DIS functioning in the context of structural layers are as follows:

1. All three layers of DIS along with many specific applications are equipped with a unique IoT application (software) for each of them. This application is an intelligent information system (IIS) based on a functional model of health management of personnel employed on OOP (**Fig. 5.1**).

2. Modules of IIS database include digitized ranges of changes in normative, edge and critical values of each health indicator (temperature, pulse, pressure, heart rate, etc.), information on standards (reference images) of activity and behavior within the framework of technological requirements and restrictions, authorized and prohibited formats and coordinates of access to hazardous geo-zones (in accordance with the map of drilling rig, working and residential sites, explosive zones on OOP, etc.), permissible limits and level of excess environmental toxicity.

3. IIS knowledge base contains cognitive information linking the expert assessments and decisions with granules of possible values of various indicators and parameters, including critical ones, provoking the emergency situations on OOP.

4. The process of continuous health and safety monitoring of workers employed on OOP generates a huge amount of data, which is problematic to analyze through traditional methods. Therefore, it is assumed that the analytical block of DIS computing platforms based on IoT solutions includes high-performance algorithms and intelligent analytical tools (Decision support tools, Softcomputing, Big Data, Machine Learning).

5. IoT monitors in parallel the streams of sensed data of all workers on OOP, compares them with the normative (reference) health status templates, behavioral patterns, geolocation and environmental parameters pre-recorded in IIS databases and knowledge bases, and identifies the deviation rate of a particular indicator and parameter in real time.

6. IoT, instantly analyzing the current situation, reveals the deviation of certain indicators and parameters from the norm and analyzes the current situation.

Depending on the criticality of the situation, the degree of its compliance with already known (typical) models, or the identification of new patterns, decision can be made according to two scenarios:

1) automatic formation of a control action by the system;

2) real time data redirecting to emergency response services to make an operational decision.

5.3.2 Assessing the current situation on the health status of employees

IoT-based geographically distributed intelligent health management system described above instantly analyzes the current situation, detects deviations of certain indicators from the norm and assesses the current situation. If the indicator values deviate from the norm, i.e., are beyond the normative range, the situation is assessed as critical and the monitoring system decides on the execution of specific actions depending on the criticality of situation (e.g., low critical, medium critical, high critical).

In other cases, the monitoring system records the facts of deviation of certain indicators from the etalon value of the parameter within the standard range and sends this information to the system database. In this case, depending on the parameter value, the following situations are possible: ideal reference, average reference, reference at the criticality edge.

Information systematically accumulated over a certain period of time will identify current changes in the health status of each employee and make informed decisions on managing their personal trajectories.

Fuzzy logic is an effective mathematical tool to identify the deviation rate of various health indicators from the norm (also from ideal) and determine the relationship between the deviation values and their expert estimates [19]. Depending on the task, various approaches, algorithms and methods for its solution are possible.

In this case, the task is reduced to the development of a methodology for determining the ideal and current (real) health status of workers and identifying the deviation degree between them. Depending on the compliance degree of indicators from the ideal value, the decision-making problem is reduced to the recognition of fuzzy images [20]. This necessitates:

– the development of models of a fuzzy ideal image and fuzzy real images of the health status of an employee located on the OOP;

– the development of an algorithm for assessing the deviation of generated medical parameters from the ideal.

5.3.2.1 Development of models of a fuzzy ideal image and fuzzy real images of the health status of an employee

Let:

$$A \quad A_1, A_2, \ldots, A_k$$

or

$$A \quad A_i, i \quad \overline{1,k}$$

be a set of workers located on the OOP and *k* – total number employee located on the OOP and provided with IoT devices for measuring medical indicators;

$$X \quad x_1, x_2, \ldots, x_n$$

or

$$X \quad x_j, j \quad \overline{1,n}$$

be vital signs of the worker's health and *n* is total number vital signs of the worker's health.

The model *D*=(*X*) of the ideal image of the health of a worker employed in the OOP can be described by a matrix $D_X = \left\| x_j \right\|_n$, where the row D_X characterizes his/her ideal state. The ideal state of health of an employee within the framework of reference and regulatory requirements, specified restrictions on specific medical indicators x_j is determined in the form of fuzzy sets with a membership function

$$_{x_j}(D) : D \quad X \qquad [0.98,1].$$

Let the model *B*=(*X*) be a real image of the health status of an employee, which is formed based on medical data obtained from IoT applications. *B*=(*X*) can be described by a matrix $B_X = \left\| x_{ij} \right\|_{kn}$, where each row $B_i(i = \overline{1,k})$ characterizes the current state of health of a particular employee x_{ij}, $j = \overline{1,n}$, located on the OOP and provided with IoT devices for measuring medical indicators.

The degree to provide the real state of health of an employee B_i with medical indicators x_{ij} is determined in the form of fuzzy sets with membership functions $_{x_{ij}}(B_i) : B \quad X \qquad [0,1]$, expressing the current level of the health status of a particular employee *i*.

In fact, there are two sets of fuzzy situations describing the ideal health status of an employee $\widetilde{D}$ and the actual health status of an individual employee $\widetilde{B_i}$ during a shift on the OOP:

$$\tilde{D} \qquad _{x_n} \; D \qquad _D(x_j)/X \; ; \; \tilde{B}_i \qquad _{x_{kn}} \; B_i \qquad _{B_i}(x_j)/X \; .$$

Here, the set $\tilde{D} \quad _D(x_j)/X \; , j \quad \overline{1,n}$ describes a fuzzy ideal situation, whereas the set $\tilde{B}_i \quad _{B_i}(x_j)/X \; , i \quad \overline{1,k}, j \quad \overline{1,n}$ describes fuzzy real situations.

5.3.2.2 Algorithm for assessing the deviation of generated medical parameters from the ideal condition

Data on health status received from IoT applications varies in its physical nature and is fuzzy. The fuzziness of health indicators is determined by the possibility of their change in various ranges, characterizing their representation intensity. These circumstances predetermine the need for scaling the input information, i.e., bringing all parameters of the health status to a generalized dimensionless indicator. The main scaling problems include the choice of an acceptable scale *X* and the choice of the affiliation function φ(*x*). The following requirements are applied to the choice of the scale:

1. Possibility of describing numerical and dimensionless information to ensure comparability of parameters of different physical nature.
2. Universality, applicability to parametric and non-parametric input information.
3. Possibility of describing the definition area for any values of all medical parameters of the health status.

When estimating the intensity of representation of signs by an expert, the followings are taken into account [19]:

1. Qualitative character of estimates.
2. Approximate estimates.
3. Symmetry of gradations of opposite estimates depending on the ideal value of the medical parameter.
4. The use of 5÷7 gradation in parameter estimation.

Thus, assessment of the deviation of real images of the health status of an employee from a fuzzy ideal image necessitates the use of a universal fuzzy scale to determine the compliance of the current parameter value with the ideal one. The advantage of the fuzzy universal scale is the ability to assess the compliance of the current medical parameters' values with the ideal one in a single term-set of linguistic variables [19].

Below, let's propose an approach to constructing a fuzzy universal scale for assessing the deviation of generated medical parameters from the norm, which covers the implementation of the following algorithm:

1) the ideal value of the parameter x_{id} is determined (for example, for the temperature parameter $x_{id} = 36.6\,°$);

2) the minimum xmin values and maximum x_{max} values of the subject scale *X* are determined, which are corresponding to the lower and upper limits of the values of the medical parameter (this takes into account the symmetry of these values, i.e., $x_{id} = (x_{min} + x_{max})/2$, e.g., for the temperature parameter $x_{max} = 42\,°$, it can be assumed $x_{min} = 31.2\,°$);

3) taking into account the accepted limits for inclusion and equality of two situations, the lower limits (x_{ll}) and upper limits (x_{ul}) of the range of parameter changes [x_{ll}; x_{ul}] within the norm, a certain value is assigned from the interval [0; 1], for example, 0.7, and it is assumed $(x_{ll}) \quad (x_{ul}) \quad 0.7$ (for example, the range of temperature parameter change can be taken [35.2 °; 38.0 °]). In other cases, i.e., for parameter values from the range [x_{min}; x_{ll}] (the parameter value is below the norm) and [x_{ul}; x_{max}] (the parameter value is above the norm) correspond to the affiliation function with a value from the interval [0; 0.7], taking into account that $(x_{\min}) \quad (x_{\max}) \quad 0;$

4) segments [x_{min}; x_{id}] and [x_{id}; x_{max}] are divided into several parts (for example, into 6 parts), depending on the choice of qualitative gradations of the linguistic variable "deviation of the real value of the medical parameter from the ideal one" and the corresponding change ranges of the value of the parameter and situation are determined. Further, depending on the severity of the linguistic variable, each level is assigned a fuzzy area from the interval [0; 1], representing the change area of the affiliation functions of fuzzy sets of verbal gradations of the linguistic variable (**Table 5.1**).

Fig. 5.2 provides a visual description of the proposed universal scale.

Table 5.1 Range of membership functions of fuzzy sets of verbal gradations "deviations of the real values of medical parameters from the ideal"

Linguistic variable	Term sets of a linguistic variable	Situation	Change ranges of parameter value x	Range of terms on the scale
1	2	3	4	5
Deviation of real value of medical parameter from ideal	Slight deviation	Ideal reference	$x_{id} \quad \frac{x_{id} \quad x_{l.l.}}{3}; x_{id}) \; or$ $x_{id}; x_{id} \quad \frac{x_{u.l.} \quad x_{id}}{3}$	[0.90; 1)
	Very low deviation	Average reference	$x_{id} \quad 2\frac{x_{id} \quad x_{l.l.}}{3}; \frac{x_{id} \quad x_{l.l.}}{3}) \; or$ $x_{id} \quad \frac{x_{u.l.} \quad x_{id}}{3}; 2\frac{x_{u.l.} \quad x_{id}}{3}$	[0.80; 0.90)
	Low deviation	Reference at the egde of critical	$x_{l.l.}; x_{id} \quad 2\frac{x_{id} \quad x_{l.l.}}{3}) \; or$ $x_{id} \quad 2\frac{x_{u.l.} \quad x_{id}}{3}; x_{u.l.}$	[0.70; 0.80)

Continuation of Table 5.1

1	2	3	4	5
	Low deviation	Reference at the egde of critical	$x_{l.l.}; x_{id} \quad 2\frac{x_{id} \quad x_{l.l.}}{3}) \;\; or$ $x_{id} \quad 2\frac{x_{u.l.} \quad x_{id}}{3}; x_{u.l.}$	[0.70; 0.80)
	Significant deviation	Low critical	$x_{l.l.} \quad \frac{x_{ll} \quad x_{\min}}{3}; x_{ll} \;\; or$ $x_{iul}; x_{iul} \quad \frac{x_{\max} \quad x_{ul}}{3};$	[0.50; 0.70)
	High deviation	Average critical	$x_{l.l.} \quad 2\frac{x_{ll} \quad x_{\min}}{3}; x_{l.l.} \quad \frac{x_{ll} \quad x_{\min}}{3} \;\; or$ $x_{iul} \quad \frac{x_{\max} \quad x_{ul}}{3}; x_{iul} \quad 2\frac{x_{\max} \quad x_{ul}}{3};$	[0.30; 0.50)
	Very high deviation	High critical	$x_{\min}; x_{l.l.} \quad 2\frac{x_{ll} \quad x_{\min}}{3} \;\; or$ $x_{iul} \quad 2\frac{x_{\max} \quad x_{ul}}{3}; x_{\max}$	[0; 0.30)

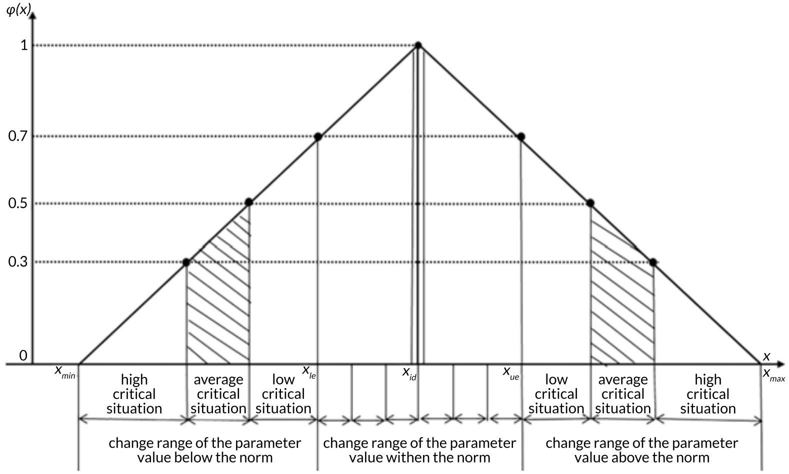

Fig. 5.2 Universal fuzzy scale showing the correspondence of the medical parameters' value with the ideal value

For each situation, the affiliation function in a fuzzy set defined in the interval [0; 1] can be selected based on the expert assessment. There are different approaches to the formation of a single collective value based on individual experts' assessment [21, 22].

According to [21], the sought collective value of the situation under consideration is perceived as the intersection of the individual values of individual experts in the same fuzzy set.

[22] accepts the value occupying the "middle position" in relation to external values in the set of individual values as the collective single value of the individual values included in the same fuzzy set. Thus, according to the approach proposed in [22], the affiliation function value in fuzzy sets is determined.

Based on these results, the rules for expressing the affiliation function representing the compliance of the current values of medical parameters with the ideal one, are as follows:

$$If\ ((x_{id} \quad \frac{x_{id} \quad x_{l.l.}}{3} \quad x \quad x_{id}) \quad (x_{id} \quad x \quad x_{id} \quad \frac{x_{u.l.} \quad x_{id}}{3}))$$
$$then \quad (x) \quad 0.91.$$

$$If\ ((x_{id} \quad 2\frac{x_{id} \quad x_{l.l.}}{3} \quad x \quad x_{id} \quad \frac{x_{id} \quad x_{l.l.}}{3}) \quad (x_{id} \quad \frac{x_{u.l.} \quad x_{id}}{3} \quad x \quad x_{id} \quad 2\frac{x_{u.l.} \quad x_{id}}{3}))$$
$$then \quad (x) \quad 0.8.$$

$$If\ ((x_{l.l.} \quad x \quad x_{id} \quad 2\frac{x_{id} \quad x_{l.l.}}{3}) \quad (x_{id} \quad 2\frac{x_{u.l.} \quad x_{id}}{3} \quad x \quad x_{u.l.}))$$
$$then \quad (x) \quad 0.71.$$

$$If\ ((x_{l.l.} \quad \frac{x_{ll} \quad x_{\min}}{3} \quad x \quad x_{ll}) \quad (x_{iul} \quad x \quad x_{iul} \quad \frac{x_{\max} \quad x_{ul}}{3}))$$
$$then \quad (x) \quad 0.6.$$

$$If\ ((x_{l.l.} \quad 2\frac{x_{ll} \quad x_{\min}}{3} \quad x \quad x_{l.l.} \quad \frac{x_{ll} \quad x_{\min}}{3}) \quad (x_{iul} \quad \frac{x_{\max} \quad x_{ul}}{3} \quad x \quad x_{iul} \quad 2\frac{x_{\max} \quad x_{ul}}{3}))$$
$$then \quad (x) \quad 0.4.$$

$$If\ ((x_{\min} \quad x \quad x_{l.l.} \quad 2\frac{x_{ll} \quad x_{\min}}{3}) \quad (x_{iul} \quad 2\frac{x_{\max} \quad x_{ul}}{3} \quad x \quad x_{\max}))$$
$$then \quad (x) \quad 0.15.$$

5.3.3 Decision-making on the health status of an employee

As noted above, depending on the deviation degree of certain medical indicators from the ideal value, the task of decision-making on the health status of an employee is reduced to the fuzzy image recognition. The search and decision-making in this case is reduced to comparing the fuzzy real image of the health status of each employee with the fuzzy ideal image and to identifying the compliance degree. In this setting, decision-making (logical inference) about the health status of an employee is based on the situational management using the measures to determine the proximity degree of two fuzzy situations. Various measures for determining the degree of similarity between two fuzzy situations including one-step or multi-step estimation procedures are discussed in [20].

In the present work, the degree of fuzzy inclusion of situation $\tilde{B}_i$ into situation $\tilde{D}$ and the degree of fuzzy equality $\tilde{B}_i$ and $\tilde{D}$ were used as the measures of estimation of the degree of proximity of fuzzy real and ideal situations.

1. According to [20], the degree of fuzzy inclusion of situation $\tilde{B}_i$ into situation $\tilde{D}$ is defined as follows:

$$(\tilde{B}_i,\tilde{D}) \quad \& \; (\quad _{B_i}(x_j), \quad _D(x_j)) \quad \underset{x_j \quad X}{\&} (\max(1 \quad _{B_i}(x_j), \quad _D(x_j))) \qquad (5.1)$$
$$\min(\max(1 \quad _{B_i}(x_j), \quad _D(x_j))).$$

The situation $\tilde{B}_i$ is considered fuzzily included into situation $\widetilde{D}(\widetilde{B}_i \subseteq \widetilde{D})$ if the degree of inclusion of $\tilde{B}_i$ into $\tilde{D}$ is not less than some threshold of inclusion $\quad [0.7;1]$ defined by the management conditions, i.e. $(\widetilde{B}_i,\widetilde{D}) \quad .$

In other words, the situation $\tilde{B}_i$ is fuzzy included in the situation $\tilde{D}$ if the fuzzy values of the indicators $\tilde{B}_i$ (fuzzy real values of the medical indicators of a particular employee *i*) are fuzzy included in the indicators' values of the situation $\tilde{D}$ (fuzzy ideal values of the employee's medical indicators).

