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Original article

Influence of the Competencies of Lifting Crane Specialists on the Probability of Emergencies

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Abstract

Introduction. The operation of lifting cranes is an integral part of the production processes. For the trouble-free operation of these mechanisms, certain knowledge, skills and abilities are required, which should also be possessed by specialists performing organizational and supervisory functions at facilities where such cranes are involved. Here there is an important problem — the lack of a reasonable connection between the level of development of professional competencies and possible emergency situations, as well as various incidents during the operation of lifting cranes. The authors of this study are trying to solve it. Their goal in this regard is to assess the probability of an emergency during the operation of lifting cranes, depending on the level of professional competence of specialists, through the use of neural networks.

Materials and Methods. The competencies of workers in the operation of lifting cranes (knowledge, skills and work responsibilities) provided for by the professional standard "Specialist in the operation of lifting structures" were used as initial data to train neural networks. Based on them, a list of possible incidents was compiled. For the purposes of training, the results of the certification of 200 conditional employees were generated. During the generation, the Monte Carlo method was used, and the data were output to Excel tables. Neural networks were trained in Python 3.10 in the PyCharm development environment. Open libraries Keras and TensorFlow, as well as auxiliary libraries for data representation and processing (Pandas, NumPy, Scikit-learn) were used for neural networks training.

Results. As a result, a tool was obtained — a neural network in the form of executable program code, which makes it possible to assess the probability of emergencies during the operation of lifting cranes by analyzing the degree of proficiency of specialists in professional competencies. It is proposed to implement artificial intelligence technologies based on neural networks in order to assess the knowledge, skills and abilities of specialists of facilities operating lifting cranes, both during the certification of employees and in the course of work.

Discussion and Conclusion. The main result of using neural networks to assess the knowledge of employees of facilities operating lifting cranes is the expected reduction in accidents, which can be ensured by timely identification of incompetent personnel at the stages of primary certification and, most importantly, during periodic tests of knowledge based on an impartial analysis and evaluation of data.

Keywords: accident, lifting crane, probability, assessment, competence, human factor, neural network.

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Научная статья

Влияние компетенций специалистов грузоподъемных кранов на вероятность возникновения аварийных ситуаций

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Аннотация

Введение. Эксплуатация грузоподъемных кранов является неотъемлемой частью производственных процессов. Для безаварийной работы этих механизмов необходимы определенные знания, умения и навыки, которыми должны обладать в том числе и специалисты, осуществляющие организационные и контролирующие функции на объектах, где задействованы такие краны. И здесь существует важная проблема — отсутствие обоснованной связи между уровнем освоения профессиональных компетенций и возможными аварийными ситуациями, а также различными инцидентами при эксплуатации грузоподъёмных кранов. Авторы данного исследования пытаются решить ее. Их цель в связи с этим — посредством применения нейронных сетей дать оценку вероятности возникновения аварийной ситуации при эксплуатации грузоподъемных кранов в зависимости от уровня профессиональных компетенций специалистов.

Материалы и методы. Для обучения нейронных сетей в качестве исходных данных использовались компетенции работников по эксплуатации грузоподъемных кранов (знания, умения и трудовые обязанности), предусмотренные профессиональным стандартом «Специалист по эксплуатации подъемных сооружений». На их основе был составлен перечень возможных инцидентов. Для целей обучения сгенерированы результаты аттестации 200 условных работников. При генерации использовался метод Монте-Карло, и данные выведены в таблицы Excel. Обучение нейронных сетей производилось на языке Python 3.10 в среде разработки PyCharm. При обучении нейронных сетей использовались открытые библиотеки Keras и TensorFlow, а также вспомогательные библиотеки представления и обработки данных (Pandas, NumPy, Scikit-learn).

Результаты исследования. В результате получен инструмент — нейронная сеть в виде исполняемого программного кода, позволяющая выполнить оценку вероятности возникновения аварийных ситуаций при эксплуатации грузоподъемных кранов посредством анализа степени владения специалистами профессиональными компетенциями. Предлагается осуществить внедрение технологий искусственного интеллекта на базе нейронных сетей с целью дать оценку знаний, умений и навыков специалистов объектов, эксплуатирующих грузоподъемные краны, как при проведении аттестации работников, так и в процессе трудовой деятельности.

