Analysis of human errors in the cargo logistics process in the airport zone

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Abstract: In many sectors in Poland, we are currently observing a high employee turnover rate, which may increase adverse events caused by human error. In many cases, these errors result from unsatisfactory effects of training programs implemented, insufficient experience negatively affecting employees' skills, or lack of preparation for non-standard situations. The article aims to present the results of the risk assessment of human errors in cargo logistics at a selected airport and, on this basis, to indicate possible training areas with the use of virtual reality. A 4-step research procedure, developed using the HFACS framework, was used to identify adverse events and assess the risk. The article presents the results of analyzes of selected adverse events. Based on the estimated risk index, an evaluation of the events was carried out, and the expected actions related to reducing the existing risk were indicated. The researchers' attention was focused primarily on those adverse events, the risk of which may be limited by implementing an effective and efficient training program. The development of training scenarios based on virtual reality technologies, which will be adapted to the needs of new and experienced employees, will increase the attractiveness of the training and accelerate the process of acquiring new skills and reactions. All research work was carried out as part of the project "The use of a virtual reality environment in the training system of handling employees in the field of handling goods transported by air", financed by the National Center for Research and Development.

1. INTRODUCTION

Poland's employee market currently in force results in high employee turnover in many sectors. This problem also applies to logistics processes, particularly related to the operational handling of loads in various types of warehouses. High employee turnover increases the risk of human error. This is due to new employees' lack of knowledge and experience, the required period of employee acclimatization, and "learning" of the duties performed. However, the existing employees who already have the necessary experience and knowledge are also exposed to the risk of making mistakes. This is because they are burdened with additional obligations resulting from:

- The need to prepare new employees to perform their primary duties.
- The need to perform some of the tasks that new people should perform, but due to the long service process they provide, this task must be performed by more experienced employees

For this reason, many logistics operators point to the need for changes in the systems of training new employees and training experienced employees. We are looking for solutions that allow employees to acquire and improve the required competencies related to their daily duties faster and more effectively. For this reason, the preferred employee training system is active forms of teaching that enable employees to acquire the required knowledge and improve the necessary skills in practice. Today, virtual reality technology is available to answer these needs, which enables a faithful representation of the working environment of operational employees. The developed training scenarios allow trainees to practically participate in the supported processes without exposing them to damage and disruptions.

Thanks to the training tools developed in this way, it is possible to reduce the occurrence of adverse events in which employees are the sources of risk.
The article aims to analyze the risk of human errors occurring in the logistics handling of cargo at the airport and, on this basis, to indicate possible training areas with the use of virtual reality. Therefore, section 2 provides a brief overview of the literature on the risk of human error and the HFACS concept that allows the identification of human factor-related adverse events. Section 3 describes the research methodology, which includes four research stages. The obtained research results are described in section 4 of the article. Section 5 presents the main conclusions. The entire research was carried out as part of the project "The use of a virtual reality environment in the training system of handling employees in handling goods transported by air", financed by the National Center for Research and Development.

2. LITERATURE REVIEW

Despite numerous attempts to define a human error, many authors indicate that this term does not yet have a commonly accepted definition [14]. One of the more famous approaches is the definition proposed by Reason [11], who defined human error as “a generic term to encompass all those occasions in which a planned sequence of mental or physical activities fails to achieve its intended outcome, and when these failures cannot be attributed to the intervention of some chance agency". The problem of human error is most often analyzed in the literature in two dimensions [12]:

1) The person approach focuses on unit errors, identifying the causes of their occurrence as forgetfulness, inattention, poor motivation, carelessness, negligence, and recklessness. Therefore, the associated countermeasures are directed mainly to reduce unwanted human behavior variability.
2) The system approach focuses on the working conditions of individual employees and searches for the causes of undesirable events in them. In this approach, errors are seen as consequences rather than causes, having their origins not so much in the perversity of human nature as in "upstream" systemic factors. Countermeasures are based on the assumption that though we cannot change the human condition, we can change the conditions under which humans work.