2. The degree of fuzzy equality (equivalence) as a measure for determination of proximity of any two fuzzy situations is based on the following reasoning. Let the threshold of equality of two situations (e.g., $\quad [0.7;1]$) is set and there are situations which mutually include each other, i.e. $B_i \subset D$ and $D \quad B_i, \; i \quad \overline{1,k},$ ($\underset{\sim}{\subset}$ is the sign of a fuzzy inclusion), then situations $\tilde{B}_i$ and $\tilde{D}$ are considered approximately equal. Such similarity of situations called fuzzy equality is determined from the expression:

$$(\widetilde{B}_i,\widetilde{D}) \quad (\widetilde{B}_i,\widetilde{D})\&(\widetilde{D},\widetilde{B}_i) \quad \& \; (\quad _{B_i}(x_j), \quad _D(x_j) \qquad (5.2)$$
$$\min_{x_j \quad X} \min(\max(1 \quad _{B_i}(x_j), \quad _D(x_j)), \max(1 \quad _D(x_j), \quad _{B_i}(x_j))) \; .$$

The situations $\tilde{B}_i$ and $\tilde{D}$ are considered fuzzily equal $\widetilde{B}_i \approx \widetilde{D}$ if:

$$(\tilde{B}_i,\tilde{D}) \quad , \quad 0.7;1 ,$$

where ψ is some threshold of fuzzy equality of situations.

Following the determination of the degree of fuzzy equality (equivalence) of the fuzzy ideal image and fuzzy real images of the employee's health status, decisions are made. In this regard, according to **Table 5.1**, the following rules are introduced in advance into the knowledge base of the intelligent system for continuous remote monitoring of the workers' health status:

$$If \quad (\tilde{B}_i,\tilde{D}) \quad 0.90;1$$

$$then \text{ "}employee\text{'}s\ health\ status\ is\ very\ good\text{"};$$

$$If \quad (\tilde{B}_i,\tilde{D}) \quad 0.80;0.90$$

$$then \text{ "}employee\text{'}s\ health\ status\ is\ good\text{"};$$

$$If \quad (\tilde{B}_i,\tilde{D}) \quad 0.70;0.80$$

$$then \text{ "}employee\text{'}s\ health\ status\ is\ approaching\ a\ critical\ point\text{"};$$

$$If \quad (\tilde{B}_i,\tilde{D}) \quad 0.50;0.70$$

$$then \text{ "}employee\text{'}s\ health\ status\ is\ critical\text{"};$$

$$If \left(\mu(B_i,D) \rightarrow \left[0.75;0.80\right]\right)$$

$$then \text{ "}employee\text{'}s\ health\ status\ is\ very\ critical\text{"};$$

$$If \left(\mu(B_i,D) \rightarrow \left[0.70;0.75\right)\right)$$

$$then \text{ "}employee\text{'}s\ health\ status\ is\ extremely\ critical\text{"}.$$

The systematic collection and accumulation of such information will make it possible to assess trends in the health status of workers.

5.4 Systematic monitoring of employees on OOP and identification of psychological health conditions and deviations

Taking measures to protect the employees' health allows them to successfully address the physiological, psychological and social situation, improve their functional capabilities, and most importantly, to make better decisions in non-standard situations.

In the given context, to prevent accidents on OOP, it is important to systematically monitor the OOP members' health status in the work environment (before and after the shift) and to determine their suitability for the position with a comprehensive assessment of the results.

It is possible to refer to various psychological tests for monitoring. [23] justifies the emphasis on the Cattell test to assess the professional qualities of seafarers in the recruitment process. [24] offers to develop an intelligent system for monitoring the psychophysiological condition of sailors with the reference to the Cattell test. Therefore, it is considered appropriate to refer to the Cattell test for the monitoring of a member on OOP performing a certain task. The Cattell test is the most popular multifactorial method to examine a person on 16 factors and determine his/her psychological state. Using the test results, it is necessary to use the quality levels of natural language to assess the ability of employees on OOP performing their duties, which makes the fuzziness inevitable. Therefore, a fuzzy mathematical logic apparatus is used to assess the member on OOP seafarers' professional qualities [19]. Problem solution starts with:

– linguistic variables;
– term-sets of linguistic variables;
– determination of affiliation functions.

The 16 personal quality factors in the Cattell test correspond to linguistic variables. For each linguistic variable, the lowest factor value (weak), the average factor value (medium), the highest factor value (strong) are determined according to a 3-level unified quality measurement scale (UQMS), which generate the term sets of linguistic variables (**Table 5.2**).

Table 5.2 Linguistic variables of the Cattell test and their term-sets

Variables	Names of linguistic variables	Term-sets
1	**2**	**3**
L_1	Unsociable/sociable	Unsociable, moderately sociable, sociable
L_2	Intellect	Low intellect, intellectual development, high intellectual development
L_3	Emotionally intolerant/tolerant	Emotionally intolerant, somewhat emotionally intolerant, emotionally tolerant
L_4	Subordinate/dominant	Subordinate, moderately authoritarian, authoritarian
L_5	Restrained/emotional	Restrained, moderately emotional, emotional

Continuation of Table 5.1

1	2	3
L_6	Sensitive/having high behavior standards	Does not attempt to solve group problems, avoids responsibility, responsible
L_7	Obedient/courageous	Obedient, less courageous, brave
L_8	Cruel/arrogant	Cruel, normal, arrogant
L_9	Trusting/skeptical	Trusting, less trusting, skeptical
L_{10}	Practical/advanced imagination	Partly practical, with a creative imagination, with a very high creative imagination
L_{11}	Outspoken/diplomatic	Outspoken, partly diplomatic, diplomatic
L_{12}	Confident/unconfident	Confident, unconfident, anxious
L_{13}	Conservative/radical	Conservative, mediate, radical
L_{14}	Conformism/nonconformism	Not taking into account public opinion, sometimes taking it into account, always listening to public opinion
L_{15}	Low self-control/high self-control	Low self-control, moderate self-control, high self-control
L_{16}	relaxed/anxious	Relaxed, moderately relaxed, anxious
y	Degree of compliance of the staff member with personal qualities	Not suitable, moderately compatible, compatible

The term-sets are expressed by the affiliation function corresponding to the quality levels of UQMS. Therefore, fuzzy sets are allocated for term-set elements (**Table 5.3**).

Table 5.3 Mathematical description of linguistic variables based on 3-dimensional UQMS

Intensity levels of linguistic variable "unsociable / sociable"	Linguistic evaluation (UQMS)	Fuzzy set in the range [0; 1]	E1	E2	E3	Collective value (Levin)
Unsociable	Weak	[0.1–0.45]	0.45	0.40	0.35	0.40
Less sociable	Medium	[0.45–0.65]	0.55	0.60	0.65	0.60
Sociable	Strong	[0.65–0.99]	0.95	0.90	0.85	0.90

For each quality level, an individual fuzzy value is assigned from the set allocated within the interval [0; 1]. For this purpose, the final fuzzy value is determined as a result of combining separate values set by individual experts into a single, collective value. For this, it was considered expedient to take the value occupying the “medium position” compared to external values in the set of individual values, as a collective value [30].

Assessment of compatibility of the members on OOP with their positions based on fuzzy patterns recognition. With the comprehensive approach to the monitoring results, the proposed approach for assessing the compatibility of professional ship crew members with their positions is brought to the pattern recognition issue [20]. For this, the patterns of the position, and then the staff member performing the task, are created based on their quality indicators in the Cattell test.

For example:

$V \quad V_g \; ,g \quad \overline{1,n}$ is a set of duties on OOP;

$L \quad L_i \; ,i \quad \overline{1,16}$ indicates the evaluation criteria in the Cattell test.

Then, based on these criteria, each position can be described as $V_g = |L_{gi}|, i = \overline{1,16}$, and a person holding this position as $S_g = |L_{gi}|, i = \overline{1,16}.$

According to the methodology developed in [25], the reference pattern of position can be described as a fuzzy pattern

$$\tilde{V}_g \qquad {}_{L_{gi}}(y)/y, i \quad \overline{1,16} \; ,$$

and the real pattern of employee holding this position can be described as a fuzzy pattern:

$$\tilde{S}_g \qquad {}_{L_{gi}}(y)/y, i \quad \overline{1,16} \; .$$

Afterwards, the compatibility of the specialist with his/her position can be determined based on fuzzy similarity patterns. For this purpose, the degree of similarity of the reference and real fuzzy patterns is determined. For this, the degree of fuzzy inclusion into fuzzy situations is reenced. The similarity degree of fuzzy patterns $\theta(\tilde{S}_g, \tilde{V}_g)$ is calculated using the formula (5.1).

According to the degree of similarity of reference and real fuzzy patterns, the inclusion limit ψ is determined for making decision on the compatibility of the members on OOP for his/her position.

Assume that, in accordance with the management terms, [0.8; 1] is accepted for the term set “corresponds to the position” and $[0.5;0.79]$ is accepted for the term “moderately corresponds to the position”. In this case, the following decision-making rules are included:

1. If $(\tilde{S}_g, \tilde{V}_g) \qquad 0.8;1$, then the real fuzzy pattern $\tilde{S}_g$ is completely similar to the reference fuzzy pattern $\tilde{V}_i$ and the relevant specialist “corresponds to the position”;

2. If $(\tilde{S}_g, \tilde{V}_g)$ $0.5; 0.79$, then the real fuzzy pattern $\tilde{S}_g$ is moderately similar to the reference fuzzy pattern $\tilde{V}_i$ and the relevant specialist "moderately corresponds to the position";

3. If $(\tilde{S}_g, \tilde{V}_g)$ $0.1; 0.49$, then the real fuzzy pattern $\tilde{S}_g$ is not similar to the reference fuzzy pattern $\tilde{V}_i$ and the relevant specialist "does not correspond to the position", and it should be provided with medical support to perform this position.

When solving this issue, note that the requirements for meeting the criteria in the Cattell test may differ for each position (for example, the criterion sociable is rated as "strong" for the reference pattern for any position, whereas this criterion may be rated as "moderate" or even "weak" for another).

Based on the proposed approach, the establishment of a system for monitoring and assessing the health status of members on OOP involves the development of the following modules:

– testing the crew members on OOP based on the Cattell test;
– generating a reference fuzzy pattern of each position on OOP;
– generating a real fuzzy pattern of each crew member on OOP based on the test results;
– calculating the degree of similarity of reference and real fuzzy patterns;
– developing the decision-making unite;
– obtaining the result.

The proposed approach to assessing the psychological health of crew members on OOP can be considered as one of the solutions to the given problem. Thus, the following solutions to the problem stated are possible:

1. Some of the 16 criteria in the Cattell test may be considered significant, while the rest may be considered desirable or even insignificant, in accordance with the conditions of personnel management on OOP. In this case, the issue under consideration can be solved by bringing it to fuzzy multi-scenario decision-making methods [26].

2. In accordance with the conditions of personnel management on OOP, it may be required to take into account the importance of their personal quality criteria in relation to each other. In this case, the problem can be solved by bringing it to the multi-criteria decision-making methods, taking into account the importance coefficients of the criteria [27].

3. Monitoring of the health status of the crew members on OOP through IoT technologies [12, 13], etc.

The proposed approach can allow for the timely detection of undesirable situations in terms of the mental health of the crew member on OOP, to prevent wrong decisions and can be considered as one of the possible solutions to prevent OOP accidents.

5.5 Discussion

The possibility of making erroneous decisions by an individual worker directly depends on his/her health status and determines the behavior and actions of the latter during the shift on the OOP. To identify the current health status of workers, a technique based on fuzzy pattern recognition methods was proposed, which allowed automatically analyzing the generated data and synthesizing a diagnostic solution.

The issue of health data analysis was solved by comparing the currently generated data value with the ideal value. In this regard, a fuzzy universal scale was used, which allowed to evaluate various medical data in a single measure, and their fuzzification was performed according to the ideal conformity of the values of the medical parameters.

A fuzzy image of ideal health based on parameters characterizing the health of employees and fuzzy images of current health conditions based on parameters characterizing the current state of the employee were modeled [20]. For fuzzy images recognition, the method of assessing the health status of the worker by applying the formula (5.1) or (5.2) was given. The If-Then model of knowledge description was used to make decisions according to the obtained results [19].

The proposed IoT platform-based algorithm automatically analyzed the data and synthesized a diagnostic decision in typical situations that can be implemented in accordance with two scenarios:

1. Decision automatically made by the IoT application, as a response to the critical situation, instantly acts as a control action both for the wearable devices of workers (as an alarm) and for the emergency response service at HRFs. In this case, the IoT platform of the intelligent system for continuous remote monitoring is actually transformed into a cyber-physical system (CPS), which ensures the integration of the real physical world with the virtual world of computing processes without human interference in the human out of loop.

2. Decision automatically synthesized by the IoT platform is sent to the responsible clinician for confirmation (CPS human in the loop). The clinician evaluates the results of the data analysis, involving, if necessary, the relevant specialists, and makes the final decision, which is transferred to the HPF for execution within a specified period of time.

In non-standard situations, all relevant information and IoT solutions automatically proposed by intelligent decision system in real time are provided to interested coastal services and their authorized persons (supervisors, doctors, occupational safety specialists, heads of relevant departments, experts). This enables the latter to find out the reasons for deviations of indicators from the standard values and make informed decisions to eliminate hazards to health and possible incidents, thereby minimizing the impact of the human factor. In this case, the task of decision-making can be addressed by reducing it to the decision-making methods, taking into account the different types of functional and distributed knowledge (for example, each employee's electronic health records (EHR)) in the individual cloud of the employee's health.

Implementation of such a technique allows to:

– assess the health status of each employee in real time;

– automatically make decision in real time according to the critical situation;

– determine the level of health risk in accordance with the critical situation;

– acquire information about the health status of each employee in real time;

– systematically collect individual health data of each employee and form a dynamic database.

Embedding this base in the architecture of an intelligent personnel health management system as a dynamic database module and joint analytical processing of current and retrospective data will allow:

– objectively assess the changes' tendency in the health status of each employee;

– make informed and objective decisions to eliminate problems negatively affecting the personnel's health in the short, medium and long term.

The proposed technique aims at assessing the health status of employees and making decisions with the reference to only medical parameters generated by IoT-applications, and fuzzy image recognition as artificial intelligence methods, and the If-Then model of knowledge representation. At present, due to the lack of possibility to obtain real data, it is impossible to experimentally implement the proposed technique.

In the distributed system of remote intelligent monitoring of the health and safety of employees, the concept of situation assessment and decision-making is put forward, taking into account the parameters related to demography, geolocation, behavior, and the environment of the employee, along with health data. The solution of this problem requires the application of big data, deep learning methods, and machine learning methods, in addition to the methods of artificial intelligence used above.

5.6 Conclusions

The study proposes a technique for the decision synthesis in the remote continuous intelligent monitoring system of the health status of the OOP personnel, designed to timely eliminate incidents related to the human factor. The technique provides an opportunity to:

a) collect and evaluate real-time information about the health status of each worker employed on the OOP;

b) identify the criticality rate of the values of vital health indicators;

c) automate decision-making appropriate to the current situation. These interacting operations, as links in the decision-making process, combine the levels of a distributed intelligent system for managing the health of workers and ensure its functioning as a whole.

The number, heterogeneity and uncertainty of medical parameters characterizing the health status of an employee, the variation of each parameter within different limits determine the multivariance of possible situations related to the health status of an employee. In this regard, let's introduce the concepts of «fuzzy image of the current health status of an employee» and «fuzzy image of the ideal health status of an employee» and propose their formal models. Based on these models, let's offer a method for making decisions on the health status of an employee based on fuzzy image recognition using similarity (identity) measures of two fuzzy situations, i.e., the current and ideal health status of an employee. As the similarity measures of two situations, fuzzy equality and fuzzy inclusion of the ideal image and fuzzy real images of the health status of an employee are chosen with the establishment of a certain inclusion threshold, the introduction of which enhances the interpretability at the fuzzy control system level.

To interpret the recognition results, i.e., to transform the data into knowledge at the level of the knowledge representation model, the «if-then» model is chosen. The use of this model will allow further introduction of new rules into the knowledge base, including other context-dependent parameters (geolocation, environmental toxicity, etc.), without causing problems for existing rules.

A fuzzy universal scale is developed for the identification of medical parameters, taking into account the diversity and fuzziness of these parameters. When constructing the scale, the following requirements are taken into account: the possibility of describing numerical and dimensionless information to ensure comparability of parameters of different physical nature; universality, applicability to parametric and non-parametric input information; the possibility of describing the definition domain for any values of the considered medical parameters of the health status. When evaluating the intensity of manifestation of signs by an expert, the qualitative and quantitative nature of medical indicators, the inaccuracy of estimates, the symmetry of the gradations of opposite estimates depending on the ideal value of the medical parameter and its acceptable threshold are taken into account.

The method for constructing a fuzzy universal scale, its visualization and a stepwise algorithm provide an increase in interpretability at the level of fuzzy term sets of linguistic variables.

A technique proposed for decision synthesis in the remote continuous intelligent monitoring system of the health status of personnel on the OOP can be used in modeling semi-structured processes at other objects with a high health risk, occurring under other uncertainty conditions.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

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CHAPTER 6

Expert assessment of engineering and planning solutions to improve the safety of vulnerable road users in Ukraine

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Abstract

The aim of research, based on the results of which this article was prepared, is the analysis of the main methodological provisions of providing an expert assessment (audit) of engineering and planning decisions, organizational and management measures to ensure **road safety (RS)** for vulnerable road users, as well as determining ways to improve it in Ukraine taking into account the specific features of the movement of the specified categories of the population and progressive world practices.