Обсуждение и заключения. Основным результатом использования нейронных сетей для оценки знаний работников объектов, эксплуатирующих грузоподъемные краны, является предполагаемое снижение аварийности, что может быть обеспечено за счет своевременного выявления некомпетентного персонала на стадиях первичной аттестации и, что особенно важно, при периодических проверках знаний на основании беспристрастного анализа и оценки данных.

Ключевые слова: авария, грузоподъемный кран, вероятность, оценка, компетенция, человеческий фактор, нейронная сеть.

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Introduction. Enterprises operating lifting equipment (lifting cranes, loader cranes, lifts (towers), construction lifts, etc.), in accordance with the legislation[1] belong to hazardous production facilities (HPF), as a rule, of hazard class IV, but may also be part of objects of hazard class I, II or III. The Federal Service for Environmental, Technological and Nuclear Supervision (Rostekhnadzor) is responsible for accounting, control of activities, investigation and accounting of accidents that occurred at the HPF.

According to Rostekhnadzor[2], in 2021, about 600 thousand lifting mechanisms were operated at enterprises and organizations of the Russian Federation, of which 209,935 were lifting cranes. In 2021, there were 29 accidents during the operation of lifting structures, 27 deaths. Compared to 2020, we can observe a slight positive trend — then there were 30 accidents, 28 fatal injuries.

The largest number of accidents in 2021, as in 2015-2020, occurred during the operation of tower cranes:

– during the operation of tower cranes in 2020, 12 accidents occurred, in 2021 13 accidents occurred;

– during the operation of vehicle-mounted cranes, four accidents occurred in 2020, and four accidents also occurred in 2021;

– during the operation of overhead cranes there was one accident in 2020, in 2021 there was also one accident;

– during the operation of frame cranes there was one accident in 2020, in 2021 there were three accidents;

– during the operation of loader cranes, two accidents occurred in 2020, and two accidents also occurred in 2021.

Analyzing the above data, one can distinguish among others such a cause of accidents as the lack of proper control over production processes at facilities by responsible specialists (human factor).

Causes of accidents are:

– lack of production control over the compliance with industrial safety requirements by the management of the organization and owners of a hazardous production facility, as well as persons responsible for the maintenance of lifting structures in working condition and for the safe production of works;

– in some organizations, the facts of non-assignment of specialists responsible for this area of control are recorded, as required by regulatory legal acts[3];

– involvement of personnel who do not have the necessary qualifications in the production of works;

– absence of work production projects, work production rules, job descriptions and production instructions at the facility;

– untimely scheduled inspections, repairs and technical inspections of lifting structures.

[1] *O promyshlennoi bezopasnosti opasnykh proizvodstvennykh ob"ektov*. Federal Law No. 116-FZ of 21.0.1997. Consultant Plus. URL: http://www.consultant.ru/document/cons_doc_LAW_15234/ (accessed 18.01.2023). (In Russ.).

[2] *Otchet o deyatel'nosti Federal'noi sluzhby po ekologicheskomu, tekhnologicheskomu i atomnomu nadzoru v 2021 godu*. Rostekhnadzor. URL: https://www.gosnadzor.ru/public/annual_reports (accessed 18.01.2023). (In Russ.).

[3] *Ob utverzhdenii federal'nykh norm i pravil v oblasti promyshlennoi bezopasnosti "Pravila bezopasnosti opasnykh proizvodstvennykh ob"ektov, na kotorykh ispol'zuyutsya pod"emnye sooruzheniya"*. Order No. 461 of the Federal Service for Environmental, Technological and Nuclear Supervision dated November 26, 2020. Electronic Fund of Legal and Regulatory and Technical Documents. URL: https://docs.cntd.ru/document/573275657 (accessed 30.03.2023). (In Russ.).

Often, the root cause of violations committed in terms of not properly organized production control over the compliance with industrial safety requirements is the desire of owners of hazardous production facilities to reduce financial costs.