These approaches focus on different causes of errors (sources of threats) and manage (limits their occurrence) in various ways. In their research, some authors also recognize that the personal models represent the old approach to human error, while the system models - represent the new approach (e.g. [4]).

The most commonly used model to study systemic accidental accidents is the Swiss cheese model, which explains how accidents could be regarded as the result of interrelations between "unsafe acts” of front operators and latent conditions from a systems perspective [6]. In this model, the cheese slices symbolize the four levels of protective barrier for the system, while the holes in these slices refer to unintended system failures in each piece. These openings can contribute to the occurrence of active or hidden failures that will lead to an accident in a situation where the holes of each barrier align in a straight line [12]. Although the Swiss cheese model has become the dominant paradigm in aviation safety research, many researchers note that the lack of comprehensive explanations of the meaning of holes in the cheese slices makes it challenging to apply the model to real systems [18].
Due to the difficulties in the practical application of the Swiss Cheese Model, it was developed in the following years, and on its basis, the concept of the Human Factors Analysis and Classification System (HFACS) was created [16]. This concept refined the idea of "holes" in cheese slices by characterizing four primary areas of analysis which relate to (1) Unsafe Acts, (2) Preconditions of Unsafe Acts, (3) Unsafe Supervision, and (4) Organization Influence. Each category consists of casuals that represent specific human behaviors or system situations that may lead to errors. The proceeding procedure assumes systematic analysis of occurring adverse events and assigning them to one or more categories of causes. This rigor creates standardization of the investigative process and allows systematic analysis of common causes of adverse events [5].

The HFACS framework is used to investigate the causes of accidents, which may be of various complexity [18]. Initially, it was proposed to analyze pilot errors in naval aviation accidents and incidents [16]. However, since the beginning of the 21st century, we can observe its wide application in civil aviation and other domains to study human errors in accidents because of its high reliability [9]. Today, the HFACS methodology has been shown to be comprehensive, diagnostic, reliable, usable, and valid across several industries [5]. Examples of modifications of the HFACS formulated to analyze the causes of adverse events occurring in various sectors of the economy are presented in Table 1.