Since the current level of mortality and injuries due to **traffic accidents (TA)** in Ukraine significantly exceeds the average European indicators, and the level of effectiveness of scientific and methodological support of activities in the field of road safety is insufficient, the relevance and social significance of the research topic are obvious.

The research results are presented in the form of the authors' opinions regarding the following problems (areas of activity) in the RS field, which should be subject to expert assessment:

– the actual level of traffic accidents among the main categories of vulnerable road users in Ukraine;

– modern domestic and foreign scientific-methodical and engineering-planning approaches to the formation of individual elements of an effective and safe transport infrastructure, as well as progressive **traffic management systems (TS)**;

 DOI: 10.21303/978-9916-9850-2-1.ch6

– the possibilities and expediency of implementing engineering and planning solutions, organizational and management measures to improve RS in Ukraine in accordance with the principles of sustainable mobility, taking into account the interests of certain types of vulnerable traffic participants (pedestrians, low-mobility population groups, children, cyclists).

Keywords

Expert assessment, road traffic, safety, emergency, infrastructure, vehicles, management, mobility, pedestrians, groups with reduced mobility, children, cyclists, measures, solutions.

6.1 Introduction

RS is a key element in the development of any modern society. Therefore, significant attention is now being paid worldwide to the development and implementation of practical measures aimed at preventing road traffic injuries.

In Ukraine, this concept refers to the state of the TS process (system), which determines the degree (level) of protection of its participants from road accidents and their consequences [1].

The current level of mortality and injuries due to road accidents in Ukraine is quite high, and the level of RS management remains low, as the experts of the WHO, the World Bank and other international institutions have repeatedly emphasized in their reports. To solve this problem, in 2020, the "Strategy for increasing the level of road safety in Ukraine for the period until 2024" was adopted [2].

The purpose of this Strategy is to reduce the death rate due to RA by at least 30 % by 2024, to reduce the severity of the consequences of such accidents for RA participants and to reduce socio-economic losses from road traffic injuries, as well as to introduce an effective RS management system to ensure the protection of life and public health. In the future, it is predicted that the number of dead and seriously injured persons due to RA will decrease by 50 % by 2030 compared to 2019, as well as the approximation of national indicators of road accidents to the average European level.

During the development of this Strategy, considerable attention was paid to the issues of improving the safety of **vulnerable** road users – pedestrians, cyclists, people driving on two-wheeled mopeds or motorcycles, children, the elderly, and people with disabilities [1]. Let's note that in normative and special literature, the concept of **low-mobility population groups** is also used – persons who experience difficulties in independent movement, receiving services, necessary information, or orientation in space [3]. This category includes a rather large share of the population (according to data from various sources, it is from 30 to 50 %) – pregnant women; children up to 7 years old; persons who accompany minor children; people of respectable age; people with disabilities; people with permanent and/or temporary functional impairments (physical, sensory, mental, mental); people who have received a temporary injury or are ill; people with non-standard body sizes (significantly more or less than the average body weight, short or too tall); people who may be inattentive for some time (for example, under the influence of stress).

According to the obligations (goals) of the Stockholm Declaration [4], which was adopted as a result of the III Global Ministerial Conference on RS, among the main directions of the implementation of the national Strategy are [2]:

– ensuring that the interests of TS participants are prioritized during the development of measures to increase RS in accordance with the approaches of sustainable urban mobility, namely, taking into account their interests in the following sequence: pedestrians (primarily low-mobility population groups), cyclists and other vulnerable TS participants, public transport and transport emergency and communal services, cargo vehicles, passenger vehicles;

– implementation of programs and implementation of measures aimed at significantly improving the safety of pedestrians, including persons with disabilities and other groups of the population with reduced mobility (sidewalk of sidewalks, speed limits of vehicles, installation of pedestrian fences, renewal of pedestrian infrastructure, lighting of roads and streets);

– construction of separate bicycle lanes in cities and other settlements, on suburban roads, development of bicycle infrastructure;

– provision during the design of road construction of a full set of road safety measures, in particular pedestrian safety, including persons with disabilities and other groups of the population with reduced mobility;

– installation of appropriate road signs, markings, pedestrian fences, forced speed reduction elements, external lighting, etc. near educational institutions;

– arrangement of transport infrastructure in settlements taking into account the needs of persons with disabilities and other groups of the population with limited mobility.

It should be noted that the specified areas of activity are particularly relevant in connection with the expected significant increase in the number of people with disabilities and various functional disorders, as well as the destruction and damage to the transport infrastructure as a result of aggressive hostilities on the territory of Ukraine after the full-scale military invasion of Russia.

Expert assessment of the RS level in the general case involves the study of a set of means, structures, devices, structures, characteristics and indicators (including engineering, design, technical, design, architectural, technological and other solutions) and is a basic element of a security audit – an independent, systemic, technical and detailed assessment of the impact of project decisions on RS [5].

The relevance and importance of the specified expert assessment (audit) is also taken into account in the national strategy for increasing the RS level, for the implementation of which it is provided [2]:

– preparation (training) of specialists in matters of road safety, including road safety audits;

– development of mechanisms for stimulating the involvement of RS experts in the development and examination of urban planning documentation at the local level in terms of planning, formation and improvement of the street and road network;

– providing for the audit and assessment of traffic safety in all decisions regarding the planning and development of cities and on public roads during major repairs, reconstruction and/or new construction, meeting the needs for safe mobility, ensuring the development of parking infrastructure;

– determination of infrastructural factors in the places of TA concentration, carrying out a safety assessment of the existing road infrastructure and introducing engineering solutions to improve safety indicators, designing roads taking into account speed regimes.

An auditor (expert) in Ukraine can be a natural person who has passed qualification confirmation, received a certificate for the right to conduct a safety audit from a personnel certification body accredited in the relevant field, and is included in the register of road safety auditors [5].

6.2 Traffic accidents

In order to make a general assessment of the actual RS state for vulnerable road users, **a statistical analysis of traffic accidents and injuries in Ukraine** over the past 9 years (2015–2023) was conducted, the source data for which was information from the annual reports of the National Police of Ukraine [6].

Table 6.1 shows the indicators that are most important from the point of view of BDR management:

– the number of RA with victims;

– the number of persons killed in RA;

– the number of persons injured in RA;

– the share of the main categories of vulnerable road users (pedestrians, cyclists, children) according to each of the indicated indicators.

Table 6.1 Traffic accidents in Ukraine [6]

Year	In general, in Ukraine	Hitting a pedestrian		Hitting a cyclist		RA involving children	
		Total	Share, %	Total	Share, %	Total	Share, %
RA with victims							
2015	25493	8734	34.3	1732	6.8	3577	14.0
2016	26782	9103	34.0	1661	6.2	3757	14.0
2017	27220	9338	34.3	1668	6.1	4135	15.2
2018	24294	8190	33.7	1496	6.2	3739	15.4
2019	26052	8612	33.1	1526	5.9	3903	15.0
2020	26140	7641	29.2	1768	6.8	3574	13.7
2021	24521	7509	30.6	1355	5.5	3691	15.1
2022	18628	5284	28.4	1196	6.4	2625	14.1
2023 (9 months)	17394	4435	25.5	1123	6.5	3115	17.9
The number of persons killed in RA							
2015	4003	1449	36.2	270	6.7	216	5.4
2016	3410	1261	37.0	239	7.0	181	5.3
2017	3432	1274	37.1	241	7.0	175	5.1
2018	3350	1237	36.9	218	6.5	176	5.3
2019	3454	1261	36.5	223	6.5	164	4.7
2020	3541	1198	33.8	235	6.6	168	4.7
2021	3238	1148	35.5	195	6.0	193	6.0
2022	2791	874	31.3	148	5.3	125	4.5
2023 (9 months)	2157	601	27.9	146	6.8	139	6.4
The number of persons injured in RA							
2015	31600	8067	25.5	1569	5.0	3907	12.4
2016	33613	8546	25.4	1500	4.5	3998	11.9
2017	34677	8787	25.3	1495	4.3	4483	12.9
2018	30884	7591	24.6	1347	4.4	4059	13.1
2019	32736	8005	24.5	1392	4.3	4435	13.5
2020	31974	6959	21.8	1610	5.0	3957	12.4
2021	29738	6849	23.0	1208	4.1	4160	14.0
2022	23145	4799	20.7	1119	4.8	2978	12.9
2023 (9 months)	21888	4143	18.9	1030	4.7	3567	16.7

As it is possible to see, **the share of road accidents involving vulnerable road users** (collisions with pedestrians and cyclists) in our country over the past 9 years remains significant (35÷41 %), the **severity level** of such RAs is characterized in a similar way (first of all, with regard to fatalities, the share of which in recent years, before Russia's full-scale military aggression, it consistently exceeded 40 %) (**Fig. 6.1**).

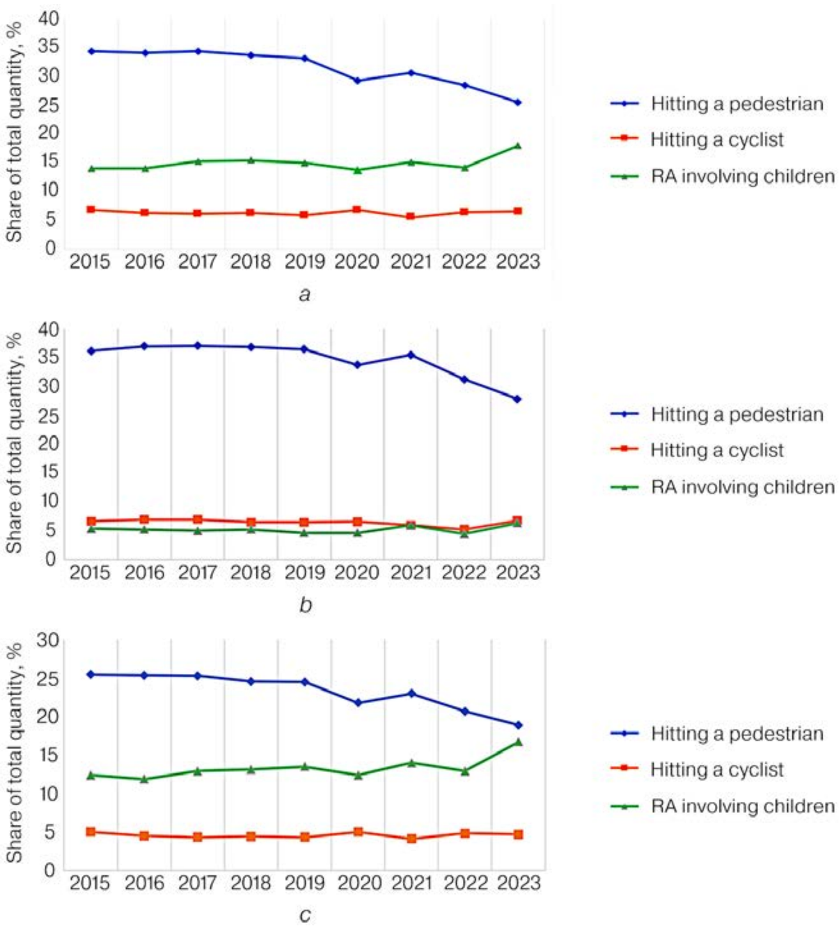


Fig. 6.1 Relative RA indicators with the participation of the main categories of vulnerable participants in the movement in Ukraine (2015–2023): *a* – road accident with victims; *b* – dead; *c* – injured

For comparison (**Fig. 6.2**):

– in Germany, in 2022, the RA share involving pedestrians and cyclists was 38.0 % (8.7 % and 29.3 %, respectively), the share of those killed and injured as a result of these accidents was 31.3 % (13.5 % and 17.8 %) and 38.0 % (8.6 % and 29.4 %) of their total number [7];

– in Poland, in 2022, pedestrians and cyclists were involved in about a third of all RAs (the share of such accidents was 21.6 % and 10.1 %, respectively), the share of those killed in these accidents was 30.7 % (23.9 % and 6.8 %), injured – 26.5 % (18.0 % and 8.5 %) of their total number [8].

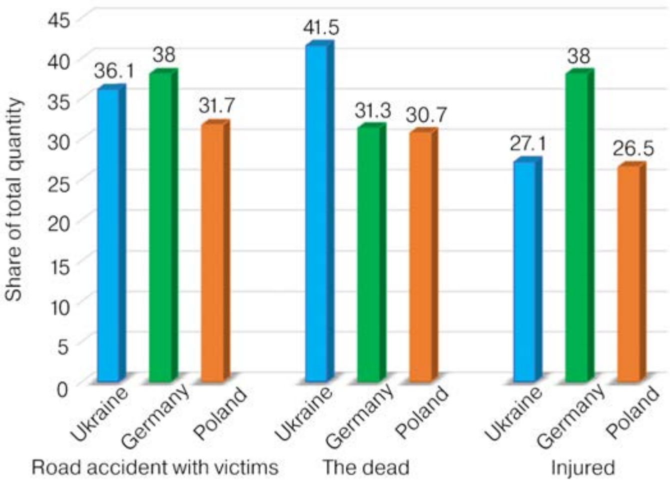


Fig. 6.2 Relative indicators of traffic accidents by participation of pedestrians and cyclists (Ukraine – 2021; Germany, Poland – 2022)

Children's accidents are also an actual problem in Ukraine – the relative indicators of the severity of the RA consequences among children under the age of 18 also significantly exceed similar indicators in Germany and Poland (in particular, by the number of fatalities by 36 % and 46 %, respectively – **Fig. 6.3**).

Thus, in recent years, **about half of all RAs** with victims have involved vulnerable road users (pedestrians, cyclists, children), and there is no steady tendency to decrease this share. At the same time, **the significant mortality among pedestrians and children**, which significantly exceeds the corresponding level in European countries, is of particular concern. Therefore, the task of increasing the level of security for this category of RS participants **is currently relevant and socially important**.

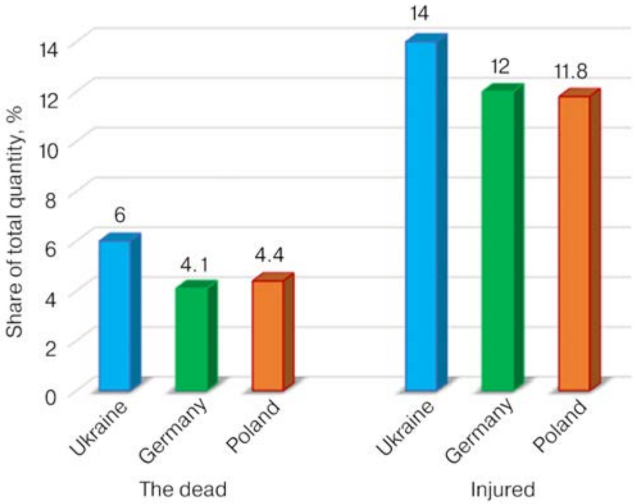


Fig. 6.3 Relative indicators of the severity of the RA consequences involving children (Ukraine – 2021; Germany, Poland – 2022)

6.3 Pedestrian traffic

Walking is the main and most common type of mobility for all social groups in all countries of the world, since even any use of vehicle (trip) begins and ends with walking. It is also important that this type of movement is good for both human health and the environment.

According to the results of a study by the Institute for Applied Social Science GmbH (Germany), which was carried out for the Federal Ministry for Digital and Transport [9] (**Fig. 6.4**):

– **pedestrian traffic is the second most popular type of mobility** in the country – pedestrian trips with a share of 22 % are twice as large as bicycle trips (11 %) and those made by public transport (10 %);

– in **megacities**, as well as in **big cities** and central cities in rural areas, pedestrian movements are even more massive with a share of 27 % and 24 %, respectively.

Ensuring the convenience and safety of pedestrian traffic is one of the most responsible directions of the RS management. Collisions with pedestrians, like other types of road accidents, are not fatal events, as they can be both predicted and prevented. The main **risk factors** for pedestrians are well known: **dangerous behavior of drivers** (primarily, in terms of speeding and driving while intoxicated); **unsatisfactory**

condition of pedestrian infrastructure (for example, lack of sidewalks, crossings or their proper arrangement); **shortcomings of the vehicle design** in terms of their passive safety. The problem of **untimely (low-quality) provision of emergency medical care** to injured pedestrians is also relevant for Ukraine. **An additional internal risk factor** – the actions of pedestrians are more difficult to regulate than the actions of motor vehicle drivers, and when calculating control modes, it is difficult to reliably take into account the psychophysiological factors of pedestrian behavior with all the deviations inherent in their individual groups.

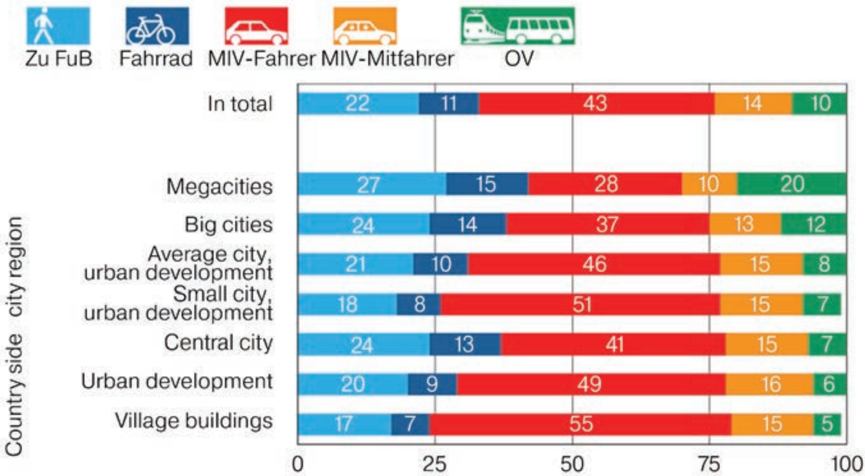


Fig. 6.4 Distribution of mobility in Germany by types of travel (2017) [9]

Therefore, a necessary condition for safe pedestrian movement is taking into account psychophysiological features (for example, the desire of people to move along the shortest path, while saving effort and time) and physical capabilities of people (in particular, general features of vision and a significant deterioration of its efficiency in the dark) when developing appropriate technical solutions. So, for example, the general speed limit for cars in the cities of Great Britain is 30 mph (54 km/h) and is based on the fact that the average speed of a pedestrian is 3 mph, and more than 10 times exceeding this figure by a moving object of significant mass can be dangerous for the human psyche (psychophysical law of Weber–Fechner) [10].

