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DEVELOPMENT OF A PERSONALIZED LEARNING TRAJECTORY USING A BRAIN-COMPUTER INTERFACE

pages 6–12

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The object of research is electroencephalogram (EEG) signals obtained as a result of a non-invasive test that records the electrical activity of the brain by placing small sensors (electrodes) on the scalp. The article analyzes brain wave patterns to monitor a learner's memory ability.

One of the persistent issues in contemporary education is the misalignment between the competencies of graduates and the evolving demands of the labor market. A key contributing factor to this gap lies in the individual differences in how students perceive and process information. Empirical studies suggest that, excluding individuals with clinically diagnosed cognitive impairments, the population exhibits varied abilities in information retention depending on the modality of content delivery.

To address this issue, the study explores brain-computer interface technologies, particularly electroencephalography (EEG), as a means of assessing individual learning profiles. An artificial intelligence (AI)-based model employing a decision tree algorithm was developed to analyze EEG signals acquired from a 256-electrode system. A publicly available dataset from Kaggle was utilized to train and refine the model, enabling the classification of preferred memorization modalities – namely, reading, multimodal, auditory, and visual.

The applied phase of the study involved 32 students who had previously received failing ("F") grades. Based on their EEG-derived cognitive profiles, these students were subsequently taught using tailored content delivery methods aligned with their dominant memorization styles. Remarkably, this personalized approach resulted in significant academic improvement, with students achieving "C", "B", and even "A" grades in subsequent assessments.

The proposed model offers a scalable and time-efficient method for identifying optimal learning modalities at the individual level. It holds promise for enhancing educational outcomes by enabling more personalized and neuroadaptive instructional strategies.

Keywords: electroencephalography (EEG), brain-computer interface (BCI), cognitive profiling, learning modalities, personalized education, artificial intelligence (AI), decision tree algorithm, memory retention, neuroadaptive learning, educational technology.

References

1. Gu, X., Cao, Z., Jolfaei, A., Xu, P., Wu, D., Jung, T.-P., Lin, C.-T. (2021). EEG-Based Brain-Computer Interfaces (BCIs): A Survey of Recent Studies on Signal Sensing Technologies and Computational Intelligence Approaches and Their Applications. *IEEE/ACM Transactions on Computational Biology and Bioinformatics, 18 (5)*, 1645–1666. https://doi.org/10.1109/tcbb.2021.3052811
2. Gasimov, H. (2020). Modelling support systems for selecting professions for applicants in the content of personalization of education. *EUREKA: Physics and Engineering, 2,* 83–97. https://doi.org/10.21303/2461-4262.2020.001181
3. Mammadova, M., Mammadzadeh, F. (2012). Formation of supply and demand for IT specialists on the base of competency model. *2012 IV International Conference "Problems of Cybernetics and Informatics" (PCI),* 199–201. https://doi.org/10.1109/icpci.2012.6486486
4. A. Duque-Vaca, M., Carmona, J. A. R.-, Yungán, J. I. G., Builes, J. A. J. (2025). Implementation of Instructional Design Modelswithout Considering Inclusive Education. *International Journal of Modern Education and Computer Science, 17 (1),* 17–27. https://doi.org/10.5815/ijmecs.2025.01.02
5. Abbasov, A. M., Mamedova, M. H., Orujov, G. H., Aliev, H. B. (2001). Synthesis of the methods of subjective knowledge representations in problems of fuzzy pattern recognition. *Mechatronics, 11 (4),* 439–449. https://doi.org/10.1016/s0957-4158(00)00027-1
6. Hu, P.-C., Chen, P.-H., Kuo, P.-C. (2018). Educational Model Based on Hands-on Brain-Computer Interface: Implementation of Music Composition Using EEG. *2018 IEEE International Conference on Systems, Man, and Cybernetics (SMC),* 982–985. https://doi.org/10.1109/smc.2018.00174
7. Lyu, L., Sokolova, A. (2022). The effect of using digital technology in the music education of elementary school students. *Education and Information Technologies, 28 (4),* 4003–4016. https://doi.org/10.1007/s10639-022-11334-8
8. Alibeyli, T. (2025). Brain-computer interfaces: neural signal processing and algorithmic approaches. *ScienceRise, 1,* 89–95. https://doi.org/10.21303/2313-8416.2025.003767
9. Xu, W., Chen, L., Sui, X., Tian, Y., Liu, Z. (2022). Brain-computer interface – Brain information reading and activity control. *Chinese Science Bulletin, 68 (8),* 927–943. https://doi.org/10.1360/tb-2022-0338
10. Flesher, S. N., Downey, J. E., Weiss, J. M., Hughes, C. L., Herrera, A. J., Tyler-Kabara, E. C. et al. (2021). A brain-computer interface that evokes tactile sensations improves robotic arm control. *Science, 372 (6544),* 831–836. https://doi.org/10.1126/science.abd0380
11. Pitt, K. M., McKelvey, M., Weissling, K., Thiessen, A. (2024). Brain-computer interface for augmentative and alternative communication access: The initial training needs and learning preferences of speech-language pathologists. *International Journal of Speech-Language Pathology, 27 (1),* 14–22. https://doi.org/10.1080/17549507.2024.2363939
12. Gupta, E., Sivakumar, R. (2025). Response coupling with an auxiliary neural signal for enhancing brain signal detection. *Scientific Reports, 15 (1).* https://doi.org/10.1038/s41598-025-87414-9
13. Salehzadeh, R., Mynderse, J. (2024). Board 143: Work in Progress: Mind and Computer: Integration of Brain-Computer Interfaces in Engineering Curricula. *2024 ASEE Annual Conference & Exposition Proceedings.* https://doi.org/10.18260/1-2--46702
14. Badcock, N. A., Mousikou, P., Mahajan, Y., de Lissa, P., Thie, J., McArthur, G. (2013). Validation of the Emotiv EPOC®EEG gaming system for measuring research quality auditory ERPs. *PeerJ, 1,* e38. https://doi.org/10.7717/peerj.38
15. Cuesta, D. L., Rivera, A. F. G., Borrero, J. S. M. (2020). Interfaz BCIE (Brain Computer Interface Educational) en Rasberry Pi utilizando sensor neurosky. *2020 15th Iberian Conference on Information Systems and Technologies (CISTI),* 1–6. https://doi.org/10.23919/cisti49556.2020.9141128
16. Akhtar, M. T., Mitsuhashi, W., James, C. J. (2012). Employing spatially constrained ICA and wavelet denoising, for automatic removal of artifacts from multichannel EEG data. *Signal Processing, 92 (2),* 401–416. https://doi.org/10.1016/j.sigpro.2011.08.005

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DEVELOPMENT OF A RULE-BASED LLM PROMPTING METHOD FOR HIGH-ACCURACY EVENT-SCHEMA EVOLUTION

pages 13–19

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The object of this research is the process of selecting an architectural strategy for event-schema evolution in event-sourcing systems. This process involves complex architectural trade-offs and is a critical task for maintaining the integrity and long-term viability of the immutable event log.

The addressed problem is the inconsistent performance and reliability ceiling of standard LLM prompting techniques like few-shot learning. These methods rely on heuristic pattern matching and thus lack the systematic framework required for high-stakes architectural decisions. This issue is compounded by the subjectivity inherent in the manual selection process by engineers.

The principal result is the development of a rule-based "atomic taxonomy" method. This approach enabled large-scale models (GPT-5, Gemini-2.5-pro) to achieve perfect predictive performance (1.0 Macro F1-score), while simultaneously degrading the performance of most medium-sized models when compared to the few-shot prompting baseline.

This divergence is explained by the cognitive demands of the task. The proposed method shifts the process from heuristic pattern matching to structured, compositional reasoning. The results indicate that large models possess the necessary architectural capabilities to execute this formal logic, whereas medium-sized models are overwhelmed by its cognitive overhead, making a simpler, example-based approach more effective for them.

In practice, the findings provide a clear, actionable guideline for architects. The atomic taxonomy serves as a robust framework to assist in manual decision-making. For automated support systems, its application is recommended exclusively with large-scale LLMs capable of advanced reasoning. The study concludes that for systems leveraging smaller, more efficient models, traditional few-shot prompting remains the more reliable and superior strategy.

Keywords: data evolution, decision support, event sourcing, large language models.

