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Challenges of Integrating Artificial Intelligence Into Testing Laboratories

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Abstract:

Research Question (RQ): How do testing laboratories use artificial intelligence (AI) and what challenges arise from the use of AI tools?
Purpose: To investigate the use of AI in Slovenian and Croatian testing laboratories, to analyse the impact of the complexity of measurement methods and equipment and to predict trends in this area.
Method: A questionnaire was developed for the study. Representatives of 125 randomly selected testing laboratories in Slovenia and Croatia performing accreditation activities according to SIST EN ISO/IEC 17025:2017 were invited to participate. In addition to descriptive statistics, the Kruskal-Wallis and Mann-Whitney U tests were used to analyse the data.
Results: 44 laboratories responded. The survey shows that most testing laboratories expect increased use of AI tools in the future and that laboratory staff recognise the benefits in terms of efficiency, accuracy and error reduction. However, according to the participants, the use of AI in Slovenian and Croatian laboratories is still limited due to the lack of qualified personnel, technical limitations and high initial costs. Laboratories that have more sophisticated measuring equipment perceive AI tools differently than laboratories that do not operate such equipment. The challenge for the future is to use AI to improve the quality of laboratory services, increase efficiency, improve progress and limit costs.
Organisation: The use of AI enables the development of new business models based on the automation and digitalisation of laboratory processes. Research enables organisations to better understand and exploit the potential of AI.
Society: For society, research can bring many benefits that improve the quality of life, promote economic and technological development and contribute to sustainable development and progress.
Originality: The research topic is unexplored in Slovenia and Croatia, and even in the international environment such concrete research is still quite limited.
Limitations / further research: Only a limited number of Slovenian and Croatian testing laboratories were included in the study, which could limit the generalization of the conclusions at the global level. It would make sense to carry out further research in a wider geographical area. As well as focus further research on determining the economic impact of using AI in laboratories, on determining the effectiveness and reliability of measurements, on studies to identify long-term research opportunities, the development of analytical methods using AI, a more in-depth analysis of differences between laboratories taking into account AI approaches and the analysis of cultural, economic and regulatory factors.

Keywords: artificial intelligence, AI, testing laboratories, monitoring, challenges, opportunities.

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1 Introduction

Advanced technologies are being used in production, research and other processes, among which artificial intelligence (AI) stands out as one of the most important innovations. AI is transforming many areas. Monitoring, testing products, controlling industrial processes, research activities, medicine and the development of new materials for production and logistics - it is also playing an increasingly important role in testing laboratories. Laboratories, which are essential for quality products and services, industrial innovation and development, are faced with increasing demands on the accuracy, efficiency and reliability of measurements. AI for testing laboratories brings many benefits in various scientific and technical fields. However, it also brings new challenges that the laboratory must recognise and overcome. It is unresearched how analytical chemistry staff adopt new technology, for what purpose and to what extent they even use available AI tools. It is also unknown how laboratories are willing to face the new opportunities and risks that the development of AI brings. We assumed that the decision on the scope and use of AI is related to the complexity of the measuring equipment that the laboratory manages. The purpose of the research is to find answers to these questions for testing laboratories in Slovenia and Croatia.

We have analysed the main challenges faced by laboratory personnel when implementing AI in monitoring procedures and proposed possible solutions to address the identified risks. We believe that a systematic approach to addressing the identified challenges can ensure that the use of AI maximises the benefits without compromising the quality and reliability of the reported results.

We wanted to know how testing laboratories in Slovenia and Croatia recognise the benefits of AI and to what extent they are already use AI tools. We were also interested in whether the complexity of the analytical methods and measuring equipment influences the extent of AI use in the laboratories, both currently and in the future. To this purpose, we analysed a limited number of testing laboratories, all of which perform at least some monitoring as an accredited activity that complies with SIST EN ISO/IEC 17025:2017. The field of using AI for the needs of various monitoring in Slovenia and Croatia was unexplored; even for the international area, these studies were still quite limited. For the reasons mentioned above, the research conducted is important for organisations and society.

2 Theoretical Framework

2.1 Function of testing laboratories and risk management

The most important function of testing laboratories is to provide accurate, reliable and repeatable measurements that are critical for the validation of research results, the quality of production processes, the development of new materials, products and technologies, and regulatory compliance. The international standard SIST EN ISO 9001:2015 specifies the requirements for a quality management system (QMS) and supports testing laboratories in establishing and maintaining a high quality of their work activities. This contributes to greater

confidence in their results, greater customer satisfaction and increased competitiveness in the market. In a demanding and multidimensional competitive environment, more than one million certificates have been issued to organisations in 189 countries since 1987, demonstrating compliance with the quality management requirements of SIST EN ISO 9001:2015 (International Organization for Standardization, 2024).

SIST EN ISO 9001:2015 is the most widely used standard for quality management worldwide. The ISO 9001 standard is derived from the quality management principles of successful organisations. It integrates good business practises and helps organisations to achieve their highest goals. The next international standard, SIST EN ISO/IEC 17025:2017, has been developed to provide confidence in the operation of laboratories. Testing and calibration laboratories operating to SIST EN ISO/IEC 17025:2017 generally operate in accordance with the principles of ISO 9001 (ISO 17025:2017, 2018, p. 9). The currently valid revisions of the international standards SIST EN ISO 9001:2015 (Quality management systems) and SIST EN ISO/IEC 17025:2017 (General requirements for the competence of testing and calibration laboratories) bring new requirements for dealing with risks and opportunities that must be comprehensively managed. (Fonseca, 2015, p. 174; ISO 17025:2017, 2018, p. 38) The effective identification of risks, the limitation of consequences and the management of crisis situations are decisive factors in the activities of laboratories.

Tziakou, Fragkaki and Platis (2023, pp. 167–177) consider that worker safety, accuracy and reliability of laboratory results, as well as financial sustainability and environmental protection issues, play an important role in decision-making in both industry and the service sector. For a laboratory to be considered reliable, safe and therefore competitive, it is advisable to fulfil the requirements of international standards and other legal regulations and to use risk management tools and procedures. The main sources of risk in a laboratory are the personnel themselves, the samples to be analysed, the chemical reagents and waste, the equipment, the test methods, the measurements, the non-updated quality control procedures, the reporting of results, impartiality and confidentiality, digitalisation and, last but not least, the financial aspects. The continuous management of risks is necessary in order to set new priorities and continuously implement the necessary safety and prevention measures. Risk management is essential to ensure a safe internal and external laboratory environment and to ensure the provision of reliable and competent services. In addition, implementing a risk-based mindset can positively influence the outcome of regular assessments to explore opportunities to increase the effectiveness of the management system and avoid negative impacts.