Table 1: Application of the HFACS framework to research in various sectors

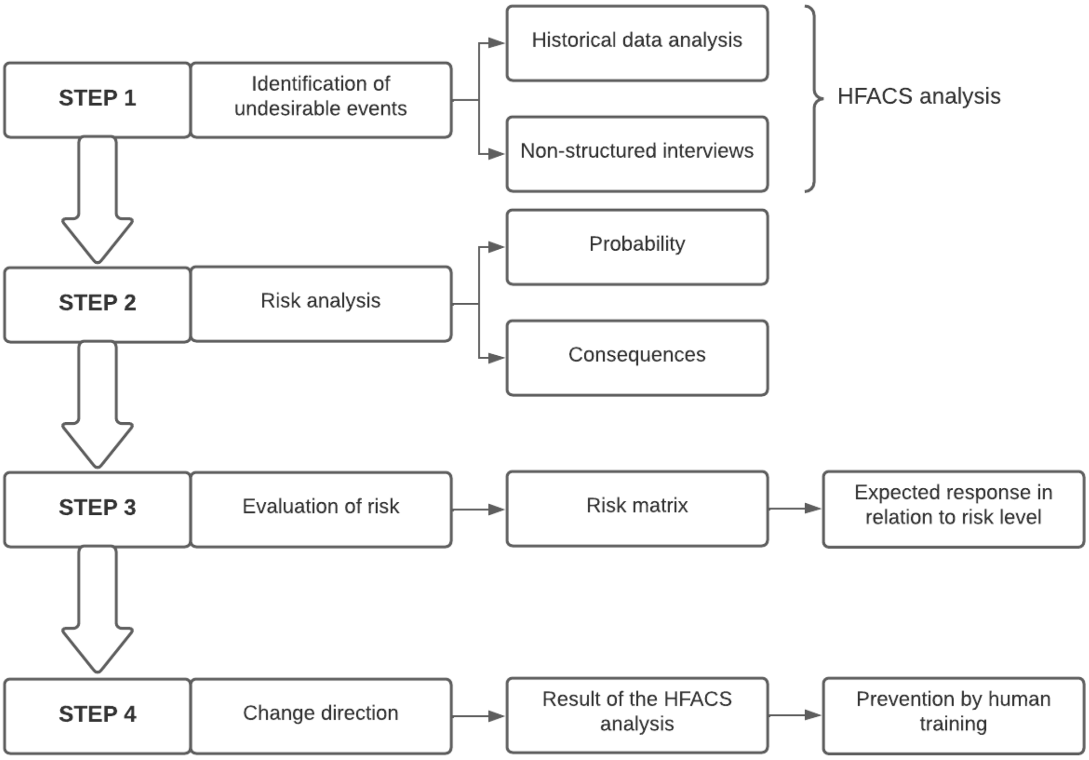
Publications	Application area
Scarborough & Pounds [15]	Operational errors of the air traffic control
Krulak [8]	The aircraft mishaps caused by human factors in maintenance
Chen & Wall [3]	The HFACS-Maritime Accidents framework based on the International Maritime Organization guidelines to conduct the analysis for human factors
Celik & Cebi [1]	The analytical HFACS framework for investigating human errors in shipping accidents
Chauvin & Lardjane [2]	The HFACS-Coll framework to analyze the reasons for decision errors of collisions at sea
Patterson & Shappell [10]	The HFACS-Mining Industry framework to analyze systemic causes of accidents in the mining industry
Zhan, Zheng, & Zhao [18]	The HFACS-Railway Accidents to analyze railway accidents
Reinach & Viale [13]	The HFACS-RR framework to conduct train accident/incident investigations
Diller, Helmrich, Dunning, Cox, Buchanan & Shappell [5]	The HFACS framework is tailored to the needs of the medical error in health care sector analysis

The most important feature that distinguishes HFACS from the other accident causation model is paying attention to the role of management and organization in building safe systems [18]. For this reason, the results of the HFACS analysis make it possible to distinguish areas that can be improved by changing procedures or process organization and those that require employee training. For example, the research authors presented in [17] indicated that operator skills are one of the four most common causes of human error. It is a source of risk, the occurrence of which can be limited precisely through an appropriately designed and conducted training program.
The HFACS framework was also selected for the research due to the universality of this tool in security analysis and the research base that makes its application clear. At the same time, the proposed division allows for the classification of adverse events and indicates those areas for which the implementation of an effective training program is a dedicated procedure for the occurring risk.

3. METHODOLOGY

Research on the identification of adverse events using the HFACS framework and risk assessment was carried out in a selected CARGO warehouse in one of the airports in Poland. Due to the subject of research carried out as part of the project "The use of a virtual reality environment in the training system of handling employees in the field of handling goods transported by air", the procedure aimed to assess the risk associated with human errors, the occurrence of which may be limited by the implementation of an effective and efficient training system based on scenarios using virtual reality technology. The research on risk assessment was qualitative and quantitative and was carried out in four steps, as shown in Figure 1.

Figure 1: Methodology of research works



Identification of adverse events was carried out based on two sources of information: (1) historical data recorded in the internal documentation of the warehouse and (2) unstructured interviews conducted among the staff and managers responsible for servicing the CARGO warehouse. Brainstorming was used for unstructured interviews, and adverse events were generated according to the structure of the HFACS analysis. Thanks to this, it was possible to classify events already at the identification stage, and at the same time, the identification process was supported by the guidelines resulting from the assumptions of the HFACS analysis. Thanks to the classification of events according to the HFACS concept, it was possible to proceed further.