References

1. Alongi, F., Bersani, M. M., Ghielmetti, N., Mirandola, R., Tamburri, D. A. (2022). Event-sourced, observable software architectures: An experience report. *Software: Practice and Experience, 52 (10),* 2127–2151. https://doi.org/10.1002/spe.3116
2. Lima, S., Correia, J., Araujo, F., Cardoso, J. (2021). Improving observability in Event Sourcing systems. *Journal of Systems and Software, 181,* 111015. https://doi.org/10.1016/j.jss.2021.111015
3. Overeem, M., Spoor, M., Jansen, S. (2017). The dark side of event sourcing: Managing data conversion. *2017 IEEE 24th International Conference on Software Analysis, Evolution and Reengineering (SANER).* Klagenfurt: IEEE, 193–204. https://doi.org/10.1109/saner.2017.7884621
4. Lytvynov, O., Hruzin, D. (2025). Decision-making on Command Query Responsibility Segregation with Event Sourcing architectural variations. *Technology Audit and Production Reserves, 4 (2 (84)),* 37–59. https://doi.org/10.15587/2706-5448.2025.337168
5. Remadi, A., El Hage, K., Hobeika, Y., Bugiotti, F. (2024). To prompt or not to prompt: Navigating the use of Large Language Models for integrating and modeling heterogeneous data. *Data & Knowledge Engineering, 152,* 102313. https://doi.org/10.1016/j.datak.2024.102313
6. Zhou, X., Zhao, X., Li, G. (2024). *LLM-Enhanced Data Management.* arXiv. https://doi.org/10.48550/arxiv.2402.02643
7. Vyshnevskyy, O., Zhuravchak, L. (2025). Combined Large Language Models and Ontology Approach for Energy Consumption Analysis Software. *CEUR Workshop Proceedings, 4035,* 213–226. Available at: https://ceur-ws.org/Vol-4035/Paper18.pdf
8. Ojuri, S., Han, T. A., Chiong, R., Di Stefano, A. (2025). Optimizing text-to-SQL conversion techniques through the integration of intelligent agents and large language models. *Information Processing & Management, 62 (5),* 104136. https://doi.org/10.1016/j.ipm.2025.104136
9. Bajgoti, A., Gupta, R., Dwivedi, R. (2025). ASKSQL: Enabling cost-effective natural language to SQL conversion for enhanced analytics and search. *Machine Learning with Applications, 20,* 100641. https://doi.org/10.1016/j.mlwa.2025.100641
10. Overeem, M., Spoor, M., Jansen, S., Brinkkemper, S. (2021). An empirical characterization of event sourced systems and their schema evolution – Lessons from industry. *Journal of Systems and Software, 178,* 110970. https://doi.org/10.1016/j.jss.2021.110970
11. López Espejel, J., Ettifouri, E. H., Yahaya Alassan, M. S., Chouham, E. M., Dahhane, W. (2023). GPT-3.5, GPT-4, or BARD? Evaluating LLMs reasoning ability in zero-shot setting and performance boosting through prompts. *Natural Language Processing Journal, 5,* 100032. https://doi.org/10.1016/j.nlp.2023.100032
12. Loo, A., Pavlick, E., Feiman, R. (2026). LLMs model how humans induce logically structured rules. *Journal of Memory and Language, 146,* 104675. https://doi.org/10.1016/j.jml.2025.104675
13. Musker, S., Duchnowski, A., Millière, R., Pavlick, E. (2025). LLMs as models for analogical reasoning. *Journal of Memory and Language, 145,* 104676. https://doi.org/10.1016/j.jml.2025.104676
14. Wang, Y., Coiera, E., Gallego, B., Concha, O. P., Ong, M.-S., Tsafnat, G. et al. (2016). Measuring the effects of computer downtime on hospital pathology processes. *Journal of Biomedical Informatics, 59,* 308–315. https://doi.org/10.1016/j.jbi.2015.12.016
15. Klettke, M., Storl, U., Shenavai, M., Scherzinger, S. (2016). NoSQL schema evolution and big data migration at scale. *2016 IEEE International Conference on Big Data (Big Data).* Washington: IEEE, 2764–2774. https://doi.org/10.1109/bigdata.2016.7840924
16. Carvalho, I., Sá, F., Bernardino, J. (2023). Performance Evaluation of NoSQL Document Databases: Couchbase, CouchDB, and MongoDB. *Algorithms, 16 (2),* 78. https://doi.org/10.3390/a16020078
17. Jolak, R., Karlsson, S., Dobslaw, F. (2025). An empirical investigation of the impact of architectural smells on software maintainability. *Journal of Systems and Software, 225,* 112382. https://doi.org/10.1016/j.jss.2025.112382
18. Fedushko, S., Malyi, R., Syerov, Y., Serdyuk, P. (2024). NoSQL document data migration strategy in the context of schema evolution. *Data & Knowledge Engineering, 154,* 102369. https://doi.org/10.1016/j.datak.2024.102369
19. Chen, B., Zhang, Z., Langrené, N., Zhu, S. (2025). Unleashing the potential of prompt engineering for large language models. *Patterns, 6 (6),* 101260. https://doi.org/10.1016/j.patter.2025.101260
20. Malyi, R., Serdyuk, P. (2025). *Test Cases.* Zenodo. https://doi.org/10.5281/zenodo.17455591
21. Malyi, R., Serdyuk, P. (2025). *Few-shot and atomic prompts.* Zenodo. https://doi.org/10.5281/zenodo.17455986

SYSTEMS AND CONTROL PROCESSES

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DEVELOPMENT OF A NEURAL NETWORK FOR FORECASTING PASSENGER FLOWS IN SMART CITY PUBLIC ELECTRIC TRANSPORT

pages 20–25

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The research object is a hybrid deep learning model for passenger flow forecasting. These passenger flows constitute complex time series, influenced by a combination of temporal, spatial, and operational factors. The study addresses the fundamental mismatch between stochastic passenger demand and the static supply of transport services. This disparity results in operational inefficiency and a reduced quality of service for passengers. A lack of accurate forecasting tools hinders the optimal daily allocation of rolling stock, thereby limiting the efficiency of transport operators.

A hybrid deep learning model was developed and validated to predict daily passenger flows with high accuracy ($R^2 = 0.91$). The findings significantly outperform the baseline models and approaches described in scientific sources. This performance is attributed to a sophisticated strategy combining advanced feature engineering. This included the use of cyclic, lagged, and moving average features. This approach was paired with residual modelling, enabling the neural network to capture complex non-linear deviations. Furthermore, robust data preparation methods enhanced the model's high generalization capabilities.

The findings demonstrate that the proposed hybrid approach is an effective tool for operational planning. The results of the neural network work facilitate the optimization of the distribution of rolling stock allocation and improve resource utilization. Consequently, it enhances passenger comfort, contributing to the sustainable development of urban mobility. For practical applications, the model requires reliable historical passenger flow data. It enables operators to mitigate economic losses from underutilized vehicles and prevent overcrowding on high-demand days.

Keywords: passenger flow, neural network, LSTM, public transport, smart city, residuals modelling.