However, as statistics show, as well as numerous studies on this topic, there is a direct dependence of the occurrence of accidents on the level of qualification of managers and responsible specialists [1–3].

The probability of emergencies during the operation of lifting cranes is determined by assessing the degree of proficiency of professional competencies of personnel. In order to evaluate such knowledge, it is proposed to use artificial intelligence technologies based on neural networks during the certification of employees.

In accordance with the decree of the President of the Russian Federation[4] and the National Strategy for the Development of Artificial Intelligence for the period up to 2030, it is necessary to use artificial intelligence technologies based on neural networks to assess the residual knowledge of responsible specialists of organizations operating lifting cranes in the following cases:

– on the eve of attestation in the attestation commissions of the enterprise or the territorial attestation commission of Rostekhnadzor;

– in case of an accident or injury at the HPF, etc.

The level of competence of engineering and technical employees of the HPF operating lifting cranes, appointed by responsible specialists, is determined not only by the availability of specialized higher professional education, but also by periodic attestation in accordance with the requirements of the legislation of the Russian Federation, which is preceded by obtaining additional professional education for certain categories of specialists[5,6].

Verification of the level of knowledge and competencies based on the results of advanced training in the field of industrial safety is carried out by educational organizations through assessments developed for specific programs [4–6].

Verification of the level of knowledge and competencies during periodic examinations in the attestation commissions of Rostekhnadzor or the operating organization is carried out through testing in a unified testing system[5]. The results of the test tasks will contribute to the assessment of knowledge of legislative and regulatory documents relevant to the field of attestation[7].

There is also a need to evaluate the knowledge, skills and abilities of the HPF specialists operating lifting cranes in accordance with professional standards for specific positions[8]. At the same time, not only answers to questions, that is, theoretical knowledge, are taken into account, but also skills and abilities through practical tasks (solving thematic problems, reading drawings, making relevant documentation).

Materials and Methods. During the attestation for each type of inspections, specialists put down points. The attested person must score at least 80 % of the correct answers for admission to work. In this way, a data matrix can be formed, and statistical data in the matrix can be linked to the causes of accidents, injuries and accidents. Then it

[4]*O razvitii iskusstvennogo intellekta v Rossiiskoi Federatsii*. Decree of the President of the Russian Federation No. 490 of 10.10.2019. URL: https://www.garant.ru/products/ipo/prime/doc/72738946 / (accessed 30.03.2023). (In Russ.).

[5]O *podgotovke i ob attestatsii v oblasti promyshlennoi bezopasnosti, po voprosam bezopasnosti gidrotekhnicheskikh sooruzhenii, bezopasnosti v sfere elektroenergetiki*. Resolution of the Government of the Russian Federation No. 1365 of October 25, 2019. Information and legal base of the Russian Federation. URL: https://ipbd.ru/doc/0001201910290010/ (accessed 30.03.2023). (In Russ.).

[6]*Ob attestatsii v oblasti promyshlennoi bezopasnosti, po voprosam bezopasnosti gidrotekhnicheskikh sooruzhenii, bezopasnosti v sfere elektroenergetiki*. Resolution of the Government of the Russian Federation No. 13 of January 13, 2023. Official Internet portal of legal information. URL: http://publication.pravo.gov.ru/Document/View/0001202301170020 (accessed 30.03.2023). (In Russ.).

[7]*Ob utverzhdenii Perechnya oblastei attestatsii v oblasti promyshlennoi bezopasnosti, po voprosam bezopasnosti gidrotekhnicheskikh sooruzhenii, bezopasnosti v sfere elektroenergetiki*. Rostechnadzor Order No. 334 of September 4, 2020. Official Internet portal of legal information. URL: http://publication.pravo.gov.ru/Document/View/0001202102040015 (accessed 30.03.2023). (In Russ.).