The analysis of the risk of adverse events was carried out based on a structured interview. Its purpose was to determine the frequency and effects of each of the analyzed events. Structured interviews were conducted among managers responsible for servicing the CARGO warehouse. Historical data recorded in the internal documentation of the airport was used to estimate the initial frequency of each event. However, due to some adverse events (no measurement or the requirement to record their occurrence), the estimated frequency was verified by the managers participating in the study. The frequency of occurrences estimated by managers was expressed by linguistic variables, the characteristics of which are presented in Table 2. A numerical value was assigned to each variable to calculate the risk index.

Table 2: Scale for assessing the frequency of adverse events

Rating Category	Value	Description
RARE (F1)	1	Could happen but probably never will
UNLIKELY(F2)	2	Not likely to occur in normal circumstances
POSSIBLE (F3)	3	May occur at some time
VERY LIKELY (F4)	4	Expected to occur at some time
CERTAIN (F5)	5	Expected to occur regularly under normal circumstances

The potential effects of adverse events were also determined by management cooperating with a group of researchers. The consequences were related to the aspects of logistics services expressed mainly by the indicator of timely delivery and damage to the cargo. The linguistic variables assigned to the scale of assessed adverse event effects are presented in Table 3. A numerical value was assigned to each variable to calculate the risk ratio.

Table 3: Scale for assessing the consequences of adverse events

Rating Category	Value	Punctuality	Cargo
NEGLIGIBLE (C1)	1	Without affecting the process	Damaged packaging without affecting the cargo
MODERATE (C2)	2	Delay at the reloading airport	Damage to the cargo
HIGH (C3)	3	Delay at the destination airport	Total cargo loss
CATASTROPHIC (C4)	4	---	Negative effect of the cargo on the environment (fire, spillage)

For the risk evaluation, a risk matrix was used, on which the individual levels of probability and effects were mapped. Based on direct interviews with the management staff, the level of risk acceptance was determined, and thresholds for the remaining values of the estimated risk were set. This approach is used to characterize the expected reaction from managers to the undertaken actions related to risk management. The matrix distinguishes three levels of risk evaluation along with the required response of managers, which are presented in Table 4.