References

1. Himanen, V., Nijkamp, P., Padjen, J. (1992). Environmental quality and transport policy in Europe. *Transportation Research Part A: Policy and Practice, 26 (2),* 147–157. https://doi.org/10.1016/0965-8564(92)90009-v
2. Matseliukh, Y., Bublyk, M., Bosak, A., Naychuk-Khrushch, M. (2024). The role of public transport network optimization in reducing carbon emissions. *CEUR Workshop Proceedings, 3723,* 340–364. Available at: https://ceur-ws.org/Vol-3723/paper19.pdf
3. Liyanage, S., Abduljabbar, R., Dia, H., Tsai, P.-W. (2022). AI-based neural network models for bus passenger demand forecasting using smart card data. *Journal of Urban Management, 11 (3),* 365–380. https://doi.org/10.1016/j.jum.2022.05.002
4. Matseliukh, Y., Lytvyn, V., Bublyk, M. (2025). K-means clustering method in organizing passenger transportation in a smart city. *CEUR Workshop Proceedings, 3983,* 219–240. https://doi.org/10.31110/colins/2025-2/017
5. Fornalchyk, Y., Koda, E., Kernytskyy, I., Hrytsun, O., Royko, Y., Bura, R. et al. (2023). Wpływ natężenia ruchu pojazdów na zachowanie przechodniów na przejściach bez sygnalizacji. *Roads and Bridges – Drogi i Mosty, 22 (2),* 201–219. https://doi.org/10.7409/rabdim.023.010
6. Ouyang, Q., Lv, Y., Ma, J., Li, J. (2020). An LSTM-Based Method Considering History and Real-Time Data for Passenger Flow Prediction. *Applied Sciences, 10 (11),* 3788. https://doi.org/10.3390/app10113788
7. Katrenko, A., Krislata, I., Veres, O., Oborska, O., Basyuk, T., Vasyliuk, A. et al. (2020). Development of traffic flows and smart parking system for smart city. *CEUR Workshop Proceedings, 2604*, 730–745. Available at: http://ceur-ws.org/Vol-2604/paper50.pdf
8. Postranskyy, T., Afonin, M., Boikiv, M., Bura, R. (2024). Identifying patterns of change in traffic flows' parameters depending on the organization of public transport movement. *Eastern-European Journal of Enterprise Technologies, 5 (3 (131)),* 72–81. https://doi.org/10.15587/1729-4061.2024.313636
9. Fornalchyk, Y., Kernytskyy, I., Hrytsun, O., Royko, Y. (2021). Choice of the rational regimes of traffic light control for traffic and pedestrian flows. *Scientific Review Engineering and Environmental Studies (SREES), 30 (1),* 38–50. https://doi.org/10.22630/pniks.2021.30.1.4
10. Fu, R., Zhang, Z., Li, L. (2016). Using LSTM and GRU neural network methods for traffic flow prediction. *2016 31st Youth Academic Annual Conference of Chinese Association of Automation (YAC),* 324–328. https://doi.org/10.1109/yac.2016.7804912
11. Makridakis, S., Spiliotis, E., Assimakopoulos, V. (2020). The M4 Competition: 100,000 time series and 61 forecasting methods. *International Journal of Forecasting, 36 (1),* 54–74. https://doi.org/10.1016/j.ijforecast.2019.04.014
12. Matseliukh, Y., Bublyk, M., Vysotska, V. (2021). Development of intelligent system for visual passenger flows simulation of public transport in smart city based on neural network. *CEUR Workshop Proceedings, 2870,* 1087–1138. Available at: http://ceur-ws.org/Vol-2870/paper82.pdf
13. Podlesna, L., Bublyk, M., Grybyk, I., Matseliukh, Y., Burov, Y., Kravets, P. et al. (2020). Optimization model of the buses number on the route based on queuing theory in a Smart City. *CEUR Workshop Proceedings, 2631,* 502–515. Available at: http://ceur-ws.org/Vol-2631/paper37.pdf
14. Xiong, Z., Zheng, J., Song, D., Zhong, S., Huang, Q. (2019). Passenger Flow Prediction of Urban Rail Transit Based on Deep Learning Methods. *Smart Cities, 2 (3),* 371–387. https://doi.org/10.3390/smartcities2030023
15. Goodfellow, I., Bengio, Y., Courville, A. (Eds.) (2016). *Deep Learning.* MIT Press, 800. Available at: https://mitpress.ublish.com/ebook/deep-learning-preview/107/26
16. Pei, Y., Ran, S., Wang, W., Dong, C. (2023). Bus-Passenger-Flow Prediction Model Based on WPD, Attention Mechanism, and Bi-LSTM. *Sustainability, 15 (20),* 14889. https://doi.org/10.3390/su152014889
17. Fornalchyk, Y., Vikovych, I., Royko, Y., Hrytsun, O. (2021). Improvement of methods for assessing the effectiveness of dedicated lanes for public transport. *Eastern-European Journal of Enterprise Technologies, 1 (3 (109)),* 29–37. https://doi.org/10.15587/1729-4061.2021.225397
18. Zhang, J., Chen, F., Cui, Z., Guo, Y., Zhu, Y. (2021). Deep Learning Architecture for Short-Term Passenger Flow Forecasting in Urban Rail Transit. *IEEE Transactions on Intelligent Transportation Systems, 22 (11),* 7004–7014. https://doi.org/10.1109/tits.2020.3000761
19. Cui, H., Si, B., Wang, J., Zhao, B., Pan, W. (2024). Short-term origin–destination flow prediction for urban rail network: a deep learning method based on multi-source big data. *Complex & Intelligent Systems, 10 (4),* 4675–4696. https://doi.org/10.1007/s40747-024-01391-6
20. Boikiv, M., Postransky y, T., Afonin, M. (2022). Establishing patterns of change in the efficiency of regulated intersection operation considering the permitted movement directions. *Eastern-European Journal of Enterprise Technologies, 4 (3 (118)),* 17–26. https://doi.org/10.15587/1729-4061.2022.262250
21. An, J., Zhao, J., Liu, Q., Qian, X., Chen, J. (2023). Self-Constructed Deep Fuzzy Neural Network for Traffic Flow Prediction. *Electronics, 12 (8),* 1885. https://doi.org/10.3390/electronics12081885
22. Liu, S., Du, L., Cao, T., Zhang, T. (2024). Research on a Passenger Flow Prediction Model Based on BWO-TCLS-Self-Attention. *Electronics, 13 (23),* 4849. https://doi.org/10.3390/electronics13234849
23. Wu, Z., Pan, S., Chen, F., Long, G., Zhang, C., Yu, P. S. (2021). A Comprehensive Survey on Graph Neural Networks. *IEEE Transactions on Neural Networks and Learning Systems, 32 (1),* 4–24. https://doi.org/10.1109/tnnls.2020.2978386
24. Baghbani, A., Rahmani, S., Bouguila, N., Patterson, Z. (2023). Predicting Passenger Flow Using Graph Neural Networks with Scheduled Sampling on Bus Networks. *2023 IEEE 26th International Conference on Intelligent Transportation Systems (ITSC),* 3073–3078. https://doi.org/10.1109/itsc57777.2023.10422701
25. Chang, Y., Zong, M., Dang, Y., Wang, K. (2024). Multi-Step Passenger Flow Prediction for Urban Metro System Based on Spatial-Temporal Graph Neural Network. *Applied Sciences, 14 (18),* 8121. https://doi.org/10.3390/app14188121
26. Shi, B., Wang, Z., Yan, J., Yang, Q., Yang, N. (2024). A Novel Spatial–Temporal Deep Learning Method for Metro Flow Prediction Considering External Factors and Periodicity. *Applied Sciences, 14 (5),* 1949. https://doi.org/10.3390/app14051949
27. Chukhray, N., Shakhovska, N., Mrykhina, O., Bublyk, M., Lisovska, L. (2019). Consumer aspects in assessing the suitability of technologies for the transfer. *2019 IEEE 14th International Conference on Computer Sciences and Information Technologies (CSIT),* 142–147. https://doi.org/10.1109/stc-csit.2019.8929879
28. Bublyk, M., Matseliukh, Y. (2021). Small-batteries utilization analysis based on mathematical statistics methods in challenges of circular economy. *CEUR Workshop Proceedings, 2870,* 1594–1603. Available at: https://ceur-ws.org/Vol-2870/paper118.pdf

29. Bublyk, M., Lytvyn, V., Vysotska, V., Chyrun, L., Matseliukh, Y., Sokulska, N. (2020). The decision tree usage for the results analysis of the psychophysiological testing. *CEUR Workshop Proceedings, 2753,* 458–472. Available at: https://ceur-ws.org/Vol-2753/paper31.pdf

30. Matseliukh, Y., Vysotska, V., Bublyk, M., Kopach, T., Korolenko, O. (2021). Network modelling of resource consumption intensities in human capital management in digital business enterprises by the critical path method. *CEUR Workshop Proceedings, 2851,* 366–380. Available at: https://ceur-ws.org/Vol-2851/paper34.pdf

31. Vysotska, V., Bublyk, M., Vysotsky, A., Berko, A., Chyrun, L., Doroshkevych, K. (2020). Methods and Tools for Web Resources Processing in E-Commercial Content Systems. *2020 IEEE 15th International Conference on Computer Sciences and Information Technologies (CSIT),* 114–118. https://doi.org/10.1109/csit49958.2020.9321950

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ASSESSING THE RISKS OF APPLYING ARTIFICIAL INTELLIGENCE TO OCCUPATIONAL SAFETY

pages 26–32

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This paper explores the opportunities, advantages, and risks of integrating artificial intelligence (AI) into occupational health and safety management systems. It is noted that the use of intelligent technologies contributes to improved workplace safety by enabling automatic monitoring of working conditions, detection and prediction of hazardous situations, and real-time analysis of workers' behavior. The potential of AI is demonstrated in identifying safety violations, monitoring the use of personal protective equipment, responding to dangerous events, and organizing preventive actions. Special attention is given to technical, legal, ethical, and organizational risks associated with AI implementation in industrial settings. The study analyzes risks related to AI-based systems in occupational safety using the example of a food processing plant with an automated packaging line. An incident involving worker injury due to the AI system's failure to detect human presence in the manipulator zone is examined. The application of the FMEA (failure modes and effects analysis) method identified key risk sources: failure to detect a person in the hazardous zone ($RPN = 270$), lack of integration between AI and emergency stop systems ($RPN = 192$), and loss of communication between modules ($RPN = 140$). All risks exceeded the $RPN > 100$ threshold, indicating high priority. The relevance of a multisensor approach, implementation of fail-safe protocols, and redesigning human – machine interaction architecture is substantiated. A comparison is made between the FMEA method and the PTSR (Probability – Time – Severity Risk), which incorporates the time factor of hazard exposure, increasing risk assessment accuracy in dynamic environments. A combined risk management approach is proposed, integrating preventive analysis (FMEA) and real-time operational evaluation (PTSR), which enhances safety control effectiveness when using adaptive AI systems.