Solving the problem of pedestrian traffic involves a spatial organization and a planning solution of pedestrian movement routes, which must be supplemented with the necessary measures for its management. Let's note that due to the specific conditions of pedestrian traffic, it is necessary, first of all, to proceed from a high-quality planning solution, since management measures, which provide for certain prohibitions, are applied in cities only to a limited extent, namely:

– prohibition of pedestrian traffic on city expressways;

– mandatory use by pedestrians for movement of sidewalks or the left shoulder, in an exceptional case – the left edge of the carriageway;

– mandatory use by pedestrians of crossings across the carriageway (street, underground or above-ground) if they are available. In other places, they must cross the carriageway perpendicularly, they must not delay or stop on it without significant reasons.

The most obvious and simple way to ensure the safety of longitudinal pedestrian traffic is the arrangement of separated paths (routes), that is, its separation from traffic (according to the conclusions of the US Federal Highway Administration (FHWA), on roads without sidewalks, the probability of a vehicle hitting a pedestrian increases by 1.5–2 times [11]).

Pedestrian routes include street sidewalks, pedestrian paths on inter-street and intra-object territories, alleys, boulevards, pedestrian areas, squares, streets and paths, ground, overground and underground pedestrian crossings [12]. The main norms regarding the conditions of their use, constructive parameters and arrangement in Ukraine are determined by the requirements [13, 14]; in particular, **footpaths (sidewalks)**:

– outside the population centers, it is necessary to accommodate the intensity of pedestrian traffic of more than 200 people per day, their width should be at least 1.0 m;

– along highways of the I-a category should be arranged behind a mesh fence on a separate ground;

– railway crossings located in populated areas must be equipped with pedestrian paths, sidewalks and sound signaling, regardless of the intensity of pedestrian traffic;

– it is not allowed to install road fences, supports, advertising structures, temporary structures, pits from hatches and rain receivers, stairs and porches of buildings, etc.;

– their longitudinal slopes should be no more than 60 % (for larger slopes, sidewalks and walkways should have handrails and may have stairs (from 3 to 12 steps in one march); the height of the step should be no more than 12 cm, the width should not be less than 38 cm; after each march (10–12 steps) it is necessary to arrange platforms with a length of at least 1.5 m; sidewalks and pedestrian paths with longitudinal slopes of more than 60 % can be equipped with systems for heating the surface of the sidewalk or other systems that prevent the formation of ice on them;

– for embankment heights of more than 2 m, a barrier must be installed on the sidewalks on the side of the carriageway;

– the covering of the pedestrian area of the sidewalk must be smooth without gaps, the surface of the covering must not be slippery; it should, if possible, differ from the covering of other areas of the sidewalk in color and/or material.

Pedestrian comfort and safety issues are particularly important from the point of view of sustainable urban mobility, and therefore should be prioritized as **a central component of the human-centered design of street space in any city**. Thus, specialists of the World Resources Institute Ross Center for Sustainable Cities suggest building (reconstructing) and arranging sidewalks taking into account the following **principles** [15].

1. **Proper Sizing**. Sidewalks consist of three functional areas: the pedestrian, along which people actually move; furnishing areas where the so-called street furniture (benches, garbage cans); frontage, which gives access from the sidewalk to the street building (**Fig. 6.5**).

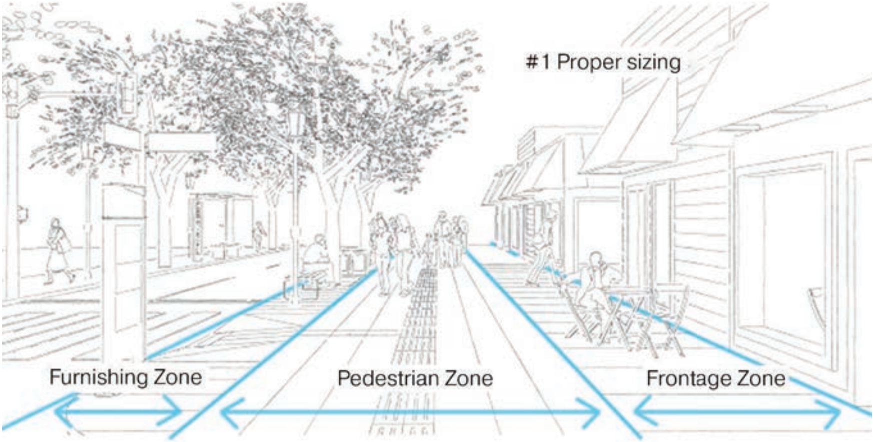


Fig. 6.5 Functional zones of the sidewalk [15]

2. **High-quality surface coatings**. The materials used for the construction of the sidewalk must be strong and resistant to slipping.

3. **Effective drainage**. The transverse slope of the sidewalk must ensure effective drainage, and the presence of the so-called green infrastructure should contribute to this.

4. **Universal accessibility**. The sidewalk is a public space that should be accessible to a wide range of users, including people with reduced mobility (**Fig. 6.6**).

5. **Secure connections**. Pedestrians not only move along the sidewalk, but also visit various objects in the city. Therefore, the pedestrian network of the city should

integrate safe and accessible connections between such objects (stops, crossings, alleys, stairs), which involves the design of shorter blocks and pedestrian crossings, elevated crossings, traffic light regulation taking into account the average speed of pedestrian movement, etc.

6. **Attractiveness of street space**. Sidewalks can play an important role in making urban environments more pleasant. Interesting and bright sidewalks can appeal to people and make walking more attractive.

7. **Permanent provision**. Sidewalks "work" around the clock, but during certain periods of the day and week, the number of people decreases, which can lead to potentially dangerous situations. External electric lighting and transparent facades of buildings on the first floor encourage more pedestrian activity at any time of the day.

8. **Clear Signage**. Like drivers, pedestrians also need clear information to navigate the city, as well as understanding recommendations for individual street objects located nearby (**Fig. 6.7**).

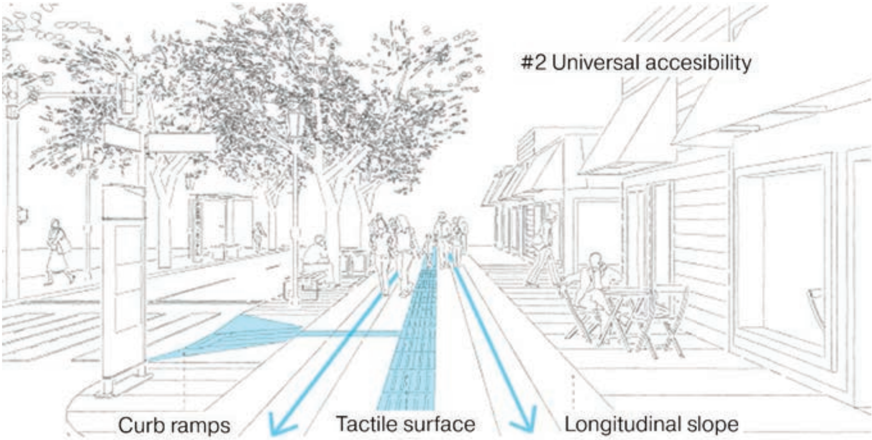


Fig. 6.6 Elements forming the universal accessibility of the sidewalk [15]

Pedestrian traffic is often associated with the need to cross the carriageway (primarily in cities), for which it is advisable to use special places – **crossings**. They can be on the same level (ground level) or on different levels with the carriageway; in turn, in terms of pedestrian traffic control, overpasses may be unregulated, with incomplete and complete traffic light regulation.

Unregulated crossings are the most numerous. The obvious purpose of arranging such crossings is to eliminate the chaotic movement of pedestrians across the carriageway and direct them to potentially safer places (first of all, from the point of view of visibility). So, at crossings in populated areas, in the absence of buildings, the so-called **visibility triangle** of not less than 50×10 m; on suburban highways, the visibility distance of the crossing zone in the direction of the vehicle approach depends on the category of the road and should be from 85 m to 300 m [16].

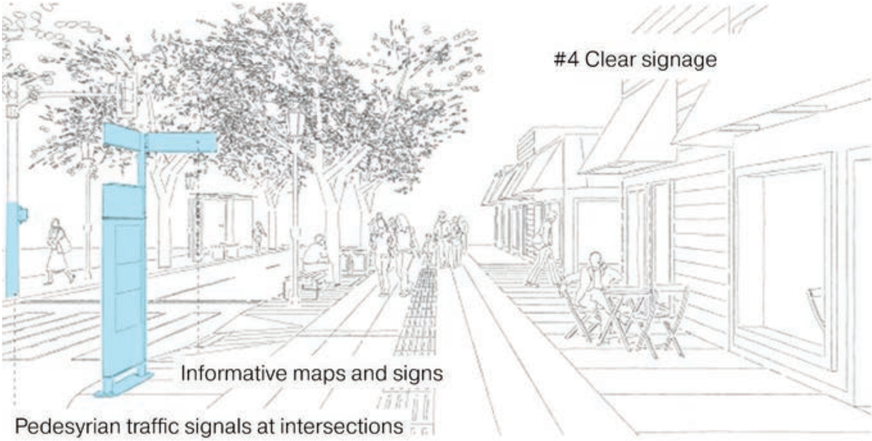


Fig. 6.7 Elements of information support for pedestrians [15]

The main task of **management** at such crossings is to inform pedestrians as efficiently as possible about the exact location of the crossing area of the carriageway by marking them with various technical means (road signs and markings, directional devices, etc.).

The following requirements must be met in order **to increase RS at pedestrian crossings** in populated areas of Ukraine [14].

On streets with 2 or more traffic lanes in one direction, central refuge islands must be installed at unregulated pedestrian crossings. If it is impossible to arrange such refuge islands, the pedestrian crossing should only be adjustable.

The minimum width of the refuge island is 2.0 m, the minimum length is 8.0 m. It can be arranged on a dividing lane or by narrowing the lanes of the carriageway to 2.75 m and bending the axis of the traffic lane (**Fig. 6.8**).

The central refuge islands should differ in the type of covering, structure or color, preferably be raised above the roadway with the possibility of unhindered pedestrian movement, marked with markings or have a zigzag appearance with a barrier-type fence (**Fig. 6.9, *a***). For elevated islands, it is necessary to provide for the lowering of the curb to the level of the carriageway or the absence of its central part to ensure the unhindered movement of groups of people with low mobility and cyclists (**Fig. 6.9, *b***).

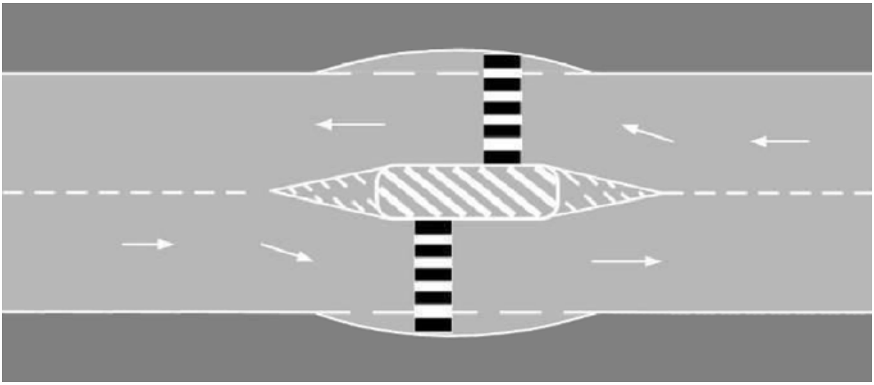


Fig. 6.8 Refuge island at a pedestrian crossing [14]

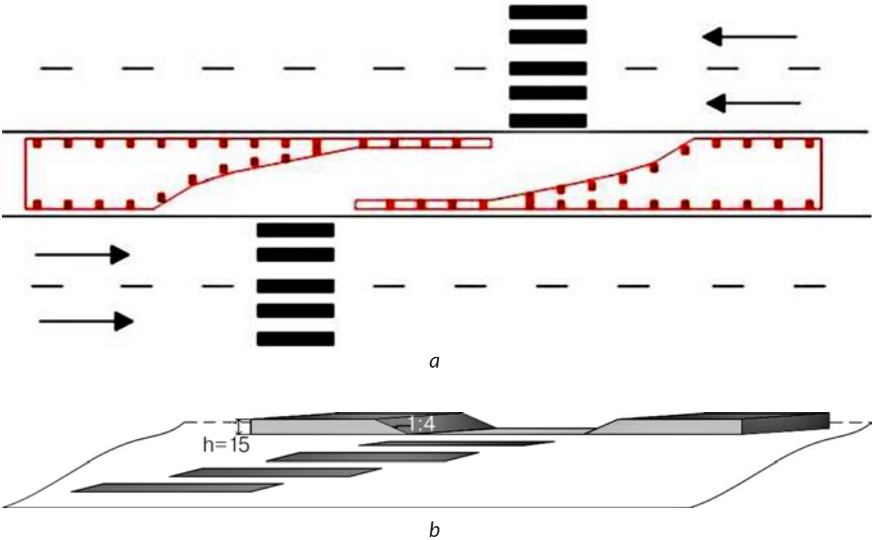


Fig. 6.9 Arrangement of a refuge island at a pedestrian crossing [14]: *a* – use of road barriers of the barrier type; *b* – absence of the central part of the island

The width of the area for the movement of pedestrians on refuge islands should not be less than the width of the pedestrian crossing. At crossings near educational institutions, as well as in other places of intense pedestrian traffic, the carriageway can be raised to the level of sidewalks, including with the help of decking.

From the point of view of improving the methods of expert assessment of pedestrian safety in Ukraine, the requirements and recommendations for **the design of unregulated pedestrian crossings in Germany** [17] can be useful, in accordance with which such crossings can be organized exclusively:

– on the territory of cities and rural settlements (because quite high speeds of motor vehicles are often observed outside the city, which do not allow drivers to react in time to the appearance of a pedestrian on the roadway) with the intensity of pedestrian traffic during the peak hours of the working day at least 100 p.p.h. and the intensity traffic in a more congested direction over 300 vehicles per hour;

– in places where a pedestrian must cross only one traffic lane in each direction (this requirement is related to ensuring mutual visibility of the pedestrian and the vehicle; parked cars and cars moving in the adjacent lane limit visibility, which is potentially dangerous);

– in places where there is a sidewalk or a separate pedestrian path on both sides of the street behind the carriageway (it is considered that in the absence of such special paths for the longitudinal movement of pedestrians, the intensity of their transverse movement is insignificant).

In turn, such crossings cannot be arranged:

– near areas with traffic light regulation;

– in areas with coordinated traffic light regulation;

– on separate lanes for city public transport;

– on streets with tram traffic not on a separate track;

– at crossings where the main street changes its direction;

– on a shared bicycle-pedestrian path.

When the intensity of pedestrian traffic during the peak hours of the working day is up to 50 pedestrians/hour and the intensity of traffic in the busier direction is up to 200 vehicles/hour, an unregulated pedestrian crossing is not required. It is also not mandatory to organize such a crossing in areas with a permitted speed of less than 30 km/h (note that this condition in Ukraine is met by residential and pedestrian zones with a current maximum speed limit of 20 km/h [18]).

The installation of a central refuge island for pedestrians is recommended on areas where the width of the carriageway exceeds 8.5 m.

Pedestrian crossings are located in front of the bus stop (in the direction of traffic) – so that the bus stopped in the entrance pocket does not interfere with the visibility of pedestrians and cars. If the bus stops on the carriageway, then an unregulated pedestrian crossing is arranged in front of it (at the same time, it is necessary to reliably prohibit other vehicles from bypassing the stopped bus (due to the arrangement of a dividing lane and (or) the installation of a fence)).

If the above recommendations are followed, **an unregulated pedestrian crossing will be safer than a crossing with traffic light regulation**. This is explained by the improvement of the conditions of mutual visibility of pedestrians and vehicles and the reduction of the probability of cars moving at high speed.

To assess the safety of pedestrians at **controlled crossings**, the length of time they take to cross the roadway is first analyzed. The most important is such an analysis at crossings with traffic light regulation, when the permission signals for pedestrians and vehicles are turned on in one phase (since the durations of these signals are taken as the basis to ensure the passage of vehicles, which are calculated for other reasons).

The minimum value of **the duration of the permission signal for pedestrians** (the time required for them to cross the roadway) is determined by the formula [19], s:

$$t_{ped} = \frac{B}{V_{ped}} + 5, \tag{6.1}$$

where B is the width of the carriageway at the crossing point, m; V_{ped} is the movement speed of pedestrians at the crossing, m/s (1.3 m/s).

Since this formula does not take into account the time required for several groups (rows) of pedestrians to enter the roadway, which may accumulate before crossing while waiting for the permission signal, with a significant intensity of pedestrians, a longer time for crossing the roadway should be assumed [20], s:

$$t_{ped} = \frac{B}{V_{ped}} + t_{dm} + \frac{d_{ped}(n-1)}{V_{ped}} + 5, \tag{6.2}$$

where t_{dm} is the duration of reaction and delay before the movement of the first row of pedestrians (recommended 2.5 s); d_{ped} is distance between rows of pedestrians (recommended 0.2 m); n is the number of rows of pedestrians.