The US Department of Energy (DOE) has published a standard for improving human performance, which emphasises that 80% of incidents in the industry are caused by human error. The other 20% are caused by equipment failure (note that this study was conducted in 2009 and that the percentage of incidents attributed to equipment failure has since declined due to improved preventive and corrective maintenance practises and other reliability controls). (Burns & Hubbard, 2021, p. 22)

Da Silva, Grochau, and Veit (2021) created a process diagram (Figure 1) for risk management, which also applies to the laboratory testing activity based on a literature review, an identification of risk management levels, and necessary tool. The proposed system, in the form of a flowchart and in accordance with the current version of SIST EN ISO/IEC 17025:2017, provides for the stages of analysis, evaluation, classification and validating risks, their cause(s), identifying existing measures, the need for additional actions and the treatment and monitoring of risks. The model contains some effective tools for risk management.

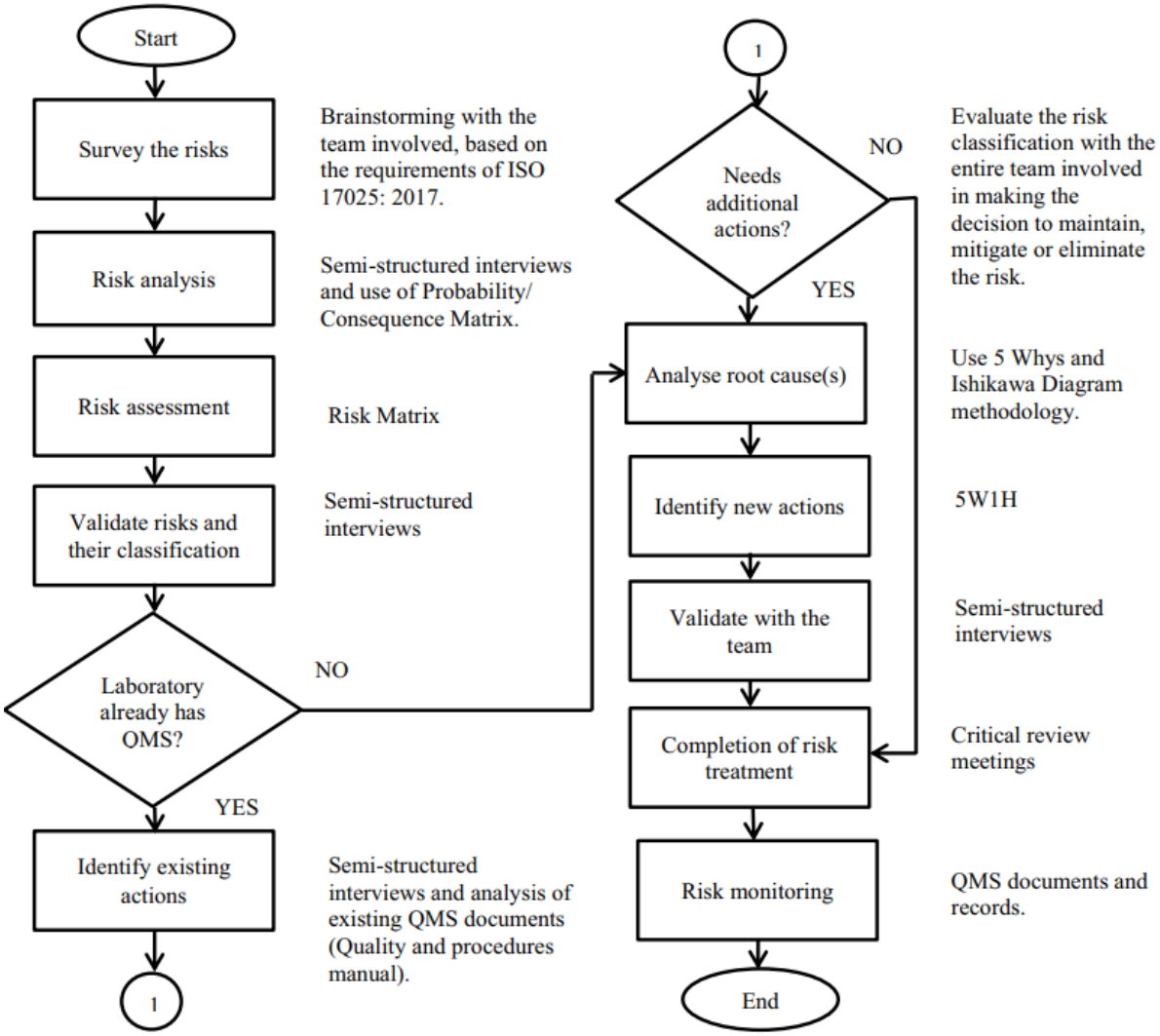

Figure 1. An example of a risk management process in laboratories. Summarised from *System proposal for the implementation of risk management in the context of ISO/IEC 17025*, Da Silva; Grochau, & Veit, 2021, Accreditation and Quality Assurance, 26, p. 274.

The quality of laboratory services contributes to the advancement of science, technology and industry; testing laboratories therefore play an important role in improving the quality of life and promoting economic development. One of the challenges and risks identified is the use of AI in the measurement and reporting processes of testing laboratories.

2.2 The status and challenges of AI in the laboratories

AI is an imitation of human cognitive processes with the help of machines. In particular, the unique implementation of AI, including specialised computer systems, artificial language processing, speech recognition and AI performed by AI machines. This is in contrast to the natural intelligence of humans or animals. Key AI textbooks emphasise that AI will present us with new challenges which will translate into new practises and ways of thinking. (Chatterjee, 2020, p. 13). Barczak (2023, p. 6) adds that the development of the practical application of AI has been very slow until recently, but in recent years AI technology has advanced at a dizzying pace. The turning point for AI has been the achievements associated primarily with deep learning, a technology for autonomous learning from large data sets.

In the next twenty to thirty years, AI will completely fill every activities and action of every person and entire societies. Each of us will face unique practical, intellectual and mental challenges. The changes that will accompany us will be revolutionary. In order to master the challenges of the age of AI, we must be perfectly and comprehensively prepared and, above all, show understanding and resilience to its temporary negative effects. Of course, companies' knowledge of the nature of the immense opportunities and the use of AI solutions will be decisive to success. (Barczak, 2023, p. 21)

We have analysed how AI is being used in the chemical industry, particularly in analytical testing laboratories.