Keywords: artificial intelligence, occupational safety, risk management, ethics, legal responsibility, automation.

References

1. Falsk, R. (2023). *AI for Predictive Maintenance in Industrial Systems.* Handbuch Ansehen. https://doi.org/10.13140/RG.2.2.27313.35688
2. Xu, S., Wang, J., Shou, W., Ngo, T., Sadick, A.-M., Wang, X. (2020). Computer Vision Techniques in Construction: A Critical Review. *Archives of Computational Methods in Engineering, 28 (5),* 3383–3397. https://doi.org/10.1007/s11831-020-09504-3
3. Chen, K., Wang, C., Chen, L., Niu, X., Zhang, Y., Wan, J. (2020). Smart safety early warning system of coal mine production based on WSNs. *Safety Science, 124,* 104609. https://doi.org/10.1016/j.ssci.2020.104609
4. Cebulla, A., Szpak, Z., Howell, C., Knight, G., Hussain, S. (2022). Applying ethics to AI in the workplace: the design of a scorecard for Australian workplace health and safety. *AI & SOCIETY, 38 (2),* 919–935. https://doi.org/10.1007/s00146-022-01460-9
5. Fernández Peñalver, M. (2024). The Foundations of AI Safety: Ensuring Technical Robustness. *Nemko.* Available at: https://www.nemko.com/blog/ai-safety-and-robustness
6. Alateeq, M. M., Rajeena, F. P. P., Ali, M. A. S. (2023). Construction Site Hazards Identification Using Deep Learning and Computer Vision. *Sustainability, 15 (3),* 2358. https://doi.org/10.3390/su15032358
7. Nagda, P. (2025). Legal Liability and Accountability in AI Decision-Making: Challenges and Solutions. *International Journal of Innovative Research in Technology, 11 (11).* Available at: https://ijirt.org/publishedpaper/IJIRT174899_PAPER.pdf
8. Čartolovni, A., Tomičić, A., Lazić Mosler, E. (2022). Ethical, legal, and social considerations of AI-based medical decision-support tools: A scoping review. *International Journal of Medical Informatics, 161,* 104738. https://doi.org/10.1016/j.ijmedinf.2022.104738
9. Fernández, J. (2024). *Integrating AI into Functional Safety Management. Safe and Explainable.* Critical Embedded Systems based on AI. Available at: https://safexplain.eu/integrating-ai-into-functional-safety-management/
10. Berezutskyi, P. S., Horbenko, S. V. (2017). Otsenka rycka ot KhPY. *Okhrana truda, 11,* 14–16. Available at: https://www.researchgate.net/publication/394486032_Formiruem_risk-orientirovannoe_myslenie
11. Mahdavinejad, M. S., Rezvan, M., Barekatain, M., Adibi, P., Barnaghi, P., Sheth, A. P. (2018). Machine learning for internet of things data analysis: a survey. *Digital Communications and Networks, 4 (3),* 161–175. https://doi.org/10.1016/j.dcan.2017.10.002
12. AI in worker management: involving people to prevent risks (2025). *ENSHPO.* Available at: https://www.enshpo.eu/ai-in-worker-management-involving-people-to-prevent-risks/
13. Lialiuk, O., Osypenko, R. (2023). Features of the implementation of artificial intelligence in construction. *Modern Technology, Materials and Design in Construction, 35 (2),* 172–176. https://doi.org/10.31649/2311-1429-2023-2-172-176
14. Implementing safer AI worker management through policy and prevention (2024). *European Agency for Safety and Health at Work (EU-OSHA).* Available at: https://osha.europa.eu/en/oshnews/implementing-safer-ai-worker-management-through-policy-and-prevention
15. Chauhan, S., Vashishtha, G., Zimroz, R. (2024). Analysing Recent Breakthroughs in Fault Diagnosis through Sensor: A Comprehensive Overview. *Computer Modeling in Engineering & Sciences, 141 (3),* 1983–2020. https://doi.org/10.32604/cmes.2024.055633
16. ISO 21448:2022. Road vehicles – Safety of the intended functionality (2022). *ISO.* Available at: https://www.iso.org/standard/77490.html
17. Ryan, P., Porter, Z., Al-Qaddoumi, J., McDermid, J., Habli, I. (2023). *What's my role? Modelling responsibility for AI-based safety-critical systems.* arXiv:2401.09459. https://doi.org/10.48550/arXiv.2401.09459
18. AI Risk Management Framework (AI RMF 1.0) (2023). *NIST.* Available at: https://www.nist.gov/itl/ai-risk-management-framework
19. Gunning, D. (2017). XAI: Explainable Artificial Intelligence. *DARPA.* Available at: https://www.darpa.mil/program/explainable-artificial-intelligence
20. Epelboim, M. (2025). *Cursor Rules: Why Your AI Agent Is Ignoring You (and How to Fix It).* Available at: https://sdrmike.medium.com/cursor-rules-why-your-ai-agent-is-ignoring-you-and-how-to-fix-it-5b4d2ac0b1b0
21. ISO/IEC TR 24028:2020. Information technology – Artificial intelligence Overview of trustworthiness in artificial intelligence (2020). *ISO.* Available at: https://www.iso.org/standard/77608.html
22. *Recommendation of the Council on Artificial Intelligence* (2019). Paris: OECD Publishing. Available at: https://legalinstruments.oecd.org/en/instruments/OECD-LEGAL-0449
23. Kusche, I. (2024). Possible harms of artificial intelligence and the EU AI act: fundamental rights and risk. *Journal of Risk Research,* 1–14. https://doi.org/10.1080/13669877.2024.2350720
24. An Occupational Safety and Health Perspective on Human in Control and AI (2022). *BauA.* Available at: https://www.baua.de/EN/Service/Publications/Essays/article3454

25. Huibregtse, A. (2025). AI provides innovative ways to improve compliance with labour laws. *ILO.* Available at: https://www.ilo.org/resource/article/ai-provides-innovative-ways-improve-compliance-labour-laws

26. Volkswagen robot kills worker in Germany (2015). *The Guardian.* Available at: https://www.theguardian.com/world/2015/jul/02/robot-kills-worker-at-volkswagen-plant-in-germany

27. Yang, X., Li, Y., Chen, Y., Li, Y., Dai, L., Feng, R., Duh, Y.-S. (2020). Case study on the catastrophic explosion of a chemical plant for production of m-phenylenediamine. *Journal of Loss Prevention in the Process Industries, 67,* 104232. https://doi.org/10.1016/j.jlp.2020.104232

28. Tim, B., Zoë, D., Gerald, P. (2019). Mineworker fatigue: A review of what we know and future decisions. *Minerals Engineering, 70 (3),* 33. Available at: https://pmc.ncbi.nlm.nih.gov/articles/PMC5983045/

29. Reports of Fatalities and Catastrophes – Archive. *OSHA.* Available at: https://www.osha.gov/fatalities/reports/archive

30. Travmatyzm. Statystyka. Prychyny. *Derzhavna sluzhba Ukrainy z pytan pratsi.* Available at: https://dsp.gov.ua/category/diyalnist/travmatyzm-statystyka-prychyny/

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DEVELOPMENT OF AN APPROACH FOR PREDICTING THE COST OF DAMAGED INFRASTRUCTURE RECOVERY WITH MICROSERVICE IMPLEMENTATION

pages 33–39

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The object of the research is the process of preliminary cost assessment for restoring infrastructure objects damaged as a result of the war in Ukraine. The subject of the research is an information-analytical system that enables partial automation of this process.

Problem addressed is the lack of tools for forecasting reconstruction costs, since existing solutions are limited to recording destruction, visualization, and reporting.