[8]*Ob utverzhdenii professional'nogo standarta "Spetsialist po ekspluatatsii pod"emnykh sooruzhenii"*. Order of the Ministry of Labor and Social Protection of the Russian Federation No. 169n of March 20, 2018. Electronic fund of legal and regulatory documents. URL: https://docs.cntd.ru/document/542621605 (accessed 30.03.2023). (In Russ.).

becomes possible to train a neural network, which will allow, if insufficient knowledge, skills and abilities of the attested person are detected, predicting possible injuries and accidents at facilities [7–9].

The professional standard "Specialist in the operation of lifting equipment" provides 132 competencies, divided into knowledge, skills and labor functions. To train a neural network and make it easier to present data, it is necessary to assign alphanumeric indexes to them. The results of the training of conditional attested specialists were obtained by the Monte Carlo method [10–12].

The obtained values consist of 0 and 1, which corresponds to a negative and positive (more than 80 %) result of the assessment of the possession of the relevant competence. The generation is performed in such a way that the data is evenly distributed across the matrix and the neural network is trained on various combinations of positive and negative assessments of competence acquisition. During the generation, the results of the attestation of 200 conditional specialists were obtained (Fig. 1).

On the basis of Rostekhnadzor data on emergency situations on lifting cranes and the list of professional competencies, possible incidents occurring due to insufficient development of professional competencies by specialists are formulated. The probability of an incident is estimated in fractions of one and is in the range of 0.0–1.0. Each of the possible incidents was correlated with a set of competencies from the matrix. The relevant incidents and the sets of competencies affecting them are presented in Table 1.

Production of works, flowcharts, technological regulations and work permits			
Labor actions		Required skills	
Monitoring compliance with the brand system when operating bridge cranes	Preparation of the necessary documentation	Organize their own activities and the activities of lifting equipment operators and slingers, give instructions and monitor their implementation	Monitor the compliance with the requirements of industrial safety and labor protection by machinists of lifting equipment and slingers

Fig. 1. Competence matrix (fragment) (the authors' figure)

Table 1

Possible incidents and competencies affecting them (the authors' table)

Type of incident	Influencing competence	Number of competencies
Injury to unauthorized persons and workers without access to the danger zone during the operation of lifting equipment	A1, A2, B1, B7, C1, C2, C8, C9, C11, D1, D4, D7, E2, E3, E5, F1, F2, F8, F9, F14	20
Injury to workers in violation of the performance of slinging and cargo operations	A3, A4, A5, A6, B2, B3, B4, B5, B6, B7, C6, D1, D2, D4, D7, E1, E2, E3, E5, F1, F2, F6	22
Injury to personnel and damage to material assets in violation of the requirements for the laying and maintenance of crane tracks	C4, C14, D5, D6, D7, F4	6
Injury to personnel and damage to material assets in violation of the requirements for laying, maintenance and repair of crane tracks	C4, C14, D5, D6, D7, F6, H12, I4, I5, I8, J1, M11	12
Injury to personnel and damage to material assets in violation of the requirements for the storage of goods	C5, D3, F5	3

Type of incident	Influencing competence	Number of competencies
Injury to personnel and damage to property in case of electric shock	C7, C13, E4, F7, F13, H8, K1, K14, M7, M18	10
Injury to personnel and damage to property in violation of the rules of maintenance and repair	C3, F3, F11, G1, G2, G3, G4, G5, G6, H1, H2, H3, H4, H6, H7, H8, H9, H10, H13, H14, H15, H16, H18, H19, H20, I1, I2, I3, I4, I5, I6, I7, I8, J1, J2, J3, J4, J5, J6, J8, K1, K2, K3, K4, K5, K6, K7, K8, K9, K10, K12, K14, L1, L2, L3, L4, L5, M1, M2, M3, M4, M6, M7	63
Injury to health and loss of life as a result of violation of the procedure and assistance in emergency situations	C12, F12, H5, H19, J7, K13, M5, M17	8
Injury to personnel and damage to material assets due to improper inspection and rejection of steel ropes, lifting devices, lifting mechanisms	C10, F10, H11, H17, K11, M8, M9, M10, M11, M12, M13, M14, M15, M16, M18	15

The possible incidents indicated in Table 1 are assigned alphanumeric indexes for the convenience of using data headers when training a neural network, and then the values of the probabilities of occurrence of incidents are calculated depending on the completeness of the development of competencies [13, 14] (Fig. 2).