Most examples of the use of AI tools in testing laboratories are described in the field of medical research and diagnostics. Research conducted by Paranjape et al. (2021) shows that specific knowledge about AI in medical laboratories is still poor and that education about artificial intelligence is very necessary. One strategy could be to implement new AI tools alongside existing tools. In 2020, 15.6% of medical laboratories of Roche’s Strategic Advisory Network were using AI tools, while 66.4% believed they could use it in the future. Most had an unsure attitude on what they would need to adopt AI in the diagnostics space. High investment costs, lack of proven clinical benefits, number of decision makers, and privacy concerns were identified as barriers to adoption. Education in the value of AI, streamlined implementation and integration into existing workflows, and research to prove clinical utility were identified as solutions needed to mainstream AI in laboratory medicine. (p. 823) Herman, Rhoads, Schulz, & Durant (2021, p. 1466) add that AI technologies in laboratory medicine are being rapidly developed and described, but their implementation thus far has been modest. To spur the implementation of reliable and sophisticated machine learning-based technologies, we need to establish best practices further and improve our information system and communication infrastructure. The participation of the clinical laboratory community is essential to ensure that laboratory data are sufficiently available and incorporated conscientiously into robust, safe, and clinically effective machine learning supported clinical diagnostics.

Scientists at the University of Glasgow tried to answer the question of whether robots can be trained to be chemists. Over the past few years, the team has been designing a desktop-sized robot chemist tasked with the time-consuming and repetitive job of creating chemicals. The robot carries out tasks using simple instructions from an in-house program called SynthReader. Eventually, the team hopes SynthReader will become a staple in laboratories around the world. It's this type of collaborative research that will continue to accelerate scientific discoveries and advance modern science. AI has empowered researchers with the tools to design smarter and more cost-efficient solutions for a variety of applications. AI has some incredible benefits, but it comes at a cost. In the UK, the Science and Technology Facilities Council (STFC) has teamed up with global computing giant IBM to launch the Hartree National Centre for Digital Innovation (HNCDI). Designed to offer British businesses and public sector groups access to AI and quantum computing technologies, the HNCDI program aims to boost innovation, support growth and stimulate the local economy. (International Labmate Limited, 2021)

Thurow (2023) summarizes that analytical measurement methods are used in different areas of production and quality control, diagnostics, environmental monitoring, or in research applications. He states that AI will increasingly find use in automation. The main area of application here is initially data analysis. AI can analyse large amounts of data and recognize patterns and trends. This can be particularly useful for evaluating large amounts of data, e.g., in medical research. (Bio)analytical methods often also require the automation of image recognition. AI methods are increasingly being used here. However, methods of AI can also be used to optimize process control based on measurement data and can thus take over the development and optimization of automated methods, among other things. AI methods can be used to monitor quality control processes in the laboratory. For example, AI systems can be used to detect deviations from standard values in measurement processes and to take corrective measures in good time. (p. 5063)

Kumar (2023, pp. 16–17) summarises that the era of AI is characterised by rapid and profound changes in market trends, consumer preferences and the business environment. These changes have a significant impact on the internal functioning of the organisation and its employees, especially on the demand for complex cognitive and information processing skills. These skills are critical to understanding, adapting and innovating in the AI-driven world. Some examples of these skills are:

- data analysis and visualisation,
- systems thinking and design thinking,
- data-driven decision making,
- continuous learning, and
- agility.

Olu-Lawal et al. (2024) investigated the multifaceted role of precision measurement in improving production quality. Their aim was to provide a detailed overview of advanced

metrology techniques, their use in various industries, the associated challenges and their prospects. By synthesising existing knowledge and research findings, they demonstrated the importance of precision metrology and its impact on modern manufacturing practise. Precision metrology is a cornerstone of modern manufacturing, ensuring the quality, reliability and performance of products in various industries. As highlighted in this review, precision monitoring plays a critical role in improving manufacturing quality through accurate measurement, quality assurance and standards compliance. The future of precision laboratory activities offers exciting prospects for innovation and progress fuelled by emerging technologies such as AI, machine learning and IoT (Internet of Things). Predictive maintenance and autonomous quality control systems will revolutionise metrology by enabling proactive maintenance, real-time quality monitoring and closed-loop control of manufacturing processes. Continuous research and innovation in metrology promise to address new challenges and open up new opportunities that will shape the future of modern industry. To summarise, precision work in the laboratory remains essential to ensure production quality and competitiveness in today's global marketplace. By embracing new technologies, advancing metrology techniques and fostering collaboration and innovation, manufacturers can harness the full potential of precision metrology to continuously improve and innovate their products and processes. (p. 736)

The use of AI in chemistry (in general) has increased enormously in recent years. Baum et al. (2021) studied the growth and distribution of AI-related chemistry publications over the last two decades. The volume of both journal and patent publications has increased dramatically, especially since 2015. When examining the distribution of publications across the various research areas of chemistry, they found that analytical chemistry and biochemistry incorporate AI the most and with the highest growth rates. They also analysed trends in interdisciplinary research and identified frequently occurring combinations of research areas in publications. In addition, topic analyses were conducted for journal and patent publications to illustrate emerging associations of AI with specific chemical research topics. The significant increase in the use of AI in chemistry since 2015 can probably be explained by several factors. The greater availability of software and hardware tools to implement AI has lowered the barriers to the use of AI in chemical research, while research area-specific datasets suitable for AI methods have proliferated. In addition, many researchers have learnt techniques for generating and handling data for AI methods. The frequency of AI and research area-specific concepts in publications between 2000 and 2020 shows how AI has been integrated into various research areas. Many AI methods have been adapted for chemical research and are being introduced into new areas of chemical study. As such, due to the increasingly interdisciplinary research landscape, many AI methods have been successfully adapted to chemical research. In some areas, the use of AI has even become routine. However, there are still areas of chemistry, such as organic synthesis chemistry, where AI is not yet being used. Perhaps it is only a matter of time before improvements in AI itself, experience from successful applications of AI and interdisciplinary

research come together to lift these areas from the 'valley of disillusionment' to the 'plateau of productivity'. (p. 3207)

The application of AI in chemistry is not limited to chemical laboratories, but is also useful for pharmaceuticals, drugs, advanced analytical techniques, healthcare, biochemistry and other related fields. Molecular properties of new molecules can be detected, compared and predicted against already existing databases, reducing the time for analysis and comparison and using artificial intelligence to achieve efficient results. (Rai & Chatrath, 2021, p. 18)

Best practises for the use of AI for research purposes are also useful in technological process control, medicine, quality control and other activities. Liangru, Li, and Fan (2023) investigated the impact of AI transparency on trust considering challenges and threats, the extent of trust in AI, and how employees' knowledge of AI influences the perception of challenges and threats. According to their research, the practical implications are mainly in the following areas: firstly, employees who work with AI believe that AI poses more challenges than threats. In the future, companies will be able to rely on AI as a decision-making tool for part of their daily work. Coleman Parks Research (Smith, 2019) investigated the perception of AI among hourly and salaried workers in several countries and found that four out of five workers can see the potential benefits of AI for improving the working environment. Furthermore, the research found that transparency of AI has a positive impact on workers' trust in AI, which directly and indirectly increases workers' perception of the challenge and reduces their perception of the threat. Therefore, organisations should improve the transparency of AI systems, e.g. by informing employees about the AI decision-making process or developing more transparent AI systems. When employees work with AI, it is important that they understand the benefits of the work and feel less like they have no control over the work in order to increase their appreciation of the challenge and decrease their perception of the threat.