In the course of the study, an approach was developed for predicting the cost of restoring damaged infrastructure objects based on machine learning models (Linear Regression, Random Forest, XGBoost). The proposed approach enables the automatic estimation of the expected restoration cost based on object characteristics. These estimates can serve as a basis for further analyses, including the detection of abnormal expenses and potential misuse. Experimental calculations on open data demonstrated that the use of modern ML models for processing structured data on objects makes it possible to estimate the restoration cost with an error margin of 15–20%. For practical use, the approach has been implemented as a standalone Python microservice, which ensures flexibility and scalability, and has been integrated into the existing information-analytical system (Laravel, Vue.js).

The developed solution can be used by national and municipal authorities to monitor infrastructure recovery. However, it is important to note that the models were pre-trained on open datasets of damaged objects valued from 20 million to over 90 million UAH, which include information such as object type, area, region, and other attributes. Therefore, successful application requires similarly structured and reliable data. Under these conditions, the microservice can enhance transparency in planning and improve the efficiency of reconstruction management.

Keywords: information-analytical system, Web, ML, cost prediction, Linear Regression, Random Forest, XGBoost.

References

1. Novozhylova, M. V., Chub, O. I. (2024). Matematychne zabezpechennia proiektiv vidnovlennia istorychnykh pamiatok. *Informatsiini systemy v upravlinni proiektamy ta prohramamy.* Koblevo, Kharkiv: KhNURE, 171–175. Available at: https://mmp-conf.org/documents/archive/proceedings2024.pdf Last accessed: 05.01.2025

2. Puri, A., Elkharboutly, M., Ali, N. A. (2024). Identifying major challenges in managing post-disaster reconstruction projects: A critical analysis. *International Journal of Disaster Risk Reduction, 107,* 104491. https://doi.org/10.1016/j.ijdrr.2024.104491

3. Singh, R. (2024). The role of geographic information systems (GIS) in disaster management and planning. *International Journal of Geography, Geology and Environment, 6 (2),* 195–205. https://doi.org/10.22271/27067483.2024.v6.i2c.305

4. *Russia Will Pay. The project of collecting, evaluating, analyzing, and documenting information on direct losses to civilian infrastructure in connection with Russian aggression.* KSE. Available at: https://kse.ua/russia-will-pay/ Last accessed: 05.01.2025

5. Lozano, J.-M., Tien, I. (2023). Data collection tools for post-disaster damage assessment of building and lifeline infrastructure systems. *International Journal of Disaster Risk Reduction, 94,* 103819. https://doi.org/10.1016/j.ijdrr.2023.103819

6. *Zelene vidnovlennia Ukrainy: kerivni pryntsypy ta instrumenty dlia tykh, khto ukhvaliuie rishennia* (2023). UNDP, KSE. Kyiv: PROON, 64. Available at: https://www.undp.org/uk/ukraine/publications/zelene-vidnovlennya-ukrayiny-kerivni-pryntsypy-ta-instrumenty-dlya-tykh-khto-ukhvalyuye-rishennya Last accessed: 05.01.2025

7. *Ukraine Humanitarian Needs and Response Plan 2025: Annex 4.3 – Analysis Methodology, Data Sources & Findings* (2025). Geneva: UN OCHA, 58. Available at: https://humanitarianaction.info/plan/1271/document/ukraine-humanitarian-needs-and-response-plan-2025/article/43-analysis-methodology Last accessed: 05.01.2025

8. *Centre for Economic Strategy. Biudzhet-2025: analitychnyi ohliad* (2024). Kyiv: TsES, 34. Available at: https://ces.org.ua/reports/budget-2025/ Last accessed: 05.01.2025

9. Bosenko, I. (2025). Models and methods of artificial intelligence in the process of performing building-technical expertise. *Management of Development of Complex Systems, 61,* 180–186. https://doi.org/10.32347/2412-9933.2025.61.180-186

10. *Prohrama kompleksnoho vidnovlennia terytorii Mykhailo-Kotsiubynskoi terytorialnoi hromady. Chernihivskoi oblasti* (2024). Mykhailo-Kotsiubynske, 133. Available at: https://mkocubynska-gromada.gov.ua/news/1740637546/ Last accessed: 05.01.2025

11. Bakurova, A., Bilyi, V., Didenko, A., Tereschenko, E. (2023). Analytics Module for the System for Recording Destruction Due to Russian Aggression. *17th International Conference Monitoring of Geological Processes and Ecological Condition of the Environment.* Kyiv, 1–5. https://doi.org/10.3997/2214-4609.2023520232

12. Prysiazhniuk, A. (2019). *Yak pratsiuie machine learning ta yoho zastosuvannia na praktytsi.* Na chasi. Available at: https://nachasi.com/tech/2019/01/31/yak-pratsyuye-machine-learning/ Last accessed: 05.01.2025

13. Pizhuk, O. I. (2019). Artificial intelligence as one of the key drivers of the economy digital transformation. *Economics, Management and Administration, 3 (89),* 41–46. https://doi.org/10.26642/ema-2019-3(89)-41-46

14. Pedregosa, F., Varoquaux, G., Gramfort, A., Michel, V., Thirion, B., Grisel, O. (2012). Scikit-learn: Machine Learning in Python. *Journal of Machine Learning Research, 12 (85),* 2825–2830. https://doi.org/10.48550/arXiv.1201.0490

15. Anisimov, V., Kunanets, N. (2024). Transition from Monolithic to Microservice Architecture: Methodology and Implementation Experience. *Computer-Integrated Technologies: Education, Science, Production, 55,* 30–41. https://doi.org/10.36910/6775-2524-0560-2024-55-03

16. Di Francesco, P., Lago, P., Malavolta, I. (2019). Architecting with microservices: A systematic mapping study. *Journal of Systems and Software, 150,* 77–97. https://doi.org/10.1016/j.jss.2019.01.001

17. Gooljar, S., Manohar, K., Hosein, P. (2023). Performance Evaluation and Comparison of a New Regression Algorithm. *Proceedings of the 12th International Conference on Data Science, Technology and Applications.* https://doi.org/10.5220/0012135400003541

18. Sharma, H., Harsora, H., Ogunleye, B. (2024). An Optimal House Price Prediction Algorithm: XGBoost. *Analytics, 3 (1),* 30–45. https://doi.org/10.3390/analytics3010003
19. Hyndman, R. J., Koehler, A. B. (2006). Another look at measures of forecast accuracy. *International Journal of Forecasting, 22 (4),* 679–688. https://doi.org/10.1016/j.ijforecast.2006.03.001
20. *Restoration data.* Available at: https://drive.google.com/file/d/1oIVs52C9artD6jBgDzJd5mNUwDJSi8YW/view Last accessed: 05.06.2025

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IMPROVING SAFETY AND EFFICIENCY FOR FIXED-WING UAVS BY UTILIZING AN UNMANNED GROUND PLATFORM

pages 40–46

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The object of this research was the launch process of fixed-wing unmanned aerial vehicles. Military unmanned aerial vehicle systems are rapidly improving and becoming increasingly effective on the battlefield and in the enemy's rear. However, the complex and dynamic environment of modern warfare significantly impacts the preparation and launch of UAVs. Therefore, ensuring the maximum safety of these operations is one of the key factors influencing the overall effectiveness of these systems. At the same time, the launch operation requires personnel to be in an open area, making it a critical task to find solutions to protect UAV crews from enemy attacks. A possible solution is the remote control of the UAV launch. This article proposes using unmanned ground platforms for the remote launch of fixed-wing UAVs to reduce the probability of enemy strikes against crews and equipment. The research included modeling and comparing the launch of a fixed-wing UAV from a runway and with the help of an unmanned ground platform. The modeling results showed that launching from the platform reduces the takeoff distance by 39.1% (from 273.6 m to 166.7 m) and the operation time by more than half (from ~ 23 s to 9.2 s). This overall reduction will decrease the probability of the unmanned equipment being struck by the enemy. An additional advantage of this method is reduced fuel consumption. It also allows for the use of a propeller that is more efficient for flight, which is not possible with a traditional runway takeoff. Reducing the strength requirements for the drone's airframe allows for a decrease in its mass, which, in turn, increases the mass of the warhead or reconnaissance equipment.

Keywords: unmanned ground platform, UAV, military personnel safety, remote launch, modeling.