The data obtained were used to train a neural environment in Python 3.10 in the PyCharm Community Edition development environment. The TensorFlow open library of deep machine learning, as well as the Keras open library interacting with it, were used to train the neural network. The open Pandas library is used to import data from Excel to Python. The NumPy open library was used to optimize the structure of data arrays in order to speed up neural network learning. With the help of the open library Scikit-learn, the training data was divided into train — 70 %, test — 15 % and validation — 15 %.

Injury to unauthorized persons and workers without access to the danger zone during the operation of lifting equipment	Injury to workers in violation of the performance of slinging and cargo operations	Injury to personnel and damage to material assets in violation of the requirements for the laying and maintenance of crane tracks	Injury to personnel and damage to material assets in violation of the requirements for laying, maintenance and repair of crane tracks	Injury to personnel and damage to material assets in violation of the requirements for the storage of goods	Injury to personnel and damage to property in case of electric shock	Injury to personnel and damage to property in violation of the rules of maintenance and repair	Injury to health and loss of life as a result of violation of the procedure and assistance in emergency situations	Injury to personnel and damage to material assets due to improper inspection and rejection of steel ropes, lifting devices, lifting mechanisms
EMG1	EMG2	EMG3	EMG4	EMG5	EMG6	EMG7	EMG8	EMG9
0.25	0.27	0.33	0.25	0.33	0.10	0.25	0.38	0.00
0.25	0.23	0.17	0.33	0.67	0.10	0.32	0.25	0.27

Fig. 2. Incident matrix (fragment)

During the training, the method of "training with a teacher" was used, which was an array of training data [15–17]. The training lasted 1000 epochs. A multilayer perceptron (MLP) was used as a learning model as a subclass of the Keras library's Model class. The general structure of the trained neural network is shown in Fig. 3.

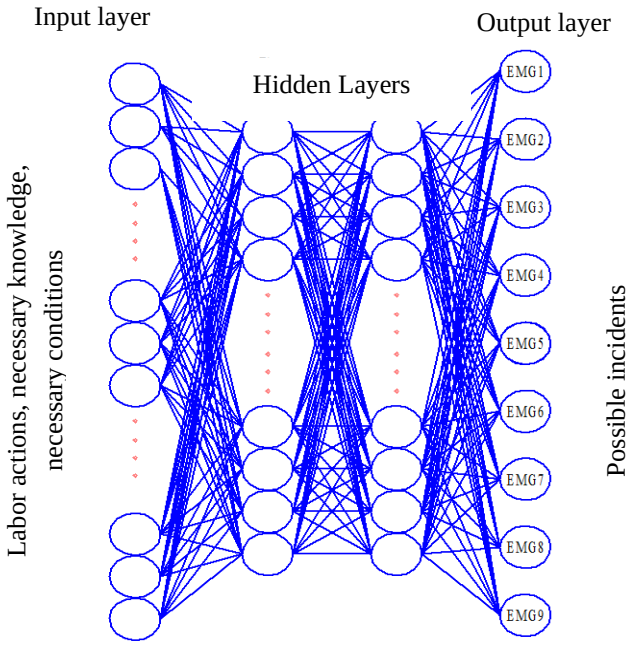

Fig. 3. The neural network diagram for assessing the probability of incidents on lifting cranes

Results. During the training, the MLP 132-25-9 neural network was obtained (25 neurons are located in hidden layers), which is a software product that makes it possible to assess the probability of incidents depending on the quality of mastering professional competencies by specialists in the field of lifting cranes.

In the process of training the neural network, various activation functions were used for the hidden layers and the output layer. The best results are obtained when using the hyperbolic tangent function (Tanh) in the hidden layer, and the Identity function in the output layer.

The mean squared error function was used as the error function. As a result, it was possible to obtain the following error values on the training, test and validation sample, respectively:

– training sample — 0.0034;

– test sample — 0.0591;

– validation sample — 0.0573.