Table 4: Assessment of risk indicators of adverse events

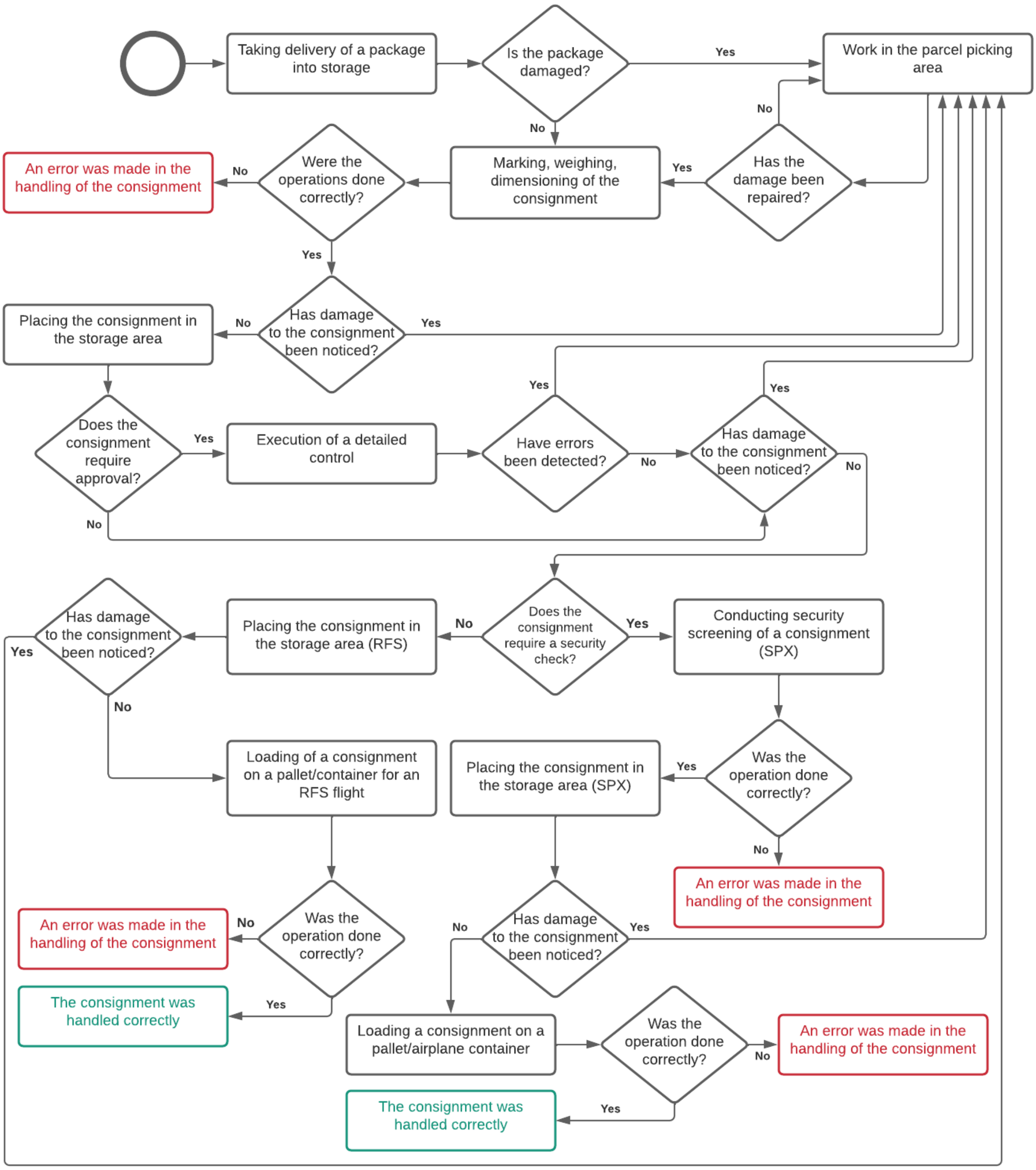
Rating Category	Value	Acceptance level	Description
LOW (RL1)	1 - 2	Acceptable risk	The risk should be monitored in the following periods
MEDIUM (RL2)	4 – 7	Unacceptable risk	Risk mitigation measures should be implemented with due regard to economic viability
HIGH (RL3)	8 - 20	Unacceptable risk	Risk mitigation measures should be put in place immediately, no matter what the cost

The last stage of the research procedure was to determine the directions of the required improvements necessary to be implemented to reduce the risk. The critical aspect of the proposed changes were preventive measures, primarily aimed at reducing the probability of occurrence of adverse events, the risk index of which exceeded the acceptable level of acceptance. In the case of other events, protective measures should also limit the potential consequences of their occurrence. Due to the scope of the project under which the research was carried out, the particular attention of the analytical team was focused on those events that could be prevented through an appropriate training package. Thanks to applying the assumptions of the HFACS analysis already at the stage of event identification, it was possible to quickly carry out a classification aimed at distinguishing this group of events, which will become the subject of further research.

4. RESULTS

A research procedure was carried out for the selected CARGO airport. The analysis concerned the cargo export process. The standard course of the process is shown in Figure 2.

Figure 2: Cargo handling process



Based on the procedures in place, the research procedure was conducted following the methodology presented in section 3. In total, 65 adverse event scenarios were identified. However, for the purposes of this article, 12 adverse events were selected for analysis. These events belong to different groups in the HFACS framework. These scenarios are described in Table 5. For each scenario, the estimated frequency and consequences of its occurrence were indicated, and the risk index was calculated following the formula (1).