References

1. Onyshchenko, S., Skryl, V., Hlushko, A., Maslii, O. (2023). Inclusive Development Index. *Proceedings of the 4th International Conference on Building Innovations.* Cham: Springer, 779–790. https://doi.org/10.1007/978-3-031-17385-1_66
2. Laktionov, O., Yanko, A., Pedchenko, N. (2024). Identification of air targets using a hybrid clustering algorithm. *Eastern-European Journal of Enterprise Technologies, 5 (4 (131)),* 89–95. https://doi.org/10.15587/1729-4061.2024.314289
3. Yanko, A., Pedchenko, N., Kruk, O. (2024). Enhancing the protection of automated ground robotic platforms in the conditions of radio electronic warfare. *Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu, 6,* 136–142. https://doi.org/10.33271/nvngu/2024-6/136
4. Laktionov, O., Yanko, A., Hlushko, A. (2024). Development of a hardware-software solution for detection of complex-shaped objects in video stream. *Technology Audit and Production Reserves, 6 (2 (80)),* 35–40. https://doi.org/10.15587/2706-5448.2024.319799
5. Barabash, O., Kyrianov, A. (2023). Development of control laws of unmanned aerial vehicles for performing group flight at the straight-line horizontal flight stage. *Advanced Information Systems, 7 (4),* 13–20. https://doi.org/10.20998/2522-9052.2023.4.02
6. Xiaoning, Z. (2020). Analysis of military application of UAV swarm technology. *2020 3rd International Conference on Unmanned Systems (ICUS),* 1200–1204. https://doi.org/10.1109/icus50048.2020.9274974
7. Jackman, A. (2019). Consumer drone evolutions: trends, spaces, temporalities, threats. *Defense & Security Analysis, 35 (4),* 362–383. https://doi.org/10.1080/14751798.2019.1675934
8. Edward, M. (2009). Exploring Transportation Applications of Small Unmanned Aircraft. *Ite Journal, 79,* 32–36. Available at: https://www.researchgate.net/publication/298279257_Exploring_Transportation_Applications_of_Small_Unmanned_Aircraft
9. Yue, S. (2013). Small Unmanned Aircraft: Theory and Practice R. W. Beard and T. W. McLain Princeton University Press. 6 Oxford Street, Woodstock, OX20 1TW, UK. 2012. 300pp. Illustrated. £69.95. ISBN 978-0-691-14921-9. *The Aeronautical Journal, 117 (1194),* 861–861. https://doi.org/10.1017/s0001924000008496
10. Cabarbaye, A., Leal, R. L., Fabiani, P., Estrada, M. B. (2016). VTOL aircraft concept, suitable for unmanned applications, with equivalent performance compared to conventional aeroplane. *2016 International Conference on Unmanned Aircraft Systems (ICUAS),* 219–226. https://doi.org/10.1109/icuas.2016.7502649
11. Liu, D., Liu, G., Hong, G. (2016). Analysis of Onboard Takeoff and Landing Characteristics for Unmanned Aerial Vehicles. *AIAA Modeling and Simulation Technologies Conference.* https://doi.org/10.2514/6.2016-3376
12. Novaković, Z., Medar, N. (2013). Analysis of a UAV Bungee Cord Launching Device. *Scientific Technical Review, 63 (3),* 41–47. Available at: http://www.vti.mod.gov.rs/ntp/rad2013/3-13/6/6.pdf
13. Lütjens, K., Lau, A., Pfeiffer, T., Loth, S., Gollnick, V., Klimek, H. et al. (2012). Airport2030-Lösungen für den effizienten Lufttransport der Zukunft. *Deutscher Luft- und Raumfahrtkongress,* 1–10. Available at: https://www.dglr.de/publikationen/2012/281494.pdf
14. Austin, R. (2010). *Unmanned aircraft systems: UAVS design, development and deployment.* John Wiley & Sons Ltd. https://doi.org/10.1002/9780470664797
15. Zhen, Z., Jiang, J., Wang, X., Li, K. (2017). Modeling, control design, and influence analysis of catapult-assisted take-off process for carrier-based aircrafts. *Proceedings of the Institution of Mechanical Engineers, Part G: Journal of Aerospace Engineering, 232 (13),* 2527–2540. https://doi.org/10.1177/0954410017715278
16. Wang, Z., Gong, Z., Zhang, C., He, J., Mao, S. (2021). Flight Test of L1 Adaptive Control on 120-kg-Class Electric Vertical Take-Off and Landing Vehicles. *IEEE Access, 9,* 163906–163928. https://doi.org/10.1109/access.2021.3132963
17. Fahlstrom, P. G., Gleason, T. J. (2012). *Introduction to UAV Systems, Fourth Edition.* https://doi.org/10.1002/9781118396780
18. Novaković, Z., Medar, N. (2014). Design of UAV Elastic Cord Catapult. OTEH 2014. *6th International Scientific Conference on Defensive Technologies*, 141–150. Available at: https://www.scribd.com/document/326791980/Zbornik-radova-sa-OTEH-2014
19. Bertola, L., Cox, T., Wheeler, P., Garvey, S., Morvan, H. (2015). Electromagnetic launch systems for civil aircraft assisted take-off. *Archives of Electrical Engineering, 64 (4)*, 535–546. https://doi.org/10.1515/aee-2015-0039
20. Kloesel, K., Sayles, E., Wright, M., Marriott, D., Kuznetsov, S., Holland, L., Pickrel, J. (2009). First Stage of a Highly Reliable Reusable Launch System. *AIAA SPACE 2009 Conference & Exposition.* https://doi.org/10.2514/6.2009-6805

21. Yi, Z., Heping, W. (2006). A study of structure weight estimating for high altitude long endurence (hale) unmanned aerial vehicle (UAV). *ICAS-Secretariat-25th Congr. Int. Counc. Aeronaut. Sci.* Available at: https://www.icas.org/icas_archive/ICAS2006/PAPERS/019.PDF
22. Yanko, A., Krasnobayev, V., Martynenko, A. (2023). Influence of the number system in residual classes on the fault tolerance of the computer system. *Radioelectronic and Computer Systems, 3,* 159–172. https://doi.org/10.32620/reks.2023.3.13
23. Ruban, I., Volk, M., Filimonchuk, T., Ivanisenko, I., Risukhin, M., Romanenkov, Y. (2018). The Method for Ensuring the Survivability of Distributed Computing in Heterogeneous Computer Systems. *2018 International Scientific-Practical Conference Problems of Infocommunications. Science and Technology (PIC S&T),* 233–237. https://doi.org/10.1109/infocommst.2018.8632099
24. Ponochovniy, Y., Bulba, E., Yanko, A., Hozbenko, E. (2018). Influence of diagnostics errors on safety: Indicators and requirements. *2018 IEEE 9th International Conference on Dependable Systems, Services and Technologies (DESSERT),* 53–57. https://doi.org/10.1109/dessert.2018.8409098
25. Alsaidi, B., Joe, W. Y., Akbar, M. (2019). Computational Analysis of 3D Lattice Structures for Skin in Real-Scale Camber Morphing Aircraft. *Aerospace, 6 (7),* 79. https://doi.org/10.3390/aerospace6070079
26. Onyshchenko, S., Zhyvylo, Y., Hlushko, A., Bilko, S. (2024). Cyber risk management technology to strengthen the information security of the national economy. *Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu, 5,* 136–142. https://doi.org/10.33271/nvngu/2024-5/136
27. Semenov, S., Jian, Y., Jiang, H., Chernykh, O., Binkovska, A. (2025). Mathematical model of intelligent UAV flight path planning. *Advanced Information Systems, 9 (1),* 49–61. https://doi.org/10.20998/2522-9052.2025.1.06
28. Hrubel, M., Kraynyk, L., Mikhalieva, M., Zalypka, V., Manziak, M., Khoma, V. et al. (2024). Improving a methodology for estimating the cross-country ability of all-wheel-drive vehicles. *Eastern-European Journal of Enterprise Technologies, 2 (1 (128)),* 64–72. https://doi.org/10.15587/1729-4061.2024.302833

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DEVELOPMENT OF AN OPTIMAL OPTIONS-FORMING METHOD FOR INFORMATION SECURITY RISK TREATMENT BASED ON QUANTITATIVE ASSESSMENT MODELS

pages 47–55

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The object of the research is the processes of forming optimal options for information security risk treatment of the organization. One of the most problematic areas is the choice of means and measures of protection from the set of available options for information security risk treatment that will allow reducing information security risks in a way that is not detrimental to the organization. The available models and methods are cumbersome, which makes their practical use impossible, and also do not take into account the economic features of implementing means and measures of protection.

The research used methods of investment theory, which allowed it to assess the effectiveness of reducing information security risks due to the implementation of a set of means and/or measures of information protection, and the ABC analysis method, which allowed it to identify the most effective ones among them by dividing them into groups. This approach simplified the process of assessing information security risks and choosing the optimal set of means and measures of protection. The proposed method involves calculating the indicators of net present value and payback period of the project, which allows the owner of the organization to assess the economic efficiency of implementing a set of means and measures of protection, as well as to understand when the costs of the information protection system will pay off.