Based on the presented values, it can be concluded that the level of errors received is quite low, which means that the neural network is trained sufficiently qualitatively for practical use [18–20] (Fig. 4).

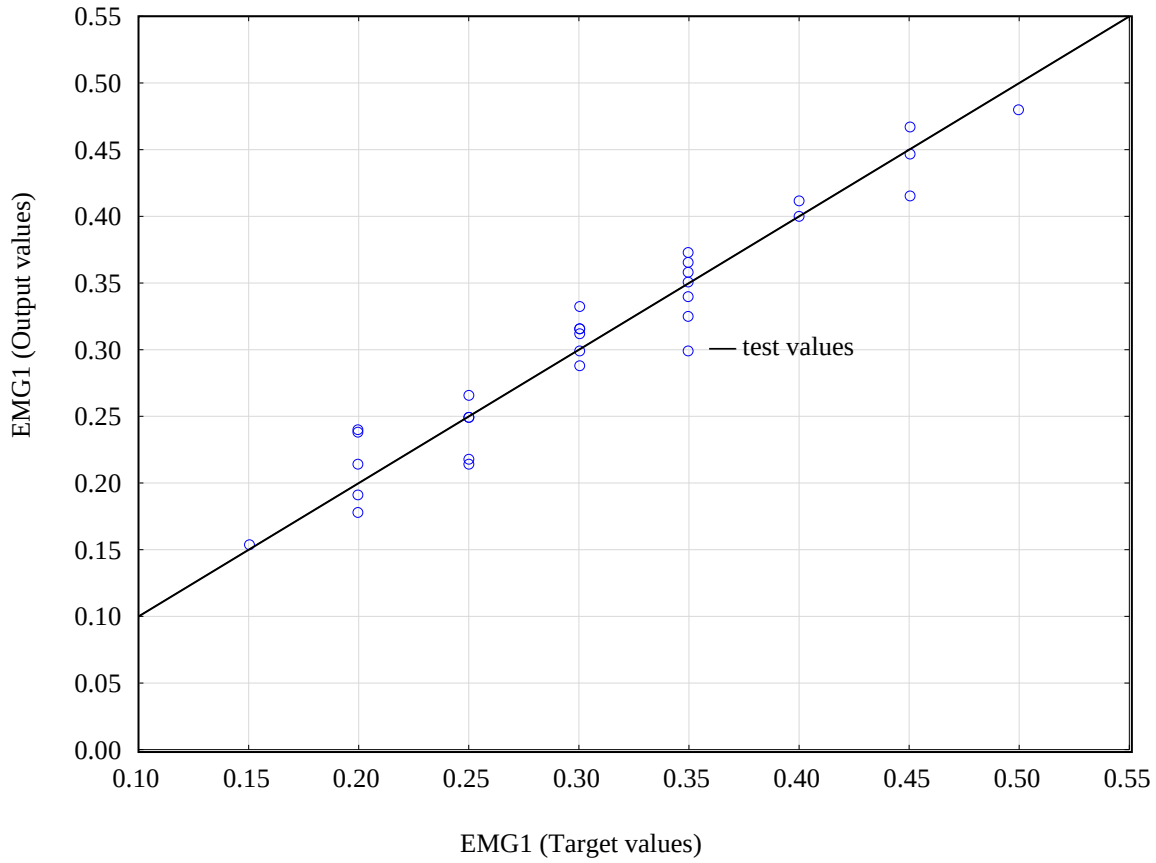

Fig. 4. Graphical representation of the results of the neural network on test data

Discussion and Conclusion. The software solution proposed by the authors, based on the use of neural networks to assess the knowledge of employees of facilities operating lifting cranes, assumes a reduction in the level of accidents, which can be ensured by timely detection of incompetence of specialists not only within the framework of attestation, but also at any stage of their professional activities based on an impartial analysis and evaluation of data. As a result of the application of the developed program, it is possible to expect informed decisions on the appointment or refusal of appointment to responsible positions related to the implementation of the evaluated labor functions. The proposed further development of this solution may be the creation of a cross-platform application that allows you to evaluate and transfer results to devices with different architectures, including mobile ones.

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