$$RI_{S(n)} = F_{S(n)} \times C_{S(n)} \quad (1)$$

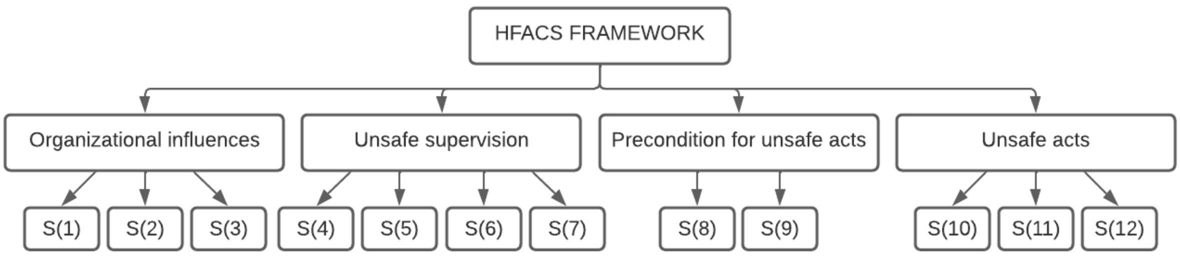
where:
$RI_{S(n)}$ – risk indicator for the scenario *n*
$F_{S(n)}$ – the frequency of the scenario *n*
$C_{S(n)}$ – consequences of the occurrence of the scenario *n*

Table 5: Description of scenarios and estimated risk measures

No scenario	Description of scenario	$F_{S(n)}$	$C_{S(n)}$	$RI_{S(n)}$
S(1)	Admitting to work of employees not fully trained	3	3	9
S(2)	Lack of knowledge of special cargo procedures	2	4	8
S(3)	Numerous overtime hours due to a shortage of personnel	4	2	8
S(4)	Lack of proper control of airline or state restrictions	3	3	9
S(5)	Incorrectly planned servicing of forklifts, which results in the use of a device that is not fully functional	3	1	3
S(6)	Lack of proper control of the securing of cargo with hazardous materials	2	4	8
S(7)	No current markings	2	2	4
S(8)	Work under time pressure	5	2	10
S(9)	Handing over a new employee a non-standard task to be performed	2	3	6
S(10)	Incorrect arrangement of the goods on the pallet	3	2	6
S(11)	Diversion of cargo to the wrong flight	3	3	9
S(12)	Fall of cargo during picking or handling	2	2	4

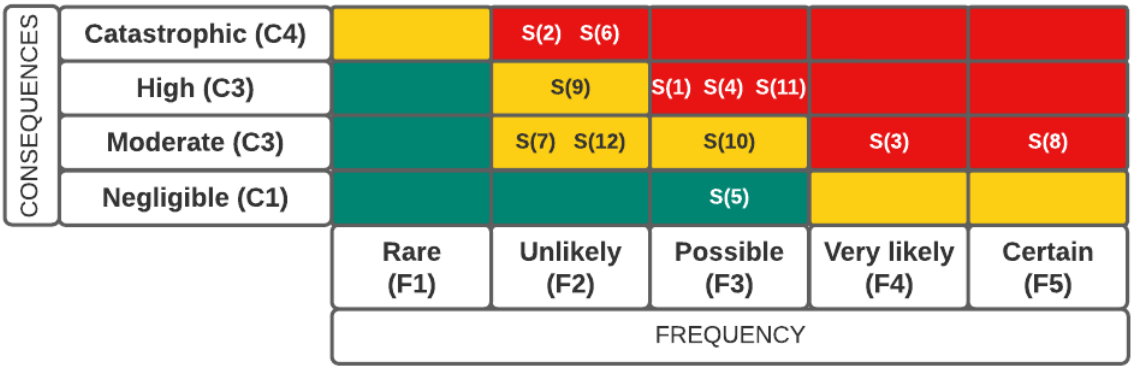
Then, individual scenarios were classified into appropriate groups in accordance with the HFACS analysis. The result of the classification is shown in Figure 3.

Figure 3: Classification of scenarios according to the HFACS framework



Based on the risk analysis, a risk evaluation matrix was created, which allows for prioritizing the implemented changes related to reducing the level of risk. The risk matrix with assigned scenarios is presented in Figure 4.