The obtained method, that significantly simplified the process of reducing information security risks at a break-even price. This is due to the fact that the proposed method has a number of features in the formation of options for information security risk treatment, particularly. It involves assessing the effectiveness of the implementation of each of the means and/or measures of protection and ranking them by effectiveness by dividing them into groups. This enables the creation of a risk-oriented information security system. Compared to similar known models and methods, this enables a simplified procedure for information security risk treatment in practice.

Keywords: risk analysis, risk treatment, risk management, information security, economic efficiency, ABC analysis.

References

1. Directive (EU) 2022/2555 of the European Parliament and of the Council of 14 December 2022 on measures for a high common level of cybersecurity across the Union, amending Regulation (EU) No 910/2014 and Directive (EU) 2018/1972, and repealing Directive (EU) 2016/1148 (NIS 2 Directive) (2022). *Official Journal of the European Union.* Available at: https://eur-lex.europa.eu/eli/dir/2022/2555/oj/eng
2. NIS2 Technical Implementation Guidance (2025). *ENISA.* Available at: https://www.enisa.europa.eu/publications/nis2-technical-implementation-guidance
3. ISO/IEC 27002:2022 Information security, cybersecurity and privacy protection – Information security controls (2022). *International Organization for Standardization.* Available at: https://www.iso.org/standard/75652.html
4. IEC 31010:2019 Risk management – Risk assessment techniques (2019). *International Organization for Standardization.* Available at: https://www.iso.org/standard/72140.html
5. Stefani, E., Costa, I., Gaspar, M. A., Goes, R. de S., Monteiro, R. C., Petrili, B. R. et al. (2025). Information Security Risk Framework for Digital Transformation Technologies. *Systems, 13 (1),* 37. https://doi.org/10.3390/systems13010037
6. Kononovych, V., Kopytin, Yu. (2010). Vykorystannia ABC analizu dlia optymizatsii system zakhystu informatsii. *Pravove, normatyvne ta metrolohichne zabezpechennia systemy zakhystu informatsii v Ukraini, 2 (21)*, 26–35. Available at: https://ela.kpi.ua/handle/123456789/9099
7. Brho, M., Jazairy, A., Glassburner, A. V. (2025). The finance of cybersecurity: Quantitative modeling of investment decisions and net present value. *International Journal of Production Economics,* 279. https://doi.org/10.1016/j.ijpe.2024.109448
8. Ofori-Yeboah, A., Addo-Quaye, R., Oseni, W., Amorin, P., Agangmikre, C. (2021). Cyber Supply Chain Security: A Cost Benefit Analysis Using Net Present Value. *2021 International Conference on Cyber Security and Internet of Things (ICSIoT).* France: IEEE, 49–54. https://doi.org/10.1109/icsiot55070.2021.00018
9. Kononovich, V., Kononovich, I., Kopytin, Yu., Staikutsa, S. (2014). Influence of delays decision action for information protection on information security risks. *Ukrainian Scientific Journal of Information Security, 20 (1)*, 83–91. Available at: http://nbuv.gov.ua/UJRN/bezin_2014_20_1_16
10. Kravchenko, V. (2022). Chysta potochna vartist (NPV). *LivingFo.* Available at: https://livingfo.com/chysta-potochna-vartist-npv/
11. Roziasnennia shchodo rozrakhunkiv prohnozovanykh pokaznykiv efektyvnosti investytsiinykh prohram subiektiv hospodariuvannia u sferi teplopostachannia, tsentralizovanoho vodopostachannia ta vodovidvedennia (2013). *Roziasnennia n0079866-13. Natsionalna komisiia, shcho zdiisniuie derzhavne rehuliuvannia u sferi komunalnykh posluh.* Available at: https://zakon.rada.gov.ua/rada/show/n0079866-13#Text
12. Kopytin, Yu. (2014). Developing a model of information security risk assessment based on colored Petri net. *Ukrainian Scientific Journal of Information Security, 20 (3)*, 293–299. https://doi.org/10.18372/2225-5036.20.7558

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IMPROVEMENT IN THE METHOD OF CASE-BASED MANAGEMENT OF END-TO-END BUSINESS PROCESSES

pages 56–64

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The object of research is the processes of case-based management a set of interconnected end-to-end business processes of the enterprise. The study is devoted to solving the problem of case-based management of interconnected end-to-end business processes of the enterprise that use shared resources. Research in this area is aimed at developing models, methods and technologies used in the management of business processes of the enterprise.

The goal and main limitations of functional and process management in the form of a set of business processes that integrate the activities of the relevant divisions of the enterprise are determined and formally described. The main disadvantage of such management is associated with the mismatch between the existing organizational structure of the enterprise and end-to-end business processes that cover several of its divisions. Therefore, a transition from process to end-to-end business process management that use shared resources is proposed. This approach involves searching for and adapting of case-based, applying it and further preserving it. In conditions of restrictions on the execution of business processes, the use of a case-based reasoning allows increasing the efficiency of process management. An improvement of the method of case-based management of a group of end-to-end business processes is proposed. Unlike the existing one, it allows to determine the priorities of their access to resources, taking into account the restrictions on the time of their execution. This ensures the execution of processes within the established deadlines, which improves the economic performance of the enterprise.

Practical application of the proposed improved method of case-based management of a group of end-to-end business processes allows to adjust the sequences of orders launch orders. This is done taking into account the restrictions on the execution time of each of the business processes, which allows to improve the process of order management at the enterprise.

Keywords: process approach, data analysis, case-based reasoning, priorities, management method, resources.

References

1. Gontareva, I., Marcel Kurt, M., Dorokhov, O., Rusin-Grinik, R., Galayko, N. (2022). A Systematic-Functional Approach in Managing Innovative Development of Construction Enterprises in Ukraine. *TEM Journal,* 125–137. https://doi.org/10.18421/tem111-15
2. Kountur, R., Sari, M. R. (2023). Risk identification approaches and the number of risks identified: the use of work breakdown structure and business process. *Humanities and Social Sciences Communications, 10 (1).* https://doi.org/10.1057/s41599-023-02028-8
3. Chalyi, S., Levykin, I., Biziuk, A., Vovk, A., Bogatov, I. (2020). Development of the technology for changing the sequence of access to shared resources of business processes for process management support. *Eastern-European Journal of Enterprise Technologies, 2 (3 (104)),* 22–29. https://doi.org/10.15587/1729-4061.2020.198527
4. Beerepoot, I., Di Ciccio, C., Reijers, H. A., Rinderle-Ma, S., Bandara, W., Burattin, A. et al. (2023). The biggest business process management problems to solve before we die. *Computers in Industry, 146*, 103837. https://doi.org/10.1016/j.compind.2022.103837
5. Dumas, M., Fournier, F., Limonad, L., Marrella, A., Montali, M., Rehse, J.-R. et al. (2023). AI-augmented Business Process Management Systems: A Research Manifesto. *ACM Transactions on Management Information Systems, 14 (1)*, 1–19. https://doi.org/10.1145/3576047
6. Chalyi, S., Levykin, I., Guryev, I. (2020). Model and technology for prioritizing the implementation end-to-end business processes components of the green economy. *Acta Innovations, 35*, 65–80. https://doi.org/10.32933/actainnovations.35.5
7. Busch, K., Rochlitzer, A., Sola, D., Leopold, H. (2023). Just Tell Me: Prompt Engineering in Business Process Management. *Enterprise, Business-Process and Information Systems Modeling*, 3–11. https://doi.org/10.1007/978-3-031-34241-7_1
8. Handriani, I., Mahendrawathi. (2024). Investigating Cost and Business Process Management: A Systematic Literature Review (SLR). *Procedia Computer Science, 234*, 805–812. https://doi.org/10.1016/j.procs.2024.03.066
9. Gošnik, D., Stubelj, I. (2021). Business process management and risk-adjusted performance in SMEs. *Kybernetes, 51 (2)*, 659–675. https://doi.org/10.1108/k-11-2020-0794
10. Perdana, A., Lee, W. E., Mui Kim, C. (2023). Prototyping and implementing Robotic Process Automation in accounting firms: Benefits, challenges and opportunities to audit automation. *International Journal of Accounting Information Systems, 51*, 100641. https://doi.org/10.1016/j.accinf.2023.100641
11. Yan, A., Cheng, Z. (2024). A Review of the Development and Future Challenges of Case-Based Reasoning. *Applied Sciences, 14 (16)*, 7130. https://doi.org/10.3390/app14167130
12. Wu, Y., Zhou, J. (2023). A Contextual Information-Augmented Probabilistic Case-Based Reasoning Model for Knowledge Graph Reasoning. *Case-Based Reasoning Research and Development*, 102–117. https://doi.org/10.1007/978-3-031-40177-0_7
13. Portinale, L. (2024). Integrating kNN Retrieval with Inference on Graphical Models in Case-Based Reasoning. *Case-Based Reasoning Research and Development,* 1–16. https://doi.org/10.1007/978-3-031-63646-2_1
14. Khanmohammadi, E., Safari, H., Zandieh, M., Malmir, B., Tirkolaee, E. B. (2024). Development of Dynamic Balanced Scorecard Using Case-Based Reasoning Method and Adaptive Neuro-Fuzzy Inference System. *IEEE Transactions on Engineering Management, 71*, 899–912. https://doi.org/10.1109/tem.2022.3140291
15. Parejas-Llanovarced, H., Darias, J. M., Caro-Martínez, M., Recio-Garcia, J. A. (2023). Selecting Explanation Methods for Intelligent IoT Systems: A Case-Based Reasoning Approach. *Case-Based Reasoning Research and Development,* 185–199. https://doi.org/10.1007/978-3-031-40177-0_12
16. Leake, D., Wilkerson, Z., Vats, V., Acharya, K., Crandall, D. (2023). Examining the Impact of Network Architecture on Extracted Feature Quality for CBR. *Case-Based Reasoning Research and Development,* 3–18. https://doi.org/10.1007/978-3-031-40177-0_1
17. Levykin, V., Ievlanov, M., Levykin, I., Petrychenko, O. (2025). Development of a concept for the task of life cycle effective management of an operated information system. *Technology Audit and Production Reserves, 2 (2 (82))*, 66–73. https://doi.org/10.15587/2706-5448.2025.326479
18. Levykin, V., Ievlanov, M., Neumyvakina, O., Levykin, I., Nakonechnyi, A. (2024). Estimation of IT-project efforts for information system creation in the conditions of re-use of its functions. *Eastern-European Journal of Enterprise Technologies, 2 (2 (128)),* 6–19. https://doi.org/10.15587/1729-4061.2024.301227
19. Badakhshan, P., Wurm, B., Grisold, T., Geyer-Klingeberg, J., Mendling, J., vom Brocke, J. (2022). Creating business value with process mining. *The Journal of Strategic Information Systems, 31 (4)*, 101745. https://doi.org/10.1016/j.jsis.2022.101745
20. Hawkins, S. R., Pickerd, J., Summers, S. L., Wood, D. A. (2023). The Development of the Process Mining Event Log Generator (PMELG) Tool. *Accounting Horizons, 37 (4),* 85–95. https://doi.org/10.2308/horizons-2022-153
21. Chalyi, S. C., Levykin, I. V. (2016). Method of adaptive process management using case based reasoning. *Science-Based Technologies, 32 (4).* https://doi.org/10.18372/2310-5461.32.11184