In the context of the increasingly widespread use of AI, the Electric Power Research Institute (EPRI, 2024) has addressed a new challenge that has not yet been assessed. In May 2024, it published a report highlighting the impact on electricity consumption in the US. As AI becomes increasingly important in our 24/7 digital economy, data centres processing AI could significantly increase energy demand. According to their study, data centres could consume more than double the electricity produced in the US by 2030. This could lead to regional supply problems, among other things. AI queries require around ten times more electricity than conventional internet searches, and the creation of original music, photos and videos requires even more. With 5.3 billion internet users, the rapid adoption of these new tools could significantly increase energy consumption. At the same time, computing power is becoming increasingly concentrated, with individual devices now consuming the equivalent of 80,000 to 800,000 households, exacerbating energy supply issues. Their comprehensive study also takes into account other forecasting variables, including extreme weather events, decentralised energy resources, electrification and emerging technologies.

2.3 Hypotheses testing

Depending on their function and purpose, test laboratories use more or less sophisticated measurement systems or analysis methods. This affects the accuracy, reliability, scope and cost of the tests. It also influences the experience of the laboratory staff, the level of expertise, working conditions, reporting and the integration of the requirements of standards and protocols. We tested the following hypothesis: “The use of AI tools is a function of the complexity of the measuring equipment and analysis methods. Testing laboratories that manage demanding measuring equipment and more demanding analytical methods in Slovenia and Croatia perceive the use of AI in laboratories differently than those working with less demanding analytical equipment.”

3 Method

In June 2024, we conducted an online survey in which 125 randomly selected testing laboratories in Slovenia and Croatia participated. All of them perform (at least to a limited extent) an accredited activity according to the requirements of SIST EN ISO/IEC 17025:2017. Their contact details can be found in the publicly accessible register of the Slovenian Accreditation Agency and the Croatian Accreditation Agency and on their websites. Depending on their function and purpose, laboratories use less or more demanding measuring equipment and consequently different measuring methods. In the survey, the participants defined the complexity of their measurement methods, the scope of the measurement systems and the number of laboratory staff. The participants were asked whether and which AI tools they already use in their laboratories and for which function. The term "the use of artificial intelligence" was introduced and meant as "technology that enables the execution of tasks with the help of a computer and can complement human intelligence, for example in data analysis, samples recognition, decision making, process automation, accuracy improvement, quality control and research optimization”.

The model of research is shown in Figure 2.

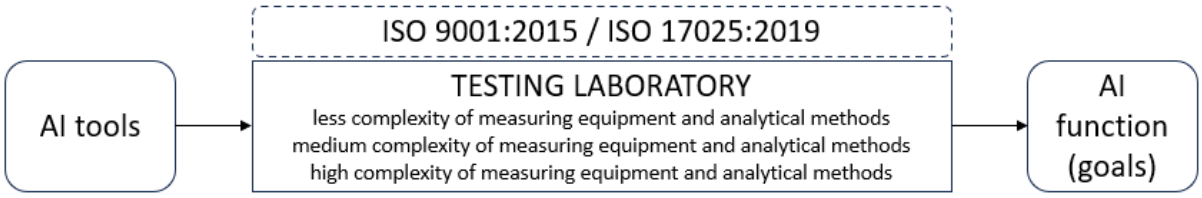

Figure 2. Model of research.

The testing laboratories involved in the research carry out accredited tests in the following areas:

- the environment,
- chemicals, chemical products, cosmetics, paints and varnishes,

- medicine,
- pharmaceuticals,
- energy production,
- agriculture, food,
- metallurgy,
- construction industry,
- quality and metrology,
- research activities.

We used an objective measurement tool that is a function of the variables we measured. A questionnaire with 11 closed-ended questions was developed for the purpose of the study. Participants indicated their agreement with the statements. In addition to the use or non-use of AI, the purpose and goals, they could also indicate what plans they have for the future and what purposes and challenges they expect in this context. If AI is not planned for the future, they were able to state the reasons for this.

The reliability of the questionnaire was tested using the Cronbach's alpha test. The value of a was 0.728, which means that the questionnaire has a moderately high reliability and is acceptable for our research purpose. The survey is replicable so that its consistency can be checked. To analyse the collected data, we used descriptive and frequency statistics, the Kruskal-Wallis and Mann-Whitney U tests to identify statistically significant differences, considering the complexity of the measurement systems used, the number of measurement systems and the use of AI tools.

4 Results

During the three-week period of data collection, representatives of 44 laboratories responded, 29 of them from Slovenia and 15 from Croatia, who completed the questionnaire in full. The number of participants by sector is shown in Figure 3.

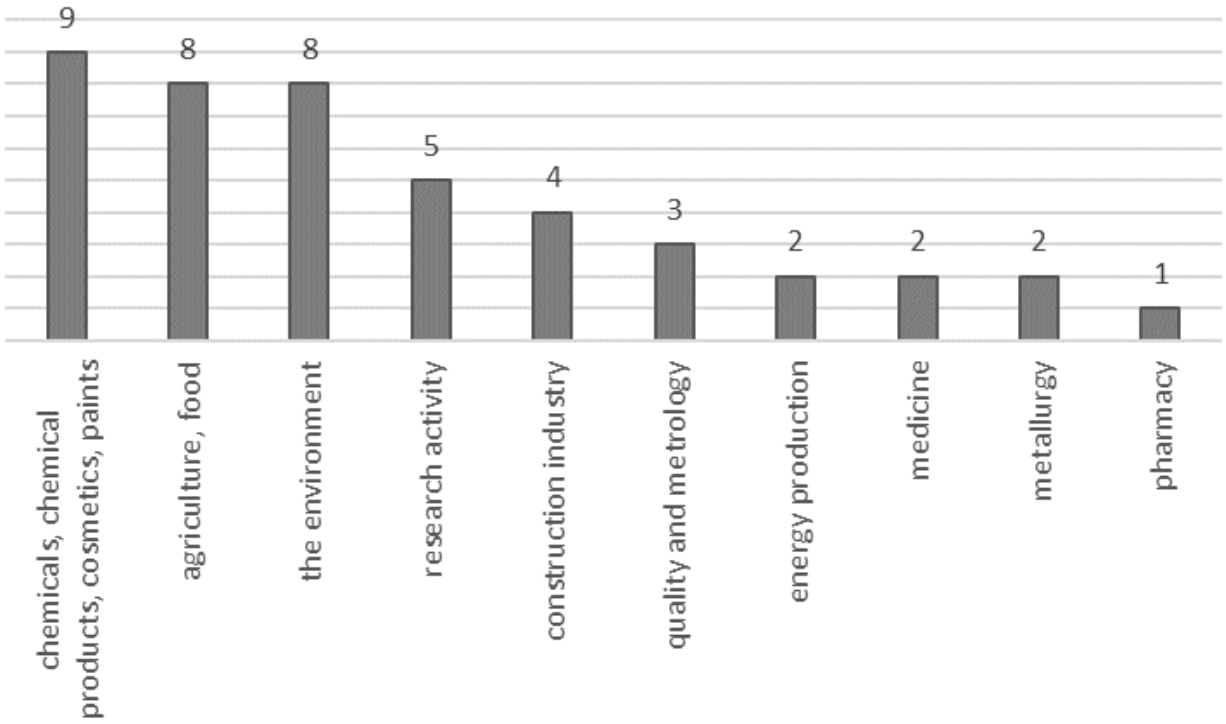

Figure 3. Number of participating laboratories by industry.