The application of the proposed approach for evaluating (correcting) the elements of the cycle of traffic light regulation will make it possible not only to increase the safety level of pedestrians in conditions of high intensity of their movement, but also to determine the conditions under which it is expedient to use a signboard counting down the time of the permission signal for pedestrians at regulated crossings as in intersection zones, as well as on street races.

Summarizing all the above considerations, it can be concluded that **the basis of a qualitative expert assessment of the level of pedestrian safety should be the analysis of the compliance of engineering and planning decisions regarding pedestrian movement routes, which are projected or exist, with the requirements of current regulatory documentation (DBN, DSTU)**. In turn, for a similar assessment of measures regarding arrangement and management, it is necessary to additionally take into account **the features of the combined movement of pedestrians and motor vehicles in potentially dangerous areas** (primarily at street crossings).

6.4 Movement of low-mobility mobile population groups

The special needs of pedestrians, who are classified as **low-mobility population groups**, must be given undisputed priority when planning measures to ensure their mobility.

Age leaves an imprint on people's behavior and habits, and therefore affects the risk of road traffic injuries. So, for example, in Germany, in 2022, every third death in a road accident (36.7 %) occurred in the elderly (over 65 years old); twice as many such cases per 1 million residents of this age group were recorded as for residents aged 25 to 55 (55 and 27 deaths, respectively) [7].

Among the main **factors** that increase such a risk for elderly pedestrians, the following are distinguished [21]:

1. Deterioration of visual acuity, which can have a negative impact on people's ability to move safely on the street and road network. In addition, elderly pedestrians are less attentive to the environment.

2. Impaired orientation in relation to one's own location relative to elements of the street (road).

3. Complicating the adequate perception of a difficult road situation, and, as a result, a slower reaction when responding to the danger that has arisen.

4. Complications when crossing the street caused by the need to reorient before crossing the middle of the carriageway.

5. Possible collisions with other pedestrians in places with heavy traffic.

6. Problems caused by an insufficient level of attention during movement (for example, observing traffic lights to the detriment of observing cars or lack of concentration of attention on returning traffic).

7. Appearance of potentially dangerous situations caused by the incorrect (incorrect, untimely) interpretation of information about the traffic regime in this area (for example, insecurity or indecision in one's own actions, misunderstanding of the

behavior of other traffic participants, slowing down the completion of the transition at the time of switching the traffic light signals from yellow light on red).

8. Certain difficulties in mutual understanding with other traffic participants and a more significant probable influence of provocative actions of other pedestrians.

9. Concomitant diseases and physical vulnerability that lead to greater severity of injuries in road accidents.

Even more difficult are the tasks of ensuring mobility and its safety for **people with disabilities (with limited health opportunities)** – people with a persistent disorder of the body's functions, which, when interacting with the external environment, can lead to a limitation of its vital activities [22].

According to official statistics, as of January 1, 2020, there were more than 2.7 million people with disabilities in Ukraine [23]; however, according to experts, such data were incomplete (that is, the actual number of such people was much higher). The correctness of such an assumption is evidenced, in particular, by EUROSTAT statistical data – if in Ukraine 6 % of the population was officially assigned to this category, then in European countries, persons with disabilities make up more than 20 % of the population (**Fig. 6.10**). In addition, it is obvious that after the full-scale military invasion of Russia as a result of aggressive hostilities on the territory of Ukraine, the number of people with disabilities and various functional disorders has increased significantly and, unfortunately, will continue to increase in the future.

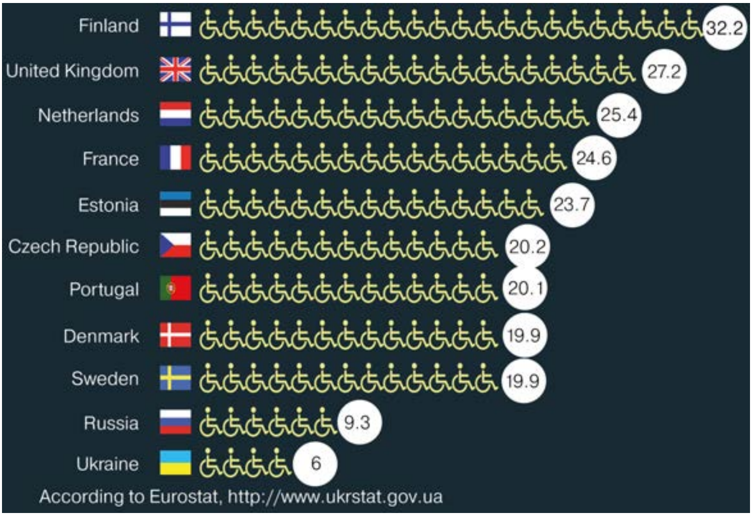


Fig. 6.10 Share of people with disabilities in European countries [24]

The increased degree of risk of committing a road accident for pedestrians with limited health opportunities is explained by the following reasons.

1. People with mobility impairments can cross the road much slower than other pedestrians, and can also fall on the sidewalk if its surface is slippery or uneven.

2. People using wheelchairs may experience difficulties if there are no gentle exits from the sidewalks or accessible routes. It is much more difficult for these people to react to the sudden appearance of vehicle, not to mention the possibility of avoiding a collision with them.

3. People with visual (hearing) impairments may not see (cannot hear) other road users, that is, they do not have an objective opportunity to detect danger to their movement in a timely manner.

4. People with mental disorders may not be aware of existing dangers (for example, before crossing the roadway or during its implementation) or perform other unpredictable actions.

The basic normative provisions regarding the provision of convenience and safety of the ways of movement of low-mobility population groups in the cities of Ukraine are defined by the requirements [22]. Let's consider those of them that directly relate to the arrangement of elements of the street and road network and transport infrastructure, and therefore are most often considered in the process of expert assessment of the RA level.

Ways of movement for people with reduced mobility should be combined with external (in relation to the site) transport and pedestrian communications, specialized parking spaces, public transport stops. When crossing the vehicle of such crossings, **informational elements for early warning of drivers** should be provided.

Means of orientation and information support (tactile and visual elements of accessibility, means of sound information) must be provided on all paths of movement of groups of the population with limited mobility for the entire period of their operation.

The width of pedestrian paths with oncoming traffic should be at least 1.8 m (**Fig. 6.11**); their longitudinal slope should not exceed 5 % (1:20). On areas with a greater slope, it is necessary to arrange external stairs and ramps.

If it is impossible to organize ground (street) pedestrian crossings for people with low mobility, it is necessary to design **underground and above-ground crossings**, which should be equipped with **ramps** with a gentle descent or **lifting devices** (elevator, lift) (**Fig. 6.12**).

The ramp slope at the exit from the sidewalk to the carriageway is 10 % (1:10), the maximum height of one rise should not exceed 0.8 m. The width of the ramp for one-way traffic should be 1.2 m, for two-way traffic – 1.8 m. After each rise, it is necessary to arrange horizontal platforms with a depth of at least 1.5 m. External ramps must have a double-sided fence with handrails. For a lifting height of more than 3.0 m, ramps should be replaced with lifting devices.

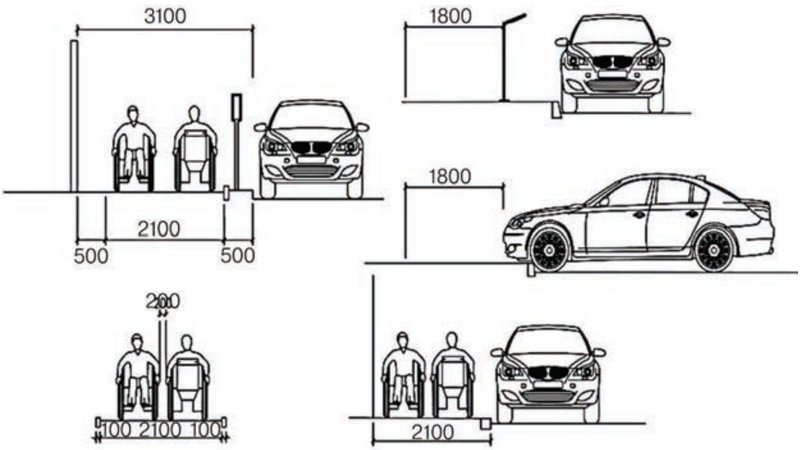


Fig. 6.11 Dimensions of sidewalks and paths for the movement of low-mobility population groups [22]

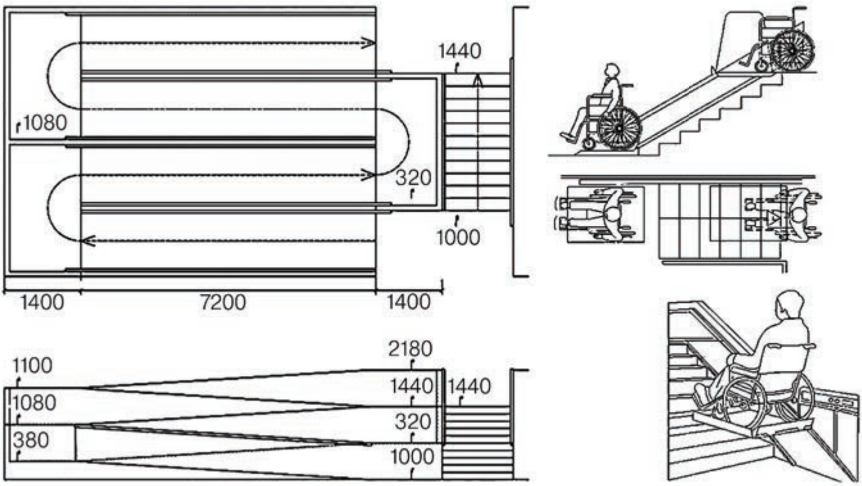


Fig. 6.12 Means of barrier-free access for people with reduced mobility on underground and above-ground pedestrian crossings [22]

In open individual parking lots near service facilities, **no less than 10 % of spaces should be allocated for the transport of persons with disabilities**. These places should be marked with road signs and markings, as well as icons of the international symbol of accessibility. Places for parking such vehicles, as well as stopping areas for the boarding (disembarkation) of their passengers, should be provided at a distance of no more than 50 m from the entrances to public buildings.

The width of the zone for parking a car of a person with a disability must be at least 3.5 m. The dimensions of parking spaces, which are located parallel to the curb, must provide access to the rear of the car to use a ramp or a lifting device.

Tactile elements of accessibility should provide people with visual impairments with the necessary and sufficient information that contributes to their independent orientation. The main of such elements for use in the infrastructure (including on the street and road network) are tactile systems, which should warn about various types of danger (obstacles), as well as provide information about the beginning and end of traffic, changes in the direction of traffic, boarding places for vehicles, etc.

Standard external tactile systems are a curb stone, a lawn, a footpath (which has on one or two sides a surface with a texture different from standard materials), a combined surface (different types of paving slabs, cobblestones, etc., which differ in texture and color are laid). Special tactile systems are surfaces that are made of special tactile indicators (for example, reefs of longitudinal or truncated cones 0.004–0.005 m high).

Warning tactile systems must be installed parallel to the barrier (obstacle) – in places where the curbstone is lowered before people enter the roadway (at a pedestrian crossing), before an overpass or underpass, along the edge of the landing platform (at tram, subway stops), at the beginning and at the end of lowering/raising the pedestrian path (**Fig. 6.13**). Such a system should be at least 0.4–0.6 m wide, have a relief in the form of truncated cones, and its beginning should be at least 0.8 m from the obstacle.

The guiding tactile system (strip) should provide free orientation for finding the necessary and safe direction of movement of persons with visual impairments and other categories of low-mobility population groups; they are arranged, for example, to indicate the route to a specific object of transport or transport infrastructure. The strip of such a system should be at least 0.3 m wide and have a relief appearance of longitudinal (parallel) reefs/ribs 0.004–0.005 m high.

The information tactile system indicates the beginning and end, as well as the place of change in the direction of movement of the guiding system; for this, a strip of width of at least 0.6 m with cut cones is used. At the beginning of the ground pedestrian crossing (or before the intersection), such a strip is arranged perpendicular to the tactile warning system along the entire width of the pedestrian path. Underground passages, boundaries of public transport stops and boarding places, ramps, stairs, etc. are similarly marked (**Fig. 6.13**).

In order to improve the orientation of people with reduced mobility, various types of tactile systems should be applied in a **complex** manner (**Fig. 6.14**).

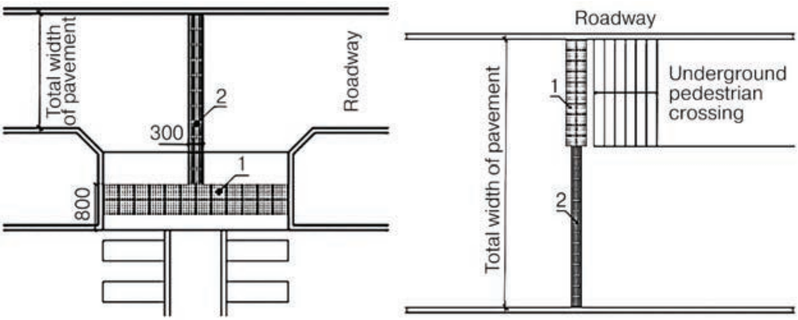


Fig. 6.13 An example of the use of tactile systems in front of pedestrian crossings [22]: 1 – warning; 2 – informative

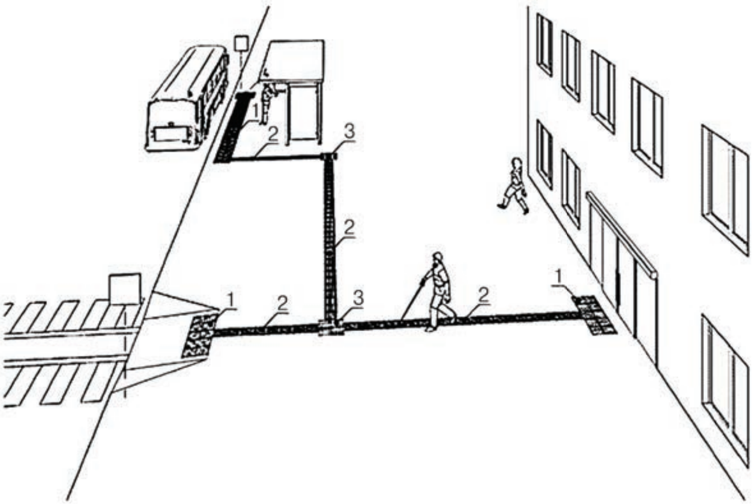


Fig. 6.14 An example of arranging traffic routes of people with reduced mobility using tactile systems [22]: 1 – warning; 2 – guide; 3 – informational (place of turning (divergence) of the guiding system); 4 – informational (place of boarding public transport)

6.5 Transport speed as a factor of traffic safety

One of the most effective ways to increase the safety of vulnerable road users is **to reduce the speed of motor vehicles** (it is a key factor not only in the risk of hitting them, but also in the severity of the consequences of such RAs). Therefore, simultaneously with measures that reduce the probability of contact of such traffic participants with moving vehicles, it is also necessary to control the speed mode of the latter.

Numerous studies by many European and American specialists have proven that **the risk of fatal injury to a pedestrian when hit by a heavy vehicle** directly depends on the speed of the latter; in addition, the indicated risk is higher for the elderly and pedestrians who have been in contact with trucks and other large vehicles. For an expert assessment of such a risk, the analytical dependence proposed by E. Rosén & U. Sander based on the results of data modeling of The German In-Depth Accident Study (GIDAS) in the period 1999–2007 can be used [25]:

$$P(v) = \frac{1}{1 + \exp(6.9 - 0.09v)}, \qquad (6.3)$$

where *P*(*v*) is the probability of a pedestrian death when hit by a vehicle at a speed of *v* (km/h).

According to the results of the conducted research, if at a speed of 30 km/h the probability of such an injury is 5 %, then at a speed of 50 km/h it increases three times (15 %), and at a speed of 70 km/h it increases to 40 % (**Fig. 6.15**).

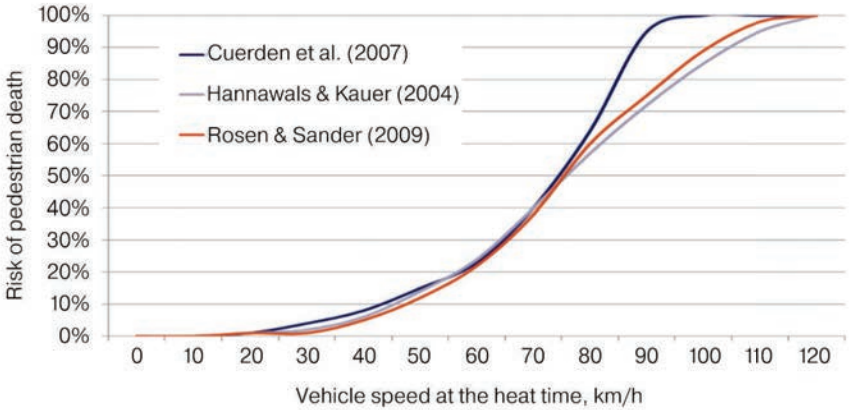


Fig. 6.15 Pedestrian fatality risk [25]

The engineering and technical approach to vehicle speed management involves many measures (solutions) aimed at limiting it (first of all, regulation of maximum values and **traffic calming measures**), as well as measures of psychological influence. All of them should not only ensure an appropriate speed limit, but also contribute to a certain reduction in the intensity of traffic. **Traffic calming means** structural elements of the road (street) or technical means designed to reduce the speed of road vehicles and increase the attentiveness of all traffic participants [26].