MATHEMATICAL MODELING

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MODELING COMBINED AND SEPARATED SEQUENCING LEGS IN POINT MERGE: IMPACT ON CAPACITY, VERTICAL PROFILE, AND CONTINUOUS DESCENT

pages 65–70

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The object of research is the process of arrival sequencing in terminal maneuvering areas under the Point Merge concept. One problematic aspect is ensuring stable time-based intervals and maintaining continuous-descent profiles under peak demand and wind perturbations, as well as the lack of simple rules for choosing between combined and separated sequencing legs and for switching between them. The study used analytical modelling of arc geometry and direct-to-merge rules; parameterization of procedures and target intervals; probabilistic models of demand and ground-speed variation; Monte Carlo simulations using open traffic, weather and Aeronautical Information Services sources; statistical analysis; construction of a proxy controllability index; a hysteresis-based switching rule; and sensitivity analysis. It was proposed to obtain a reproducible framework for designing and comparing combined and separated sequencing legs with unified metrics. This follows from combining transparent geometry parameterization with a simple hysteresis-based switching rule that avoids frequent back-and-forth configuration changes. As a result, medians are practically identical on identical geometry, while differences appear in the tails: separated legs reduce the probability of long loops and extreme low-altitude horizontal segments. Compared with static alternatives, hysteresis-based switching under peak demand reduces separation-interval violations by up to ≈ 17.5 percentage points and shortens median low-altitude horizontal time by ≈ 4–9 s, at the cost of ≈ 0.57 NM of added median distance, providing better operational support without heavy optimizers. Limitations include a single case, environmental inference via extra distance, and a proxy controllability index. Future work will include human-in-the-loop experiments and coupling with detailed aircraft-performance models.

Keywords: Point Merge, sequencing legs, continuous descent, capacity, separation interval.

References

1. *Procedures for Air Navigation Services – Air Traffic Management (PANS-ATM). Doc 4444* (2016) Montreal: ICAO. Available at: http://library.caanepal.gov.np:8080/bitstream/123456789/401/1/4444_cons_en.pdf
2. *Annex 11 to the Convention on International Civil Aviation: Air Traffic Services* (2018). Montreal: ICAO. Available at: https://ffac.ch/wp-content/uploads/2020/10/ICAO-Annex-11-Air-Traffic-Services.pdf
3. *Point Merge: Integration of arrival flows to a merge point. Operational Services and Environment Definition (OSED). Version 2.0* (2010). Brussels: EUROCONTROL. Available at: https://www.eurocontrol.int/sites/default/files/library/003_Point_Merge_OSED_V2.0.pdf
4. *Continuous Descent Operations (CDO) Manual. Doc 9931* (2010). Montreal: ICAO. Available at: https://applications.icao.int/tools/ATMiKIT/story_content/external_files/102600063919931_en.pdf
5. Favennec, B., Hoffman, E., Trzmiel, A., Vergne, F., Zeghal, K. (2009). The Point Merge Arrival Flow Integration Technique: Towards More Complex Environments and Advanced Continuous Descent. *9th AIAA Aviation Technology, Integration, and Operations Conference (ATIO).* https://doi.org/10.2514/6.2009-6921
6. *Point Merge implementation: A quick guide. Ed. 1.51* (2024). Brussels: EUROCONTROL. Available at: https://www.eurocontrol.int/sites/default/files/2024-12/eurocontrol-point-merge-guide-v1-51.pdf
7. Favennec, B., Trzmiel, A., Zeghal, K. (2018). How the geometry of arrival routes can influence sequencing? *2018 Aviation Technology, Integration, and Operations Conference.* https://doi.org/10.2514/6.2018-4000
8. Ivanescu, D., Shaw, C., Tamvaclis, C., Kettunen, T. (2009). Models of Air Traffic Merging Techniques: Evaluating Performance of Point Merge. *9th AIAA Aviation Technology, Integration, and Operations Conference (ATIO).* https://doi.org/10.2514/6.2009-7013
9. Hardell, H., Otero, E., Polishchuk, T., Smetanová, L. (2025). Optimizing air traffic management through point merge procedures: Minimizing delays and environmental impact in arrival operations. *Journal of Air Transport Management, 123,* 102706. https://doi.org/10.1016/j.jairtraman.2024.102706
10. Oren, A., Sahin, O. (2021). The flight efficiency analysis on the Multi-Arrival Route Point Merge System. *The Aeronautical Journal, 126 (1299),* 755–767. https://doi.org/10.1017/aer.2021.105
11. Dönmez, K., Çetek, C., Kaya, O. (2021). Aircraft Sequencing and Scheduling in Parallel-Point Merge Systems for Multiple Parallel Runways. *Transportation Research Record: Journal of the Transportation Research Board, 2676 (3),* 108–124. https://doi.org/10.1177/03611981211049410
12. Kharchenko, V. P., Butsyk, I. M., Alieksieiev, O. M. (2009). Methods of making the right decision Manager at Air Traffic Service. *Proceedings of National Aviation University, 40 (3).* https://doi.org/10.18372/2306-1472.40.1757
13. *OpenSky REST API.* OpenSky Network. Available at: https://opensky-network.github.io/opensky-api/rest.html Last accessed: 07.10.2025
14. *Data API.* NWS Aviation Weather Center. Available at: https://aviationweather.gov/data/api/ Last accessed: 07.10.2025
15. *EIDW(DUBLIN) New Runway 10L/28R AIP IRELAND Updates* (2022). AirNav Ireland (AIS). Available at: https://www.iaa.ie/docs/default-source/publications/ei_sup_2022_020_en.pdf?sfvrsn=88d612f3_2
16. *European AIS Database.* EUROCONTROL. Available at: https://www.eurocontrol.int/service/european-ais-database Last accessed: 07.10.2025