Table 1 shows the degree of agreement with 11 statements from the field of AI applications. The percentage of agreement and overall agreement with the individual statements is shown in Figure 4. The highest level of agreement was measured for the statements “The challenges of using AI in laboratories are considerable.”, "AI can improve the efficiency of laboratory processes.”, "Laboratories will increasingly use AI in the future” and “AI can reduce human error in measurements and reports”.

Table 1. Scale of agreement and total agreement with individual statements.

STATEMENT	total agreement	agreement	undecided	disagreement	total disagreement
			%		
AI can improve the efficiency of laboratory processes.	27.3	50.0	11.4	11.3	0.0
Using AI can lead to more accurate results.	25.0	36.4	15.9	22.7	0.0
AI can reduce laboratory operating costs.	34.1	34.1	13.6	18.2	0.0
AI can reduce human error in measurement and reporting.	36.4	36.4	9.1	15.9	2.3
Laboratories will increase their use of AI in the future.	43.2	34.1	15.9	6.8	0.0
The challenges of using AI in laboratories are considerable.	25.0	61.4	9.1	4.5	0.0
Lack of expertise is a major barrier to the use of AI in laboratories.	15.9	50.0	15.9	15.9	2.3
Lack of high-quality data is a major obstacle to the use of AI in laboratories.	6.8	31.8	22.8	38.6	0.0
High cost is a major barrier to the use of AI in laboratories.	2.3	40.9	25.0	29.5	2.3
Technical challenges are the main obstacle to the use of AI.	15.9	45.5	25.0	11.3	2.3
Legislative restrictions are the main obstacle to the use of AI.	4.5	18.2	22.7	40.9	13.7

Sixteen laboratories (36.4 % of the total) stated that they already use AI tools in their work to a greater or lesser extent, primarily for data analysis, but also for predicting results (calculating theoretical values based on input data), optimising processes, automating experiments and sample recognition. As “other”, participants mentioned the use of AI for report generation, diagnostics, spectral analysis, clinical research, research and coding and analysing digital records. All those already using AI tools plan to increase their use in the future. A further six laboratories (13.6 %) that do not yet use AI are planning to use it. 77.2 % of participants agree or strongly agree that laboratories will increase their use of AI in the future.

In Figure 5, we have summarised the AI tools that the participating testing laboratories already use in their work, their function and their purpose. Six laboratories stated that they use less demanding measurement methods in their work, 17 medium and 21 very demanding measurement methods. The proportion of those using very demanding measurement methods is 47.7%. 25 laboratories use up to 10 measurement systems, 11 laboratories use 11 to 20

measurement systems, 5 laboratories use between 21 and 30 measurement systems and 3 laboratories use more than 30 measurement systems.

The results of the Kruskal-Wallis test are summarised in Table 2. The test was carried out taking into account the number of measurement systems checked by a laboratory. A statistically significant difference was found in 6 out of 11 statements.

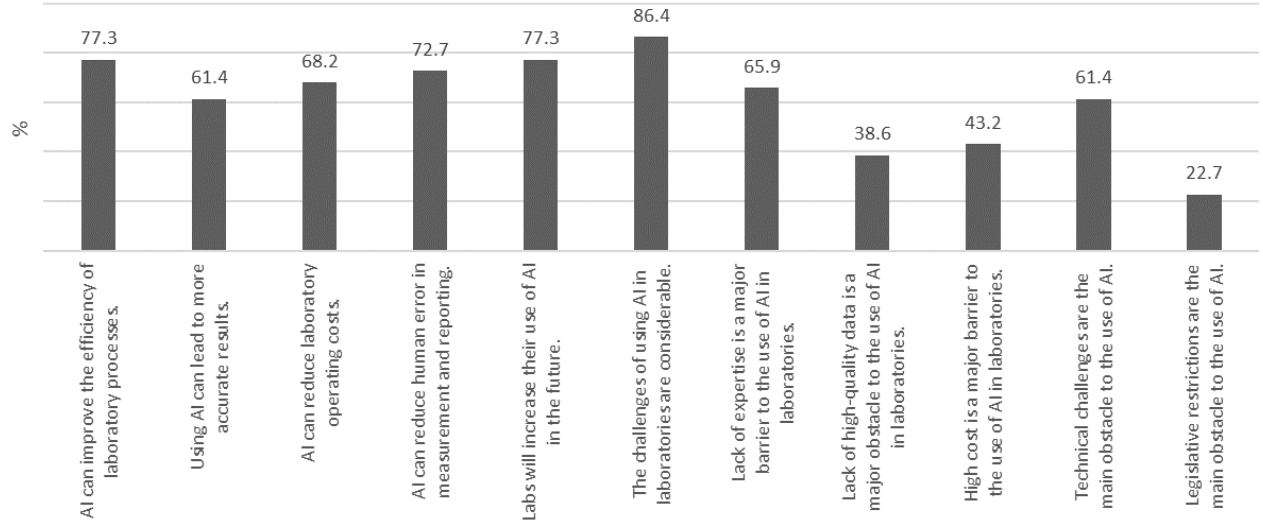

Figure 4. Scale of agreement and total agreement with individual statements.