Figure 4: Risk matrix



Based on the results of the risk assessment, it was found that:

1) Out of the seven scenarios for which the risk index was assessed as unacceptably - high, in the case of four scenarios (S1, S2, S4, S6), the source of the occurring hazard is the knowledge and skills of the crew members.
2) All four scenarios (S7, S9, S10, S12), the risk index of which was assessed as unacceptable - medium, relating to the knowledge and skills of operating operators.

For these adverse event scenarios, the method of reducing the occurring risk is the implementation of effective and efficient training systems.

Due to the high turnover rate of employees responsible for handling CARGO loads in the examined warehouse, it is necessary to implement training tools that will allow you to effectively acquire the required theoretical knowledge and practical skills in a relatively short time. Due to the specificity of the loads handled, it is unacceptable to include not fully trained employees. Their mistakes can have disastrous consequences for other staff members, the company, and even the environment. For this reason, there is a need to implement active forms of employee training, which allow them to acquire the required skills in a shorter time and more effectively than in the case of traditional training. One of such solutions is the use of virtual reality technology both in the process of training new employees and in improving the skills of employees with extensive experience. The prepared training scenarios can be adapted to preventive actions that reduce the likelihood of specific adverse events and improve the response of employees to occurring adverse events, thanks to which the consequences of their occurrence will be limited.

In the case of newly recruited employees, training programs should focus on mastering all the required skills and knowledge necessary to perform daily duties at the workplace. For this reason, the developed training scenarios should refer to the company's operating procedures, both in standard (basic) situations and in special cases (e.g., handling of dangerous goods). Thanks to the accurate mapping of the future work environment in virtual reality, the new employee can learn about the steps taken in the process and the decision-making situations he or she will participate in. This will allow him to become aware of the causal relationships that should be considered in the future when performing the tasks entrusted to him.

In the case of experienced employees, training programs should be focused on improving selected skills related to the response to non-standard or random events. Their mapping in virtual reality will allow the trainee to get used to the emotions accompanying a given situation. Thanks to this, in the event of its occurrence in reality, the employee can react appropriately faster and take action limiting the consequences of its occurrence.

5. CONCLUSION

The studies carried out on the risk assessment related to the handling of cargo in a selected airport prove that the cause of many adverse events is employees' lack of knowledge and skills. A dedicated direction of dealing with the risk of their occurrence is the introduction of active training programs to allow employees to acquire the required skills faster and more effectively. Inference based on the results of the risk assessment showed that most adverse events occur due to a lack of knowledge and skills that can be acquired through properly prepared training.

In the project "The use of a virtual reality environment in the training system of handling employees in the field of handling goods transported by air", research is conducted to develop training scenarios implemented in a virtual reality environment that will meet the needs of warehouse operators at airports. These scenarios will cover the adverse events with the highest frequency and impact. For this reason, it was necessary to conduct a detailed analysis of the cargo handling process and prepare a risk assessment for all identified adverse events. The use of the HFACS framework additionally allowed researchers to focus their attention of researchers primarily on events, the risk of which may be limited by an appropriately selected training system.

The scope of the research envisaged in the project results largely from the demand currently reported by representatives of logistics operators. The high level of employee turnover in this sector necessitates the implementation of training courses that will allow new employees to acquire the required competencies quickly and effectively. At the same time, employees and managers of selected enterprises from this sector emphasize that the effectiveness and efficiency of the training sessions are determined by a large share of active forms that allow you to improve skills and not only supplement knowledge. This opinion is consistent with Kolb's cycle [7] known in the literature, also called experiential learning theory. This concept indicates that an adult's effective acquisition of knowledge and skills requires going through 4 phases of the learning cycle. These phases include: (1) Abstract Conceptualisation; (2) Concrete Experience; (3) Reflective Observation; (4) Active Experimentation. Using Kolb's approach in the developed training scenarios will allow us to respond to the current market needs. Using a virtual reality environment for this purpose will speed up the learning process. However, to achieve the expected effectiveness, the participation of an experienced trainer is also planned, who, based on the results of the training participant, will appropriately select training scenarios to the current needs.