The scope of implementing measures (decisions) to limit the speed of motor vehicles can vary from local improvements on local streets to large-scale reconstruction and modifications in a large area. The results of numerous studies show a decrease in the number of road accidents involving pedestrians after the implementation of traffic calming measures (construction of refuge islands, arrangement of elevated pedestrian crossings and narrowing of the roadway in front of them, use of artificial obstacles and surface irregularities), as well as **complex modification** of intersections [27]. The greatest effect is given by a **combination** of several types of measures (they should be applied on different streets throughout the district).

By themselves, measures (decisions) to limit the speed and intensity of traffic do not improve conditions for its vulnerable participants. It is necessary to solve other tasks at the same time (for example, to strengthen the control of compliance with laws and Road Traffic Rules (RTR), to ensure effective external lighting of areas in the dark, etc.). General recommendations regarding the conditions and consequences of applying such measures are given in **Table 6.2**.

Table 6.2 Measures (solutions) to reduce the speed and intensity of traffic, their use and likely results [21]

Measure name (decision)	Can be used to reduce speed		Influence on traffic intensity
	main streets	local streets	
1	2	3	4
Artificial road surface irregularities (road hills)	No	Yes	Possible
Local elevation of roadway level (including in the intersection area)	With caution	Yes	Possible
Raised pedestrian crossings	Yes	Yes	Possible
Tactile elements on sidewalks	Yes	Yes	Possible
Noise strips on the sidewalk in front of pedestrian crossings	Yes	Yes	Absent

Continuation of Table 6.2

1	2	3	4
Replacement of adjustment at intersections with circular movement (mini-rings)	No	Yes	Possible
Roundabouts are on the same level	Yes	Yes	Absent
Replanning of T-shaped intersections	Yes	Yes	Possible
Reducing the turning radius at the intersection	Yes	Yes	Possible
Arrangement of the central refuge island at the pedestrian crossing	Yes	Yes	Possible
Reducing the length of the pedestrian crossing (arrangement of chokers)	Yes	Yes	Possible
Narrowing of the carriageway (reducing the number of lanes or their width)	Yes	Yes	Available
Speed limit	Yes	Yes	Absent
Designing a section of the street (road) taking into account its perception by the driver (perceptual design)	Yes	Yes	Possible
Installation of warning road signs	Yes	Yes	Absent
Blockage of traffic on half of the carriageway	Yes	Yes	Available
Diagonal division of the intersection zone by an impassable barrier	Yes	Yes	Available
Creation of artificial turns (chicane)	Yes	Yes	Absent
Barriers along the dividing line	Yes	No	Available
Differentiation of the speed regime on separate sections of the network	Yes	No	Absent
Coordinated traffic management	Yes	No	Absent

Artificial unevenness of the road surface (transverse hills of insignificant height – "recumbent policemen") make it possible to slow down the movement of motor vehicles in the necessary places quite simply and effectively. A properly designed hill allows drivers traveling at a low (safe) speed to negotiate it easily without having to slow down or accelerate sharply. According to research, it is precisely such hills that in practice most reliably ensure compliance by drivers with the speed limit.

Intersections with a raised roadway level (the sidewalk in the intersection area is raised to the level of sidewalks (**Fig. 6.16**). At the same time, each pedestrian crossing can also be raised, so that pedestrians do not have to descend from the level of the sidewalk. In cities, such intersections are constructed using special construction materials. For pedestrians with visual impairments, it is necessary to arrange contrasting warning stripes on the border between the sidewalk and the carriageway.

Fig. 6.16 Crossroads with a raised roadway level [26]

Raising the height of pedestrian crossings not only creates an anti-speed hill, but also increases the visibility of pedestrians to drivers, increasing their chances of being seen within the crossing at night or in crowded areas. The presence of such a crossing structure clearly indicates that pedestrians have priority. When such transitions are at the same level as the sidewalk, conditions are created for smooth movement (primarily for people with disabilities, people with injuries, parents with strollers, etc.).

Mini-rings are round refuge islands with curb stones, which are arranged in the central part of small intersections without heavy traffic on streets in residential areas of the city (**Fig. 6.17**). Traffic light regulation of pedestrian traffic under certain circumstances can become a prerequisite for a road accident (people tend to hurry, sometimes ignoring the prohibition signals of traffic lights), so such mini-rings contribute to reducing the speed of cars (since drivers are forced to brake when transitioning from a straight section to a curved one). Mini-rings, divided into two "islands", also make it easier for pedestrians to cross the street (especially those in wheelchairs).

Traditional roundabouts at one level involve the arrangement of a large central dividing island in the center of the intersection of several streets (**Fig. 6.18**). Such intersections can be quite convenient for pedestrians, if they are equipped with guide refuge islands at each entrance to the ring (they can be used by pedestrians as refuge islands), and also provide for a reduction in speed before entering the intersection.

For pedestrians with visual impairments who have difficulty choosing the direction of movement, these islands can be equipped with special signals and also have a coating with tactile elements.

Fig. 6.17 Roundabout at a city intersection (mini-ring) [26]

Fig. 6.18 Circular intersection at the same level [26]

Reducing the turning radius. A typical road accident involving pedestrians is a vehicle running into them, which is making a right turn at an intersection (joining). With a significant radius of rounding of the curb stone, drivers often do not reduce their speed, which increases the risk for pedestrians. Reducing the turning radius forces drivers to take a turn more carefully and at a lower speed. Another advantage is the reduction of the distance that a pedestrian must cover at the crossing, as well as the improvement of visibility conditions for all traffic participants.

Refuge islands at pedestrian crossings or dividing lanes, which are raised above the carriageway (such infrastructure objects are also called "central islands" or "pedestrian islands") allow to reduce the zones of theoretically possible contact of pedestrians with vehicles, as they become a safe place for pedestrians to stop during road crossing (**Fig. 6.19**). Landscaping may take place on such islands, but shrubs and trees must be selected taking into account the requirements for ensuring visibility (including for children and people in wheelchairs). In addition, the design of the islands should take into account the needs of pedestrians with visual impairments (a warning tactile strip is installed at the border between the pedestrian and traffic parts of the street), and ramps or through passages should be provided for people in wheelchairs.

Fig. 6.19 Separating lanes that are raised above the carriageway [26]

Choker is a means of pacifying RS, which is a lateral horizontal extension of a sidewalk, curb or refuge island onto the carriageway, which leads to the narrowing of the width of the latter on one or both sides at the same time to one or two lanes (**Fig. 6.20**). Drivers of mechanical vehicles must reduce speed and, if there is only one lane, stop to let oncoming traffic pass. Chokers should be wide enough to allow the passage of emergency vehicles and utility vehicles.

Artificial turns of the carriageway (chicanes) are most often used in residential areas. The impossibility of long-term straight-line movement of traffic is achieved by creating additional local expansions (protrusions) of the sidewalk, creating staggered parking spaces on the outer lanes of the carriageway, or the location of pedestrian-friendly infrastructure (“pocket parks” or urban furniture) (**Fig. 6.21**). The need to constantly adjust the trajectory of movement forces the driver to increase vigilance when driving through such areas and reduce the speed of the vehicle he/she is driving.

Fig. 6.20 Chokers [26]

Fig. 6.21 Artificial turns (chicanes) [26]

Most often, two main factors should be considered for the engineering and technical assessment of the RS level on a specific section of the street and road network from the point of view of the high-speed mode of transport:

– limitation of the maximum speed of the vehicle within the framework of the implementation of the adopted management option;

– the presence (absence) of traffic calming means and the effectiveness of their use.

Determinant from the point of view of ensuring the objectivity of the specified assessment is the analysis of traffic conditions, which takes into account two main factors [28]:

1. **Conflict**, that is, how often significant dangers arise in the studied area. The latter occur when a certain traffic situation (for example, a pedestrian crossing the road during a car turn) is characterized by their mutual approach and such a speed of the vehicle that could cause a collision if the driver did not take emergency actions to change its driving mode. In urban conditions, this indicator usually depends on how divided the potentially conflicting traffic is and what its intensity is for each category of participants (vehicles, pedestrians, cyclists, etc.).

2. **Activity**, i.e. the current level of loading of the site by traffic of all categories of participants and prospects for its growth. RAs with serious consequences are, as a rule, the result of negative realization of conflicts when vehicles are moving at high speeds. Therefore, on sections of the street-road network with more potentially serious conflicts and a higher level of activity, stricter (lower) speed limits should be introduced and/or traffic calming measures should be applied.

6.6 Transport safety of children

According to the WHO, up to 500 children die in road accidents every day in the world; even more of them suffer **bodily injuries and psychological traumas** as a result of collisions with motor vehicles, the consequences of which can be felt for years. Due to potential dangers (including on the street and road network), many children in modern automobile cities experience a serious **decrease in physical and mental health** due to limited access to socialization and activity.

When determining appropriate engineering and planning solutions to improve the convenience and safety of children's mobility in the cities of Ukraine, the following **recommendations of experts** from the World Resources Institute Ross Center for Sustainable Cities can be useful [29].

Creating infrastructure for safe walking and cycling, primarily near schools. Pedestrian and bicycle-oriented spaces support and encourage active mobility for everyone, but especially for children. Safe access for children to strategic locations such as schools, parks and community centers is vital. Safe streets not only prevent traffic injuries, but also allow children to feel comfortable and encourage active independent travel. The creation of safe pedestrian infrastructure (crossings, refuge islands, fences, etc.) in relatively simple ways makes it possible to reduce the duration of crossing the roadway, limit the speed of vehicles when turning, and return significant areas of street space for pedestrians (**Fig. 6.22**).

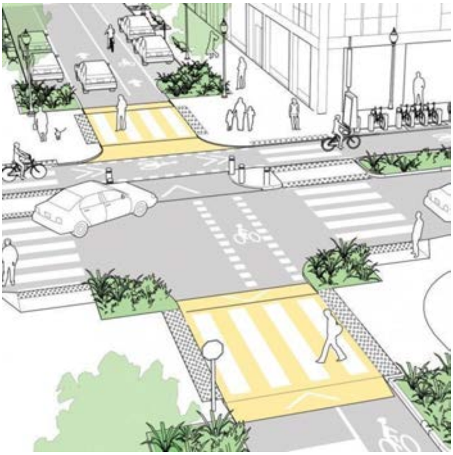


Fig. 6.22 An example of arranging safe pedestrian and bicycle paths at an unregulated intersection [30]

Creation of low-speed zones. Ensuring the low speed of cars on the street network is crucial for the safety of all pedestrians, but it is especially important for children (as the speed of the vehicle increases, the driver's field of vision narrows, making it difficult for them to detect small children in time or respond to their sudden exit carriageway).

Taking into account the peculiarities of children's psychophysiology. Due to their short stature, limited cognitive skills and vision, children perceive elements of the road environment differently than adults. Therefore, it is advisable to use (**Fig. 6.22**, **6.23**) for transport maintenance of places with intensive children's traffic (for example, at the approaches to schools and on school grounds):

– bright raised transitions designed to control the speed of traffic, which are easily visible at the level of a child's eyes;

– wide, passable and barrier-free sidewalks according to their level of comfort and coordination;

– tactile guide elements (strips) of the coating that will help children walk safely on the sidewalk;

– warning signs and interactive markings on the sidewalk for the game;

– special waiting areas near the entrance gate of the school.

Fig. 6.23 Street design for children in Milan (Italy) [24]

Creation of clean air zones. Children are particularly vulnerable to air pollution – for example, due to their height, young children inhale 30 % more carbon monoxide (CO) from car exhaust than adults. According to the WHO, almost one in ten deaths from air pollution are children under the age of five. Clean air zones can significantly improve air quality around schools or residential neighborhoods by prohibiting the entry of "dirty" vehicles and reducing engine idling, as well as encouraging environmentally safe modes of transport and infrastructure.

Creation of special routes (i.e. "walking school buses"). The path from home to school is a place of intensive contact of children with RS and, accordingly, risks. There are many reasons for this risk: often they cannot understand the difference between a dangerous and a safe place to cross the street, they are often distracted or talking on a mobile phone.

One of the strategies for ensuring the safety of children's movement in such situations is the use of the so-called "walking school buses". This model was developed in Australia and it involves parents (or other adults) accompanying groups of children on the way from their places of residence to school (one of the adults is in front, the other goes at the end of the group). Such a "bus" moves around the territory of the community, picking up children from their homes, according to the "schedule", which determines the time of its "arrival" at each "stop" on the way. Only safe and appropriately equipped routes are used for movement. After the classes, the "bus" moves in the opposite direction.

In addition to improving children's health and reducing the level of motorized traffic and environmental pollution, "pedestrian buses" teach children safe behavior on the street and road network, promote an active lifestyle and strengthen social ties between children of different age groups.

The general method of expert assessment of the safety level of children's movement on the routes of their mass movement also includes an analysis of the compliance of engineering and planning solutions, which are projected or exist, with the requirements of current regulatory documentation (DBN, DSTU). Special attention should be paid to the presence of elements of safe pedestrian infrastructure (for example, road fences in front of crossings) and effective means of forced reduction of vehicle speed in places of potential danger for children.

6.7 Bicycle traffic

In 2006, the European Commission for the first time applied in transport policy the new concept of "**joint use of modes of transport – co-modality**", which meant the independent and combined use of different modes of transport with the aim of optimal and sustainable use of resources [31]. **The co-modality concept** involves the construction of transport systems that combine priority development and shared use of public transport, systems of collective use of passenger transport, as well as various types of **active mobility** (including bicycle and pedestrian traffic, scooters, skates, roller skates, etc.).

The implementation of the latter has two positive aspects:

1. **Reduction in the frequency of use of other types of transport** (first of all, individual motor vehicles), due to which the load on the network is reduced and pollutant emissions, noise level, etc. are reduced. For example, in Germany – one of the most "automotive" countries in Europe – bicycle trips with a share of 11 % are the fourth most popular type of mobility; it is also indicative that in all types of territories (except megacities) cycling is more popular than local public transport (**Fig. 6.4**).

2. **Increasing the physical activity of the population**, which leads to a probable decrease in the level of morbidity and mortality of residents.

Active bicycle mobility can be used both independently (for travel up to 3–5 km) and as part of **combined (co-modal) transport chains.**

Cycling is an excellent way of transporting passengers to public transport stations (stops). The key advantage of such a combination is that they jointly ensure the **sustainability of "door-to-door" transportation over considerable distances** (for many users of public transport, this allows them to reduce the time to cover the so-called first and last miles to and from stations (stops) and transfer nodes). At the same time, it is extremely important to ensure the connection of these stations (stops) with the entire network of bicycle routes, as well as to create bicycle parking lots at key points of connection with the public transport network.

At the same time, the movement of cyclists in conditions of intense traffic flows (for example, on main city streets) can also be potentially dangerous, both from the point of view of the possibility of road accidents, and in connection with the significant level of atmospheric air pollution in areas of simultaneous traffic. Therefore, the **rational organization of bicycle traffic in the city** in general involves solving the following **main problems** [24]:

– creation of conditions for necessary separation and protection from automobile traffic;

– provision of sufficient capacity of bicycle lanes (tracks) (since the flow of cyclists in terms of the nature of movement is similar to vehicles in many respects, for theoretical analysis it is quite reasonable to apply the concepts of dynamic size and capacity; the theoretical capacity of a bicycle lane in conditions of continuous column traffic can be taken as equal to 1000 unit/hour);

– arrangement of safe crossings with traffic flows at level crossings and intersections;

– providing cyclists with information about the directions and modes of their movement;

– allocation and arrangement of places for temporary storage of bicycles near attractions (this is important, because every cyclist must be guaranteed the safety and ability to quickly identify its bicycle; for this, special devices are needed that allow for compact and reliable storage of bicycles, as well as to ensure convenient access to them by owners).

The conditions for cycling in the city are being modernized with the use of **innovative transport planning tools**, as well as thanks to the implementation of numerous **demand-oriented organizational measures**; they include [31]:

– constant assessment of current conditions for cyclists through relevant surveys and their analysis;

– expanding the network of bicycle routes by creating additional elements of bicycle paths and modernizing existing areas;

– expanding the the capacity of bicycle lanes in accordance with the actual and projected needs of bicycle transport;

– increasing the average speed of bicycle traffic in order to minimize the travel time (for example, joining it to the so-called "greenways", introducing the right of priority passage at intersections, organizing coordinated traffic light regulation for cyclists);

– creation of bicycle parking infrastructure (office buildings – 0.5 spaces per employee, residential buildings – 2.5 spaces per 100 m^2);

– increasing the convenience of intermodal trips;

– implementation of additional services and innovations to promote cycling (for example, LED warning sensors at intersections, footboards in front of traffic lights, air pumping stations).

In Ukraine, in the process of implementing the principles of co-modality and the spread of bicycle mobility, the main attention is currently being paid to the **formation of bicycle infrastructure**, since it practically did not exist until recently.

The main ways of movement for cyclists are [14]:

– **bicycle path** – a covered area outside the carriageway of a street and/or road, located separately or adjacent to a sidewalk or pedestrian path, intended for movement by bicycles, wheelchairs, non-motorized vehicles and marked with appropriate road signs and markings;

– **bicycle lane** – a lane intended for the movement of cyclists within the carriageway of a street and/or road, which is designated by means of road markings or structurally.

Bicycle paths should be arranged mainly one-way on both sides of the street. If there is a building on one side of the street, a two-way traffic lane should be arranged on that side (**Table 6.3**). **Bicycle lanes** are designed for one-way traffic only. On streets with one-way traffic, bicycle traffic should be provided in both directions.