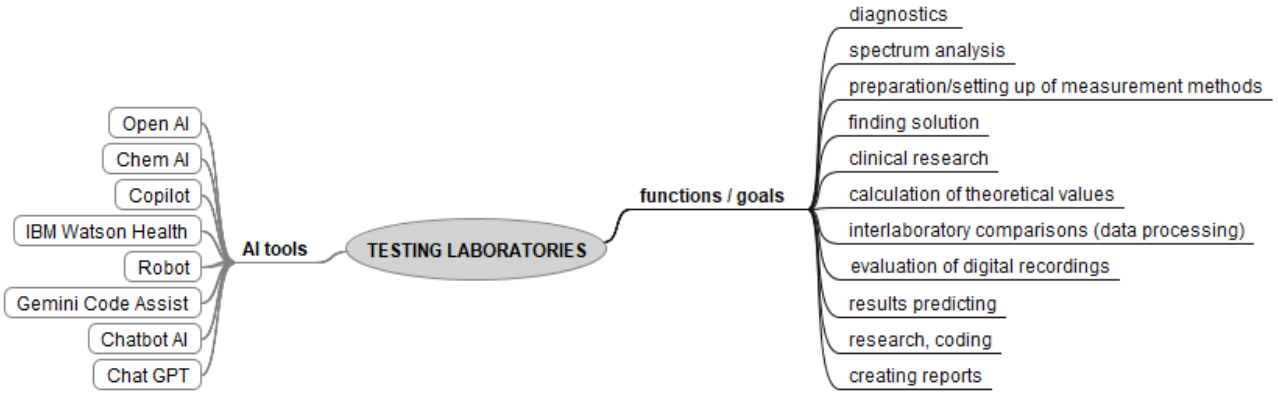

Figure 5. AI Tools and the scope of AI applications in laboratories currently and planned.

Table 2. Results of Kruskal-Wallis test.

STATEMENT (dependent variable)	***df***	***H***	***p***
AI can improve the efficiency of laboratory processes.	3	13.741	<0.05
Using AI can lead to more accurate results.	3	3.541	<0.05
AI can reduce laboratory operating costs.	3	6.217	0.102
AI can reduce human error in measurement and reporting.	3	9.961	<0.05
Laboratories will increase their use of AI in the future.	3	11.876	<0.05
The challenges of using AI in laboratories are considerable.	3	1.692	0.064
Lack of expertise is a major barrier to the use of AI in laboratories.	3	4.075	0.254
Lack of high-quality data is a major obstacle to the use of AI in laboratories.	3	6.068	0.108
High cost is a major barrier to the use of AI in laboratories.	3	9.493	<0.05
Technical challenges are the main obstacle to the use of AI.	3	8.478	<0.05
Legislative restrictions are the main obstacle to the use of AI.	3	3.569	0.312

Note. *df*: degree of freedom; *H*: K-W test statistic; *p*: statistical significance (p <0.05 means that there is a statistically significant difference).

Table 3 shows the data we used to test for statistically significant differences, taking into account the complexity of the measurement devices and the use or non-use of AI tools. We combined all those who reported using less or moderately complex methods in their work and compared them with those using high complex methods. When comparing laboratories that use very demanding measurement tools with others, there is a statistically significant difference in most responses (8 out of 11). The statistically significant difference between laboratories can also be supported by the fact that approximately 57 % of laboratories that use more sophisticated measuring equipment already use AI tools (unlike others, where this proportion is approximately 17 %). Approximately 76 % of these laboratories intend to expand the use of AI (in contrast to others, where this share is approximately 30 % only), see table 4.

Table 3. Results of Mann-Whitney *U* test.

STATEMENT (dependent variable)	CRITERION	*U*	*p*
AI can improve the efficiency of laboratory processes.	users of AI	363	<0.05
	complexity of methods	106	<0.05
Using AI can lead to more accurate results.	users of AI	359	<0.05
	complexity of methods	146	<0.05
AI can reduce laboratory operating costs.	users of AI	355.5	<0.05
	complexity of methods	121	<0.05
AI can reduce human error in measurement and reporting.	users of AI	342	<0.05
	complexity of methods	101	<0.05
Laboratories will increase their use of AI in the future.	users of AI	356	<0.05
	complexity of methods	109	<0.05
The challenges of using AI in laboratories are considerable.	users of AI	245	0.564
	complexity of methods	210	0.409
Lack of expertise is a major barrier to the use of AI in laboratories.	users of AI	202	0.172
	complexity of methods	290.5	<0.05
Lack of high-quality data is a major obstacle to the use of AI in laboratories.	users of AI	153	0.097
	complexity of methods	362	<0.05
High cost is a major barrier to the use of AI in laboratories.	users of AI	184.5	0.313
	complexity of methods	331	<0.05
Technical challenges are the main obstacle to the use of AI.	users of AI	146.5	<0.05
	complexity of methods	286	0.272
Legislative restrictions are the main obstacle to the use of AI.	users of AI	169	0.164
	complexity of methods	238.5	0.951

Note. *U*: Mann-Whitney test statistic; *p*: statistical significance ($p < 0.05$ means that there is a statistically significant difference).

Table 4. Complexity of measuring equipment, impact on the use of AI tools currently and planned.

COMPLEXITY OF EQUIPMENT	N	already use of AI tools	plan to use of AI tools in future	already use of AI tools	plan to use of AI tools in future
	number			%	
high	21	12	16	57.1	76.2
less&medium	23	4	7	17.4	30.4

Those using demanding measurement equipment are more likely to agree that AI can improve the efficiency of lab work, that AI can contribute to more accurate results, reduce costs and human error, and that the use of AI in lab work will be more pronounced in the future (Table 5). They are also more likely believe that technical challenges and finances are not a limitation to the use of AI.

Table 5. Complexity of measuring equipment, agreement and total agreement with some statements.

STATEMENT	less&medium complexity equipment	high complexity equipment	less&medium complexity equipment	high complexity equipment
	agreement or total agreement (N)		agreement or total agreement (%)	
AI can improve the efficiency of laboratory processes.	14	20	60.9	95.2
Using AI can lead to more accurate results.	12	15	52.2	71.4
AI can reduce human error in measurement and reporting.	12	20	52.2	95.2
Laboratories will increase their use of AI in the future.	14	20	60.9	95.2

5 Discussion

The use of AI in laboratories carrying out various tests is becoming an increasingly important topic and is also a trend at the international level. The research conducted among testing laboratories provide interesting insights into the current status and future possibilities of the use of AI. Most participants in the survey believe in the increased use of AI in the future. Despite the major challenges associated with this technology, they recognise the benefits it can bring to laboratory work. Participants agree that AI can significantly improve the efficiency of work in laboratories. The automation of routine tasks and advanced analyses will enable faster and more accurate results. As can be seen from the literature review, we also find that AI will reduce human error, which is particularly important when analysis and processing large amounts of complex data. In addition, process optimisation with the help of AI can lead to significant cost savings, which is crucial in today's competitive environment. Participants expressed the need for further research and improvement of AI algorithms to achieve even better results. The use of AI to predict outcomes and analyse data can produce breakthrough innovations in areas such as medical research, pharmaceuticals, biotechnology and many other scientific disciplines.

In approaches to AI parallels with the global level and Slovenian and Croatian testing laboratories can be found. Despite the potential of AI, laboratories face challenges, as shown by the low utilisation of AI in the testing laboratories in Slovenia and Croatia (similarly as the research conducted by Paranjape et al., 2021). The employees of several laboratories stated that they do not know how AI can be used in their work. The laboratories often do not have enough qualified employees who know how to use AI technologies. According to the respondents this leads to the need to invest in staff training and development, which is a long-term and financially demanding process.