Acknowledgements

The research was carried out as part of project „The use of a virtual reality environment in the training system of handling employees in the field of handling goods transported by air", which is funded by National Centre for Research and Development.

References

[1] Celik M. and Cebi S. *"Analytical HFACS for investigating human errors in shipping accidents"*, Accid Anal Prev.,vol. 41, pp. 66-75, (2009).
[2] Chauvin C. and Lardjane S. *"Human and organisational factors in maritime accidents: analysis of collisions at sea using the HFACS"*, Accid. Anal. Prev., vol. 59, pp. 26-37, (2013).
[3] Chen S.T. and Wall A. *"A Human and Organizational Factors (HOFs) analysis method for marine casualties using HFACS-Maritime Accidents (HFACS-MA)"*, Safety Science, vol. 60, pp. 105-114, (2013).
[4] Dekker S.W.A. *"Reconstructing human contributions to accidents: the new view on human error and performance"*, Journal of Safety Research, vol. 33, pp. 371-385, (2002).
[5] Diller T., Helmrich G., Dunning S., Cox S., Buchanan A. and Shappell S. "*The Human Factors Analysis Classification System (HFACS) Applied to Health Care"*, American Journal of Medical Quality, vol. 29, pp. 181-190, (2014).
[6] Dong S.K. and Wan C.Y. "*An accident causation model for the railway industry: application of the model to 80 rail accident investigation reports from the UK"*, Safety Science, vol. 60, pp. 57-68, (2013).

[7] Kolb D. *“Experiential Learning: Experience as the Source of Learning and Development”*, Prentice-Hall, Englewood Cliffs, 1984, New Jersey.
[8] Krulak D. *“Human factors in maintenance: impact on aircraft mishap frequency and severity”*, Aviat. Space Environ. Med., vol. 75, pp. 429-432, (2004).
[9] Olsen N.S. *“Coding ATC incident data using HFACS: inter-coder consensus”*, Int. J. Qual. Stat. Reliab. 2011, pp. 1365-1370, (2011).
[10] Patterson J.M. and Shappell S.A. *“Operator error and system deficiencies: analysis of 508 mining incidents and accidents from Queensland, Australia using HFACS”*, Accid. Anal. Prev., vol. 42, pp. 1379-1385, (2010).
[11] Reason J. *“Human Error”*, Cambridge University Press, 1990, Cambridge.
[12] Reason J. *“Human error: models and management”*. Bmj Clin. Res., vol. 320, pp. 768-770, (2000).
[13] Reinach S., Viale A. *“Application of a human error framework to conduct train accident/incident investigations”*, Accid Anal Prev, vol. 38, pp. 396-406, (2006).
[14] Salmon P. M., Lenné M. G., Stanton N. A., Jenkins D. P. and Walker G. H. *“Managing error on the open road: The contribution of human error models and methods”*, Safety Science, vol. 48, pp. 1225-1235, (2010).
[15] Scarborough A. and Pounds J. *“Retrospective human factors analysis of ATC operational errors”*, Aviation Space and Environmental Medicine, vol 71, (2001).
[16] Shappell S.A. and Wiegmann D.A. *“Applying reason: the human factors analysis and classification system (HFACS)”*, Hum. Factors Aerosp. Saf., vol. 1, pp. 59-86, (2001).
[17] Walker P.B., O’Connor P., Phillips H.L., Hahn R.G. and Dalitsch W.W. *“Evaluating the utility of DOD HFACS using lifted probabilities”*, Proceedings of the Human Factors and Ergonomics Society Annual Meeting, vol. 55, pp. 1793-1797, (2011).
[18] Zhan Q., Zheng W. and Zhao B. *“A hybrid human and organizational analysis method for railway accidents based on HFACS-Railway Accidents (HFACS-RAs)”*, Safety Science, vol. 91, pp. 232-250, (2017)