Table 6.3 Forms of bicycle traffic organization [14]

Street category		Path	Lane	Bicycle and pedestrian path	Traffic on the carriageway
Main roads		X			
Main streets of city-wide significance	Continuous movement	X		X	
	Regulated movement	X	X	X	
Main streets of regional significance	Regulated movement	X	X		
Streets and roads of local importance	Residential streets	X	X		X
	Streets in scientific and industrial, industrial and communal warehouse zones	X	X		X
	Pedestrian streets	X		X	
	Passages				X

Note. *A shared bicycle and pedestrian path is arranged with a total traffic intensity of no more than 75 units/hour*

Design parameters of bicycle lanes and paths are determined taking into account the intensity of traffic of cyclists, cars, freight transport, pedestrians, as well as the width of the carriageway and **side space** (lawns, sidewalks, technical sidewalks, green areas) (**Table 6.4**).

Parking spaces for short-term (up to 1 hour) and **long-term** (several hours, all day or night) **storage of bicycles**, measuring 2.0×0.6 m each, separated by risers (clamps) 0.75 m high and 1.6 m long, arrange near objects of mass attendance, as well as near subway stations and stops of suburban electric trains, at terminus stops and at nodes of transfer from street urban to suburban transport.

Bicycle crossings at the same level as the carriageway are, as a rule, arranged across streets (roads) at a distance from each other of not less than:

– on main streets (roads) of city-wide importance with regulated traffic – 300 m;
– on main streets of district significance – 250 m;
– on streets and roads of local significance:
a) on residential streets – 150 m;
b) on the roads of industrial and communal warehouse zones – 200 m.

Table 6.4 Minimum width of bicycle lanes and paths [14]

Form of bicycle traffic organization	Minimum width, m	
	New construction	Reconstruction
Bicycle lane	1.85	1.5
One-way bicycle lane	1.85	1.5
Two-way bicycle lane on both sides of the street	2.5	2.0
Two-way bicycle lane on one side of the street	3.0	2.5
Shared bicycle and pedestrian path	3.0	2.5

Refuge islands for cyclists should be arranged at unregulated and (if possible) regulated crossings. The width of the section for the movement of cyclists on them should not be less than the width of the crossing. Central refuge islands must differ in type of coating, structure or color. For elevated refuge islands, it is necessary to provide for the lowering of the curb to the level of the carriageway or the absence of the central part of the island (**Fig. 6.9, *b***).

Based on the analysis of the best practices of countries (cities) with greater experience in the implementation of bicycle networks within the framework of the development of the PRESTO (Promoting Cycling for Everyone as a Daily Transport Mode) program of the EU Intelligent Energy project, it was determined that **safety is the basic requirement and the determining factor of the quality of bicycle organization movement** [32].

Cyclists pose almost no threat to others, but they themselves are vulnerable when they move in the same space as motor vehicles. Therefore, in real conditions, the **safety of cyclists** can most often be guaranteed in three **ways**:

– **separation of bicycle traffic in time and space** from fast and large vehicles (regulated bicycle crossings, separated bicycle lanes);

– **reducing the intensity of motor vehicle traffic and reducing its speed** to 30 km/h (mixed use of roads, arrangement of bicycle lanes);

– clear **information** and clear **regulation** of the necessary actions of all road users in places where a conflict between cyclists and motor vehicles cannot be avoided (first of all, at intersections).

General information on specific measures (solutions) to improve the safety and quality of cycling is given in **Table 6.5**.

Table 6.5 Typical measures (solutions) to improve cycling safety [33]

Problem	Appropriate measures (solutions)
1	2
1. Significant speed difference between cyclists and motor vehicles	Vehicle speed limit up to 30 km/h, artificial bumps, etc. Control of compliance with such restrictions
2. Complications in conditions of mixed space for traffic and bicycle traffic: – insufficient intervals between the vehicle and the edge of the carriageway (other vehicles); – the possibility of maneuvering and opening the doors of parked cars	Provision of a specially designated space for cyclists (separate or shared with other types of traffic). Alternative parallel cycling routes. Arrangement of a dividing strip with a relief surface
3. Planning and traffic management at the intersection: – significant distance for crossing the intersection zone; – high vehicle travel speeds; – irrational (inconvenient for cyclists) modes of traffic light regulation	Reconstruction of the intersection (often with a reduction in its size). Implementation of speed limits for motorized vehicles on all approaches to the intersection. Adjustment of traffic light regulation modes taking into account the needs of cyclists
4. Presence of difficult and dangerous maneuvers for cyclists: – a left turn with the intersection of traffic lanes; – straight-line movement in areas where other vehicles turn left or right	Specially designed intersections, convenient for cyclists. Reducing the speed of motor vehicles in zones of simultaneous movement with cyclists

Continuation of Table 6.5

1	2
5. Movement of oversized vehicles in the immediate vicinity of cyclists: – problems when making turns; – formation of air vortices; – complications when driving through stops (passenger boarding and disembarking places)	Special lanes for trucks and buses. Ensuring the minimum required width of bicycle and bus lanes. Improving the construction of bus stops
6. Forced detours of gaps in existing bicycle paths	Lanes for two-way bicycle traffic on streets with one-way vehicle traffic. Proper arrangement of bicycle crossings
7. Non-compliance with the requirements of traffic rules by other traffic participants: – driving through a traffic light prohibiting signal; – speeding (especially by motorcyclists); – use of bicycle lanes by cars (in case of complications (traffic jams), for parking or loading trucks); – prohibited actions of pedestrians	Improvement of normative and legal documents (including traffic regulations). Improving the quality of knowledge of these Rules by all its participants and strengthening control over compliance with their requirements. Separation of bicycle paths from motor vehicle lanes. Arrangement of additional "pockets" for parking and loading. Increase in the duration of permission signals for pedestrians
8. Unsatisfactory conditions for detecting cyclists by other road users	Ensuring the proper level of outdoor lighting. Bicycles must have reflectors, reflectors, and bells. Creation of a waiting area for cyclists in front of the intersection. Changing the layout of the intersection to make it impossible for cyclists to stop outside the visibility (visibility) zone of motor vehicle drivers
9. Unsatisfactory condition of elements of the street and road network: – defects and damage to the road surface; – lack of maintenance or presence of contamination (snow, ice, wet leaves, broken glass, etc.); – obstacles to bicycle traffic (supports for road signs and electric lighting, road equipment (fences, signal posts), urban furniture, etc.)	Regular monitoring of the state of the network, prompt elimination of damage and high-quality maintenance. Elimination of elements of road equipment in places where they interfere with cyclists. Location of supports outside the boundaries of bicycle and pedestrian routes (if possible – cabling of electrical networks and reduction of the number of ground equipment)

The expert assessment of the safety level of bicycle traffic involves, first of all, the analysis of the corresponding infrastructure, which is designed or exists, according to the requirements of the current regulatory documentation (DBN, DSTU). For example, let's consider the features of the implementation of typical engineering and planning solutions for infrastructure elements according to the requirements [34].

If it is possible to choose several **forms of cycling** (**Table 6.3**), the choice of an acceptable form should be made taking into account the maximum values of the intensity and speed of the traffic flow (**Fig. 6.24**, **Table 6.6**). At the same time, a combination of cross-section elements (traffic lanes, bicycle lanes or paths, sidewalks, dividing strips, etc.) should be avoided when the width of all these elements is minimal.

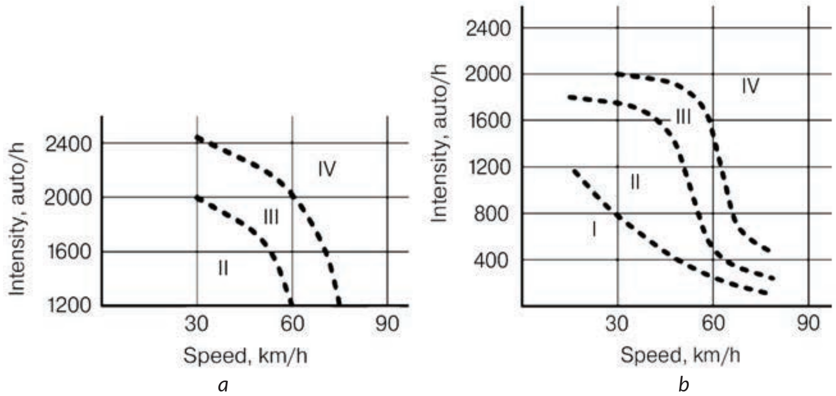


Fig. 6.24 Nomograms for choosing the cycling form [34]:
a – streets with two traffic lanes; *b* – streets with four or more traffic lanes

Table 6.6 Forms of cycling depending on traffic conditions [34]

Range	Recommended form	Acceptable form
I	Mixed traffic on the carriageway	Bicycle or bicycle-pedestrian path on steep climbs; Recommended bicycle corridor
II	Recommended bicycle corridor; Bicycle lane	Mixed traffic on the carriageway with an insignificant share of freight transport, on slopes with a longitudinal slope of more than 30 %; A bicycle path for a significant share of freight traffic, or for a formed cross-section of the street; Bicycle and pedestrian path
III, IV	Bicycle lane; Bicycle path; Shared bicycle and pedestrian path	Recommended bicycle corridor in load range III with an insignificant share of freight transport

Bicycle traffic on a roadway with a width of more than 6.0 m is allowed to be provided **together with a vehicle** at a traffic flow intensity of no more than 400 vehicles per hour.

In case of arrangement of bicycle traffic **on a separate lane for route vehicles**, the width of such lane should not exceed 3.5 m (at the intensity of bicycle traffic no more than 200 units/hour). At the same time, the distance between public transport stops or intersections should not exceed 400 m, and the maximum permitted speed is not more than 50 km/h. It is also necessary to provide for the use of technical means of TS management in accordance with the requirements [19, 35, 36].

It is permissible to arrange **shared bicycle and pedestrian paths**, taking into account the intensity of the movement of pedestrians and cyclists and the width of the space allowed for movement (**Fig. 6.25**); at the same time, the share of cyclists should not exceed 30 %.

It is forbidden to plan (design) the joint movement of cyclists on separated lanes for route vehicles with a width of more than 3.5 m, as well as if there is a lane for passing motor traffic to the right of such a lane (this requirement does not apply to areas in front of intersections where separate turning lanes are arranged in different directions).

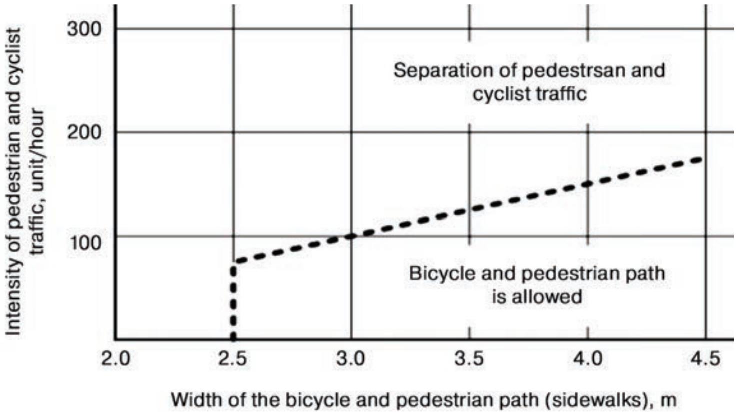


Fig. 6.25 Limits of admissible use of a joint bicycle and pedestrian path [34]

Bicycle corridors (mixed movement of cyclists on the carriageway together with cars in the passing direction) are allowed to be provided for the intensity of traffic of trucks no more than 1,000 cars/day. The width of the corresponding traffic lane should be at least 1.25 m, and the width of the passage between the recommended corridors should be at least 4.5 m. If there is **parking**, a safety lane of at least 0.5 m (for parallel parking) and 0.75 m (for parking at an angle to the carriageway or perpendicular parking) (**Fig. 6.26**).

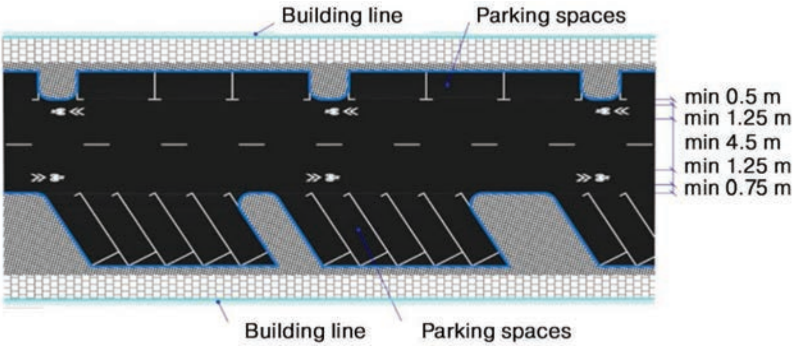


Fig. 6.26 Parameters of a bicycle corridor near street parking [34]

On main streets with one-way traffic, bicycle paths or bicycle lanes (recommended structurally separated) should be arranged for bicycle traffic facing the flow of traffic.

On residential streets (driveways) with one-way vehicle traffic and a maximum speed of 30 km/h, it is allowed to arrange **two-way traffic of cyclists** through recommended bicycle corridors. At the same time, there should be at least 3.5 m of space for movement between parked cars and the curb (**Fig. 6.27**). In order to improve the safety of cyclists who are moving towards the flow of traffic, it is necessary to provide markings and, if necessary, refuge islands.

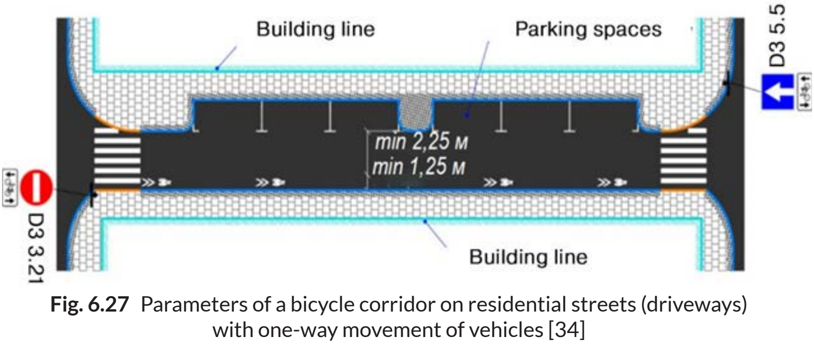


Fig. 6.27 Parameters of a bicycle corridor on residential streets (driveways) with one-way movement of vehicles [34]

The starting and ending points of the bicycle path must be arranged so that when entering or exiting it, cyclists can move as straight as possible without unnecessary maneuvers. In the case of the start of a bicycle path at or outside intersections, a ramp with a longitudinal slope of no more than 60 % and a length of at least 2.0 m must be arranged. The width of the ramp must be at least the width of the bicycle path and the dividing strip. If the bicycle path turns into a **bicycle lane with a simultaneous narrowing of the width of traffic lanes**, it is necessary to provide for the arrangement of a transition section of at least 10 m in length, protected by a dividing strip or curb (**Fig. 6.28**).

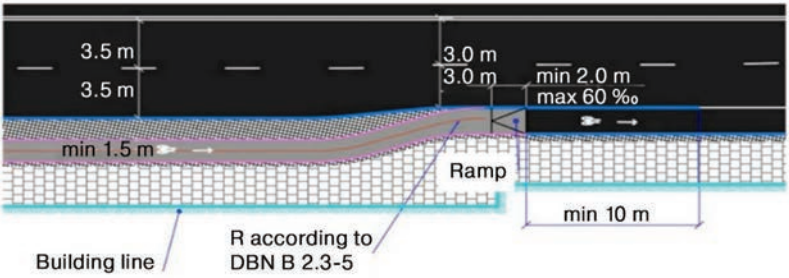


Fig. 6.28 Parameters of the transition of a bicycle path into a bicycle lane [34]

In the presence of **refuge islands or a central median strip**, the width between them and the recommended bicycle corridor should be at least 2.25 m. The transition of the bicycle lane to such a corridor should take place at a distance of at least 10 m to the narrowed place (**Fig. 6.29**).

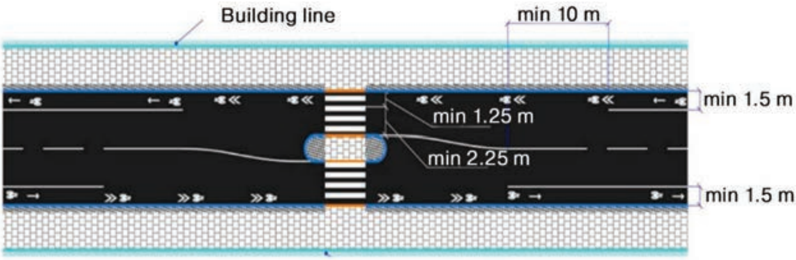


Fig. 6.29 Interruption of the bicycle lane near the refuge island [34]

During the **approach of the bicycle path to the pedestrian crossing**, measures must be taken to ensure the safety and comfort of pedestrian movement, and at the point of exit to the crossing, a space of at least 2.0 m wide should be provided, in particular:

– to change the trajectory of the bicycle path while ensuring the normative width of the pedestrian zone of the sidewalk;

– convert the bicycle path into a bicycle lane or a bicycle-pedestrian path (**Fig. 6.30**).