In the review of the available literature, we did not find research where the impact of the complexity of the used measuring equipment in approaches to AI was studied. The obtained results therefore contribute significantly to the understanding of the differences and consequences to laboratory activities. Those using less sophisticated measurement devices

believe that technical limitations are an important factor influencing the reduced use of AI. Without suitable technical solutions, the potential of AI can only be utilised to a limited extent. According to some, cost is also a barrier to the use of AI tools; the introduction of AI technologies is said to require significant initial investment. However, the long-term savings potential through improved efficiency is a strong argument in favour of overcoming this challenge. Laboratories that have adopted AI report the effectiveness of its use, indicating the possibility of recouping the initial investment. The lack of quality solutions and regulatory restrictions are additional challenges. The use of AI requires constant adaptation and optimisation of algorithms to achieve reliable results. Furthermore, it is important to monitor legal changes and adapt to regulatory requirements, which requires additional effort.

A good third of the participating laboratories already use AI tools and consider their use to be effective. The most important areas of application include data analysis, results prediction and process optimisation. These laboratories serve as examples of best practise that can motivate others to adopt AI technologies. In addition, nearly one in two laboratories plan to expand the use of AI or introduce AI into their workflows. This data points to a promising future and the willingness of laboratories to overcome existing challenges and reap the benefits of AI.

The differences between laboratories that use more advanced measurement devices and those that do not are evident in many areas. Advanced instrumentation enables more accurate measurements and lower detection limits, which is critical for some applications. Advanced equipment reduces the probability of error and improves the reproducibility of results, which means greater reliability. This enables a wide range of analyses, including more complex and specialised tests. Laboratories with sophisticated instruments have a significantly higher initial investment and manage a more powerful computer configuration. They have higher costs due to maintenance, calibration and ensuring working conditions. The services of such laboratories are consequently more expensive. Laboratories with demanding measuring equipment require personnel with a higher level of training and specialisation for the management and maintenance of demanding measuring equipment. Continuous education and training are required to keep up with the latest technologies and methods. Laboratories with sophisticated measuring equipment often fulfil stricter quality and accreditation standards, which in turn means higher quality requirements, more documentation, assessment and elimination of risks.

The results showed a statistically significant difference in the approach to AI between laboratories using complex and those using simpler measurement methods. It is difficult to conclude that the number of measurement systems mastered by the laboratories correlates with the perception of AI. However, the complexity of the measurement systems or the measurement methods certainly does. Testing laboratories in Slovenia and Croatia, which use advanced measuring devices and more advanced analysis methods, in most cases already use AI tools, at least to a lesser extent, and intend to use them even more in the future. This is how they differ from others.

Because the evaluation of 8 out of 11 statements related to AI approaches confirmed a statistically significant difference, we confirmed the hypothesis. The statistically significant difference between laboratories considering complexity of equipment can also be supported by the fact that users of more sophisticated analytical methods and equipment are already using AI tools more often, and to a greater extent than others and planning to do in the future as well. This was expressed very convincingly.

The results contribute to the understanding of the current situation and predict the possibilities of using AI in laboratories in the future. The research highlights the potential of AI to improve efficiency, accuracy and automation of laboratory processes. They also reveal challenges such as lack of trained personnel, technical limitations, and high initial costs that need to be overcome for the wider implementation of AI. Laboratories can use the information obtained to automate routine tasks, which reduces errors and speeds up data processing. The use of AI makes it possible to carry out more complex and accurate analyses, which increases the reliability of results, helps in the optimization of measurement methods and processes, and leads to better use of resources and lower costs. Laboratories that implement AI are becoming more competitive in the market due to faster and higher quality services. For even better laboratory practices, safe and effective use of AI, laboratories should increase their investment in education and training of staff in the field of AI, thereby improving the understanding and use of modern technology. They should provide access to advanced technical equipment and information support. At the global level, it would be welcome to promote research and development of new AI solutions in analytical chemistry, collaboration between laboratories, academic institutions and industry to share knowledge and good practices. At the same time, the implementation of pilot projects to test different solutions and approaches in different laboratory environments and analyse their effects would be welcome.

AI can contribute to the automation of laboratory processes, reducing errors and improving efficiency. Most users of AI tools in Slovenia and Croatia are convinced of this which has also been confirmed by other researchers. The use of advanced technology is important for improving the quality of services and increasing competitiveness on the market. Commitment to introducing continuous improvements in laboratories is one of the purposes of SIST EN ISO/IEC 17025:2017.

We confirmed the hypothesis using statistical methods. These showed significant differences in the use, perception, and approaches to AI between laboratories with more advanced measurement equipment and those with simpler ones. The results confirmed that laboratories with more advanced equipment use AI tools more often, which was further supported by the survey responses, which showed a greater willingness and ability of these laboratories to implement new technologies.

The use of AI in testing laboratories bring risks that need to be addressed and mitigated. Risks assessment is a key action to ensure quality laboratory services. It is included in the

requirements of the SIST EN ISO/IEC 17025:2017 and SIST EN ISO 9001:2015. The mentioned international standards affect work processes in many laboratories. This is also evident from the reviewed literature. Considering the theoretical starting points and research findings, here are some possible examples of risks and vulnerabilities:

- Over-reliance on AI technology may lead to a decrease in critical thinking and verification of results. This could lead to reduced oversight and misreported monitoring results.
- The more advanced use of AI involves handling larger amounts of data that may be confidential. Improper management of this data can lead to privacy and security breaches. The need for large amounts of data can lead to challenges in data management and storage.
- The implementation of more sophisticated AI tools requires specialised knowledge, training, and resources. Misinterpretation of AI results can lead to errors and higher costs.
- The use of AI in laboratories may come into conflict with existing legal and regulatory frameworks (e.g. in the fields of medicine, pharmacy, biomedicine, and food production).
- The introduction of AI can lead to changes in work processes, which can have an impact on employees. Some jobs may become redundant, while the need for new skills and knowledge will increase.
- AI systems may become the target of cyber-attacks, especially if they process sensitive data. A robust cyber security infrastructure is required to protect data and information systems.
- Integrating new AI systems into existing laboratory systems and protocols can be challenging, especially if the existing systems are outdated or incompatible with new technologies.

6 Conclusion

According to an analysis of megatrends in the global environment, the increased use of AI is predicted for practically all industries, so laboratory processes will be no exception. We conducted a study on the use of AI in testing laboratories in Slovenia and Croatia. We were interested in both the current situation and the predictions for the future. Most participants believe in the increased use of AI in the future and recognise many benefits such as the automation of routine tasks, faster and more accurate results and the reduction of human error. Nevertheless, testing laboratories in Slovenia and Croatia do not yet use AI tools very often. Practical examples were given for diagnostics, spectrum analyses, setting up and optimising measurement methods, finding solutions, clinical research, calculating theoretical results, evaluating digital records, coding, research, data processing of interlaboratory comparisons and creating reports. We have confirmed the expectation that testing laboratories that have more advanced measurement equipment are more inclined to use AI. As a result, these laboratories have a higher level of expertise and process more complex data. The scale and complexity of

measurement methods are influential factors in the adoption and implementation of AI technologies to improve measurements and optimise laboratory processes.

The main challenges in deploying AI are the lack of skilled personnel, high costs and technical limitations. This coincides with theoretical starting points that emphasize the need for continuous education, training and adaptation to new technologies to ensure a high level of quality and reliability in laboratory environments. The findings on the use of AI to improve laboratory processes and increase the accuracy and reliability of results confirm the importance of continuous development and introduction of new technologies, which is essential for progress in science, technology and industry. The study emphasises the potential for long-term savings and improved efficiency, which is important for the economic sustainability of laboratories. We believe that there will be more and more implementations of AI tools in test labs in the future. This will accelerate scientific research and development and improve the quality of laboratory activities.

The present research contributes to new approaches in analytical chemistry. This will enable more advanced tests and more accurate results in the future and contribute to a better quality of service. For organisations, the use of AI will bring many benefits, including the automation of routine tasks, faster data processing and cost control. Experience shows that AI enables better prediction of results and optimisation of processes, which is crucial in a competitive business environment. For the wider society, the study sheds light on the current state of AI use in laboratories in Slovenia and Croatia and identifies obstacles and opportunities for wider use of this technology. It emphasises the need for education and training of staff and the importance of technical solutions. Through the use of AI, laboratories will contribute to higher quality products, healthier food, better services, faster medical diagnoses, more effective treatments and general progress in various fields, which will have a direct positive impact on society. Increased efficiency, accuracy of work and automation of routine tasks with the help of AI will speed up processes and reduce the need for physical labour in the future.

The future of the use of AI in test labs is promising. As the technology evolves and integrates into laboratory processes, AI will play a key role in increasing efficiency, accuracy and innovation in scientific research and industry. However, ethical issues, data security, training, provision of technical equipment and regulatory requirements need to be considered to ensure responsible and safe use of this technology.

The survey included a limited group of testing laboratories in Slovenia and Croatia that perform partially or fully accredited activities according to SIST EN ISO/IEC 17025:2017 and could limit the generalization of the conclusions at the global level. The response rate of the laboratories was approximately 35%, which may limit the representativity of the sample. The participating laboratories have different equipment and use different methods of analysis. In the research, we did not verify the participants' experience and knowledge of AI; opinions and judgements about the use and impact of AI may be subjective.

To obtain more representative results, it would be good to extend the survey to a larger geographical area and include laboratories from different countries, regions and even more industries, compare approaches to AI and analyse the effects of cultural, economic and regulatory factors on the use of AI. For further research, it is useful to focus on determining the economic impact of using AI, on determining the effectiveness and reliability of measurements, and on studies that identify long-term research opportunities and the development of analytical methods using AI. As a suggestion for further research is a more in-depth analysis of the differences between laboratories with an investigation of which types of AI the respondents use.

We would like to thank all the laboratories from Slovenia and Croatia that participated in our research. Their contribution was crucial for the successful realisation of this study. Through their collaboration, they have contributed to a better understanding of the use of AI in laboratory environments, which will benefit both academia and industry.

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Povzetek:
Izzivi integracije umetne inteligence v preskuševalne laboratorije

Raziskovalno vprašanje (RV): Na kakšen način preskuševalni laboratoriji uporabljajo umetno inteligenco (UI) in s kakšnimi izzivi se pri tem srečujejo?
Namen: Raziskati uporabo UI v slovenskih in hrvaških preskuševalnih laboratorijih, preveriti vpliv kompleksnosti merilnih metod in merilne opreme ter predvideti trende na tem področju.
Metoda: Za raziskavo je bil razvit anketni vprašalnik. V raziskavo so bili povabljeni predstavniki 125 naključno izbranih preskuševalnih laboratorijev iz Slovenije in Hrvaške, ki izvajajo akreditacijsko dejavnost po SIST EN ISO/IEC 17025:2017. Poleg deskriptivne in frekvenčne

statistike sta bila za ovrednotenje podatkov uporabljena Kruskal-Wallis test in Mann-Whitney U test.
Rezultati: Odzvalo se je 44 laboratorijev. Raziskava je potrdila, da večina preskuševalnih laboratorijev pričakuje povečano uporabo orodij UI v prihodnosti, laboratorijsko osebje prepoznava prednosti v učinkovitosti, natančnosti in zmanjšanju napak. Vendar pa je uporaba UI v slovenskih in hrvaških laboratorijih še omejena, po mnenju sodelujočih zaradi pomanjkanja usposobljenega osebja, tehničnih omejitev in visokih začetnih stroškov. Laboratoriji z zahtevnejšo merilno opremo orodja UI dojemajo drugače kot tisti, ki s takšno opremo ne upravljajo. Izziv za bodoče je uporaba UI z namenom povečanja kakovosti storitev laboratorijev, za večjo učinkovitost, napredek in omejevanje stroškov.
Organizacija: Uporaba UI omogoča razvoj novih poslovnih modelov, ki temeljijo na avtomatizaciji in digitalizaciji laboratorijskih procesov. Raziskava omogoča organizacijam, da bolje razumejo in izkoristijo potencial UI.
Družba: Za družbo lahko raziskava prinese številne koristi, ki izboljšujejo kakovost življenja, spodbujajo gospodarski in tehnološki razvoj ter prispevajo k trajnostnemu razvoju in napredku družbe kot celote.
Originalnost: Obravnavano področje raziskav je v Sloveniji in na Hrvaškem neraziskano, tudi za mednarodno okolje so takšne konkretne raziskave še precej omejene.
Omejitve/nadaljnje raziskovanje: V raziskavo je bilo vključeno omejeno število slovenskih in hrvaških preskuševalnih laboratorijev, kar bi lahko omejilo posploševanje zaključkov na globalni ravni. Nadaljnje raziskave bi bilo zato smiselno izvesti na širšem geografskem področju. Tudi v ugotavljanje ekonomskih vplivov uporabe UI v laboratorijih, v ugotavljanje učinkovitosti in zanesljivosti meritev, v študije, kjer bi ugotavljali dolgoročne raziskovalne možnosti in razvoj analitičnih metod z uporabo UI, bolj poglobljeno analizo razlik med laboratoriji upoštevajoč pristope UI ter analizo kulturnih, gospodarskih in regulativnih dejavnikov na uporabo UI.

Ključne besede: umetna inteligenca, UI, preskuševalni laboratoriji, monitoring, izzivi, priložnosti.