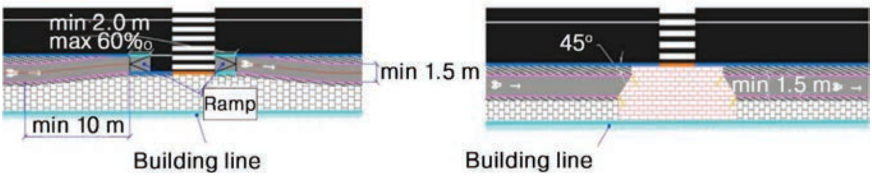


Fig. 6.30 Parameters of a bicycle path near a pedestrian crossing [34]

Bicycle crossings outside intersections are arranged by:

– at the beginning and end of the two-way bicycle path;

– at the crossing points of the main cycling routes;

– in places where a bicycle path, laid outside the boundaries of highways, crosses the carriageway;

– near places of generation or absorption of trips (educational institutions, shopping centers, public transport stops with bicycle parking, etc.).

Before a bicycle crossing, the bicycle path at a distance of at least 2.0 m from the curb must be straight in plan from the side of the approaching cyclists. Adjoining the bicycle path to the bicycle crossing must be at the same level.

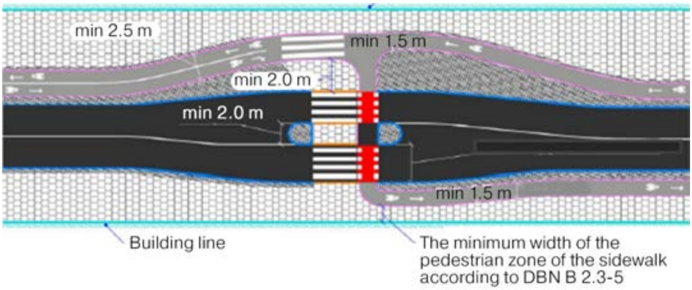
At non-regulated bicycle crossings through a carriageway with two or more traffic lanes, it is recommended to provide for the installation of refuge islands with a width of at least 3.0 m (at least 2.0 m in the case of major repairs and reconstruction). If a two-way bicycle path turns into one-way bicycle lanes or lanes, measures must be taken to improve the safety of cyclists moving from one side of the street to the other (**Fig. 6.31**).

When setting up **traffic light regulation at bicycle crossings outside intersections**, it is recommended to use the **adaptive regulation mode**, using cyclist detectors.

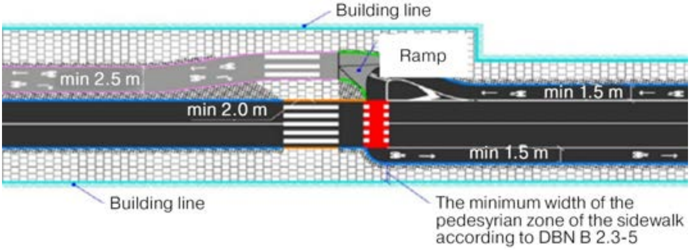
Controlled zones of detectors should be located in such a way as to minimize the waiting time of cyclists for the prohibition signal or to avoid this waiting.

At **unregulated intersections without marked priority**, it is recommended to provide for the movement of cyclists along the carriageway together with cars.

In turn, **at intersections with marked priority**, first of all, **measures should be taken to ensure the movement of cyclists moving straight and to the left** (**Table 6.7**).



a



b

Fig. 6.31 An example of arranging a bicycle crossing outside the intersection [34]: *a* – with bicycle lanes; *b* – with bicycle lanes

Table 6.7 Elements of planning the movement of cyclists at unregulated intersections [34]

Direction of movement	Moving straight	Moving left
Main street or turning lane	– continue bicycle lanes along the main street, marking them with marking 1.7 [35]; – to mark the recommended bicycle corridors on exits from the main street to the secondary street; – convert bicycle paths into recommended bicycle corridors or bicycle lanes; – bring bicycle paths to a distance of no more than 0.75 m to the carriageway and ensure the constant presence of cyclists in the driver's line of sight (**Fig. 6.32**) or arrange bicycle crossings at a distance of no less than 5 m from the edge of the right lane of the main street; – in the presence of bicycle and bicycle-pedestrian paths, mark a bicycle crossing, and if possible arrange an elevated bicycle crossing next to an elevated pedestrian crossing	– waiting space for left turns in two steps (**Fig. 6.33**); – bicycle lane for turning left (**Fig. 6.34**); – (split) central islands as waiting areas for cyclists turning left
Secondary street or turning lane	– usually mixed traffic on the carriageway with a left turn in one go; – central dividing strip (separating islands or refuge islands) as an auxiliary factor when crossing the main street	

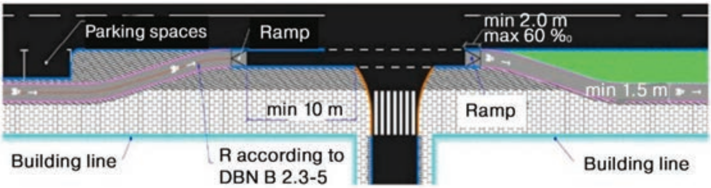


Fig. 6.32 Crossing of a bicycle path with a secondary street [34]

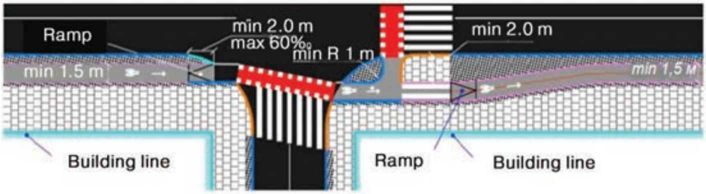


Fig. 6.33 Cyclists crossing the main street with a two-way turn [34]

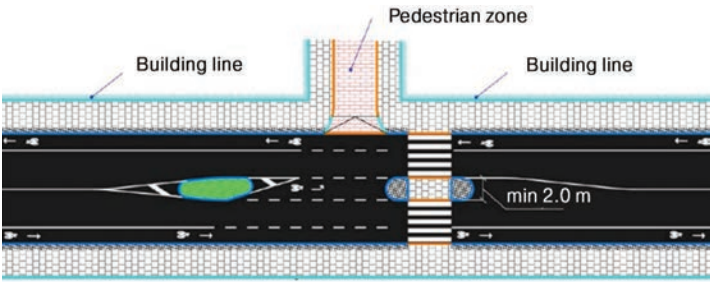


Fig. 6.34 Left-turn lane for cyclists only [34]

Cyclists turn left in one step go either together with cars (if there is no more than one traffic lane) or from a left-turn lane specially allocated for cyclists. Such a decision is permissible at the maximum permitted speed of 50 km/h and the intensity of the traffic flow on the main road no more than 800 vehicles/h.

To organize a **bicycle turn to the left in two steps**, it is necessary to shift the trajectory of bicycle traffic, and mark the waiting zone on the roadway to the left of the bicycle crossing. If the secondary street has bicycle infrastructure, waiting areas can be placed along it.

If space is available, the safety of cyclists turning left and those crossing the main street can be improved by installing a refuge island (which can be combined with a left turn lane) or a **split lane**.

At non-regulated intersections where the main street changes direction, measures must be taken to improve the safety of cyclists who travel on the outer arc and turn left from the main street.

For this, in particular, refuge islands are arranged; form a curvilinear trajectory for cars turning onto a secondary street; additionally protect cyclists who turn onto a secondary street, etc. (**Fig. 6.35**).

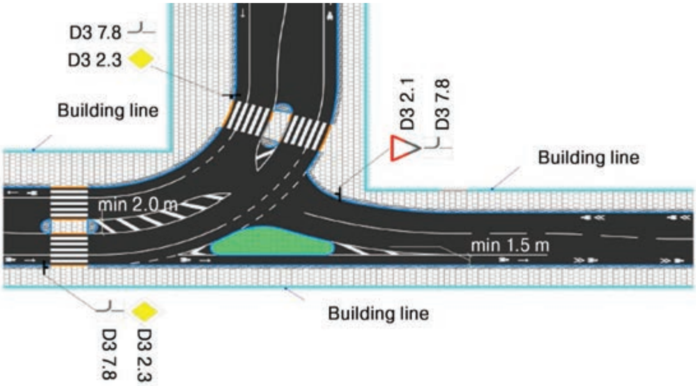


Fig. 6.35 Example of bicycle infrastructure planning at the intersection with a change in the direction of the main street [34]

At **regulated intersections**, measures must also be taken to ensure the movement of cyclists moving straight and left (**Table 6.8**).

On directions with a **significant duration of the prohibition signal for cyclists**, it is necessary to provide for the expansion of the waiting zone by drawing a stop line for cyclists over the entire width of the traffic lane for motor vehicles and at a distance of at least 5.0 m behind it (**Fig. 6.36, *b***).

In the case of arranging **a left turn for cyclists in one step** during heavy oncoming traffic, it is recommended to provide for the arrangement of a **separate adjustment phase** for turning left.

In the case of arranging **a left turn for cyclists in two steps**, it is permissible to arrange a waiting area within the intersection. At the same time, it is necessary to provide:

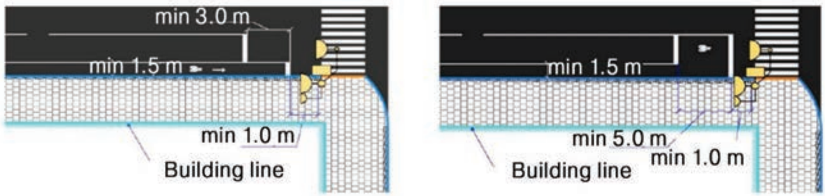
– markings at the point of separation for straight and left movement;

– marking the place where cyclists stop;

– visibility of traffic light signals, which regulates the movement of cyclists turning left.

Table 6.8 Elements of bicycle infrastructure at regulated intersections [34]

Cyclist movement direction	Moving straight	Moving left
Main street or turning lane (approach with longer resolution signal duration)	– recommended bicycle corridors (lanes, tracks) for passing cars that have stopped at a traffic light; – continuation of the specified corridor (lanes, tracks) within the intersection; – bicycle lanes continue along the main street (marked with marking 1.7 [35]); – forward (not less than 3.0 m) stop lines (marking 1.12 [35]) for cyclists (**Fig. 6.36**); – rejection of a separate car lane for turning to the right; – turning on the permission signal for cyclists earlier than for cars; – marking at bicycle crossings; – the use of traffic lights of type 7 [19] for drivers who turn in the presence of an offset bicycle crossing or two – way bicycle traffic	– waiting area for turns in two steps; – bicycle lane for turning left; – recommended bicycle corridor on the car lane for left turns; – an additional place for stopping bicycles at a traffic light
Secondary street or lane for turning (approach with a shorter duration of the permission signal)	– usually turn left in one go; – recommended bicycle corridors (lanes, tracks) for passing cars that have stopped at a traffic light; – extended bicycle lanes for waiting	



a *b*

Fig. 6.36 Arrangement of a stop line for cyclists [34]:
a – on the width of the bicycle lane; *b* – with an extended waiting area

In the case of arranging such a turn at a T-shaped intersection, if there is space, **short bicycle lanes** for turning left can be provided (**Fig. 6.37**).

To regulate the movement of cyclists, it is necessary to use:

– Types 1, 2 and 3 traffic lights [19], which also regulate the movement of cars (**Fig. 6.38**, **6.39**);

– type 3 traffic lights [19] with bicycle symbols, which regulate the movement of cyclists only (**Fig. 6.39**);

– pedestrian traffic lights [19] with bicycle symbols.

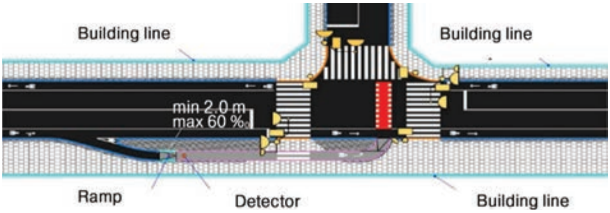


Fig. 6.37 Two-step left turn at a T-intersection [34]

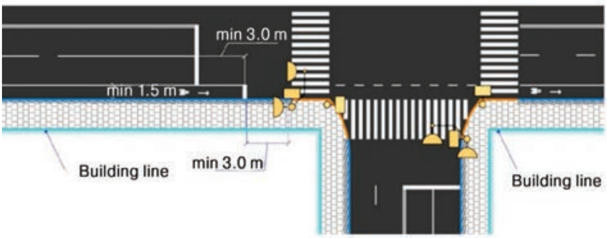


Fig. 6.38 Use of type 1 and 2 traffic lights to regulate the movement of cyclists [34]

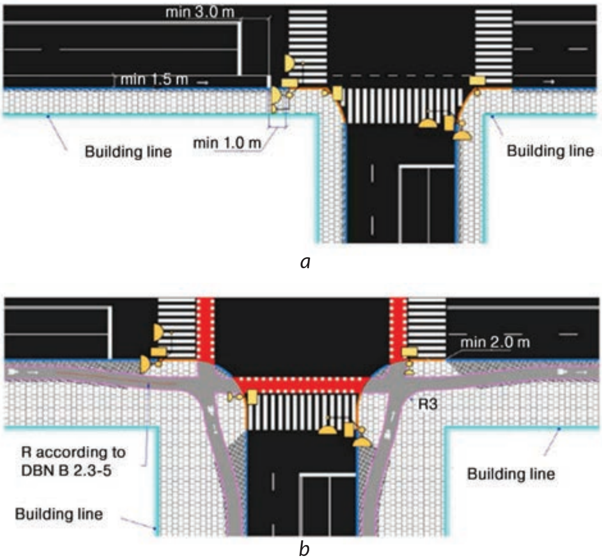


Fig. 6.39 Use of type 3 traffic lights [34] to regulate the movement of cyclists:
a – on bicycle lanes; *b* – on bicycle paths

Preference should be given to the use of **type 3 traffic lights** with **bicycle symbols**. They are used in the presence of a **separate regulation direction for cyclists** (the duration of the permission signal differs from the duration of the permission signal for cars moving in the same direction, cyclists are passed twice during the cycle, a separate regulation phase is arranged for cyclists, in which the movement of cars is prohibited, etc.). Their use is also allowed (even in the absence of a separate direction of regulation for cyclists) if the latter move along bicycle lanes or bicycle paths.

6.8 Conclusions

The current level of mortality and injuries due to road accidents in Ukraine is quite high, and the level of effectiveness of scientific and methodological support of activities in the field of road safety is insufficient. One of the real ways to solve this problem is to improve the quality of expert assessment of the RS level, which is the basis of a general security audit.

The study examines the main methodological provisions for providing such an assessment using the example of a study of engineering planning solutions and management measures that determine the level of mobility and safety of vulnerable road users. Such activities become especially relevant in connection with the expected significant increase in the number of people with disabilities and various functional disorders, as well as destruction and damage to the transport infrastructure as a result of aggressive hostilities on the territory of Ukraine after the full-scale military invasion of Russia.

In recent years, about half of all traffic accidents involving victims in Ukraine have involved vulnerable participants in road accidents, and there is no steady tendency to decrease this share. At the same time, the significant mortality among pedestrians and children, which significantly exceeds the corresponding level in European countries, is of particular concern.

In order to assess the safety of pedestrian traffic in Ukraine, it is necessary to analyze the spatial structure and planning decisions of pedestrian movement routes, which must be supplemented with the necessary management measures. The central component of the human-oriented design of street space should be the construction (reconstruction) and arrangement of sidewalks taking into account the principles of sustainable urban mobility. The arrangement of pedestrian crossings should provide for complex safety measures aimed at improving the conditions of mutual visibility of pedestrians and vehicles and reducing the likelihood of the latter moving at high speed.

The special needs of persons classified as low-mobility population groups must be given undisputed priority in the formation of any transport mobility and safety systems.

An expert assessment of the RS level most often involves an analysis of the design parameters and the quality of the arrangement of the ways of their movement as elements of the street and road network and transport infrastructure. At the same time, special attention should be paid to the availability and condition of means of orientation and information support (tactile and visual elements of accessibility, means of sound information).

Vehicle speed is a key factor not only in the risk of road accidents involving vulnerable road users, but also in the severity of their consequences. Management of this speed to increase the RS level involves, in particular, regulation of maximum values and calming of TS, complex modification of intersections, as well as measures of psychological impact. An important element of the engineering and technical assessment of the RS level from the point of view of the high-speed mode of transport is the analysis of traffic conditions, based on the study of indicators of conflict and activity in the area.

When carrying out an expert assessment of the convenience and safety of children's mobility, in addition to the analysis of measures (solutions) of a general nature, it is recommended to pay attention to the formation of appropriate infrastructure for safe walking and cycling of children (primarily – near schools) and the need to take into account the peculiarities of children's psychophysiology when arranging elements of transport maintenance of places with intensive children's traffic.

In the process of implementing the principles of co-modality and the spread of bicycle mobility in Ukraine, the formation of bicycle infrastructure is an urgent task, since until recently it practically did not exist. In addition, further development and improvement is required for regulatory and methodological support for the organization of such a movement.

Safety is a basic requirement and a determining factor of the quality of bicycle traffic organization. In real conditions, it can most often be guaranteed due to the separation of bicycle traffic in time and space from fast and large vehicles, reducing the intensity of motor traffic and reducing its speed to 30 km/h, clear information and clear regulation of the necessary actions of all traffic participants in places possible conflict between cyclists and motor vehicles.

An expert assessment of the level of cycling safety involves, first of all, an analysis of the corresponding infrastructure, which is being designed or exists, in accordance with the requirements of current regulatory documentation. For example, the paper considers the peculiarities of the implementation of typical engineering and planning solutions for bicycle infrastructure elements in accordance with the requirements of DSTU 8906:2019.

Conflict of interest

The authors declare that there is no conflict of interest in relation to this paper, as well as the published research results, including the financial aspects of conducting the research, obtaining and using its results, as well as any non-financial personal relationships.

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