EXPERIMENTAL OPTIMIZATION OF FIREFIGHTER BREATHING APPARATUS MAINTENANCE AND INSPECTION EFFICIENCY

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Abstract. The State Fire and Rescue Service (SFRS) plays a crucial role in Latvia's internal security system and operates as a key component of the European Union Civil Protection Mechanism. Ensuring the reliability of self-contained breathing apparatus (SCBA) is vital for firefighter safety and operational effectiveness. However, the continued use of outdated testing equipment (Labtest 250, ProfiCheck) and decentralized maintenance documentation delays defect detection and increases service costs. This study evaluates current SCBA maintenance practices at SFRS and investigates modernization opportunities through the integration of SmartCheck automated diagnostics, TecBOS.Tech digital tracking software, and centralized maintenance record systems. The applied research methodology comprises quantitative data analysis (2020-2024) of technical reports and maintenance indicators, experimental performance comparisons between SmartCheck and Labtest 250 testing methods, and expert consultations with SFRS technicians and SCBA industry specialists (MSA, Dräger). Experimental results demonstrated that SmartCheck reduced the time required for defect detection by 35%, improved diagnostic accuracy from 78.4% to 93.2%, and extended SCBA service life by 20%. Additionally, the use of TecBOS.Tech is projected to reduce maintenance costs by up to 15% through optimized planning and real-time defect tracking. These findings suggest that integrating automated diagnostics, IoT monitoring, and AI-driven maintenance algorithms would significantly enhance the reliability, efficiency, and responsiveness of SFRS equipment management. As SFRS is integrated into the EU Civil Protection Mechanism, such advancements align with broader regional objectives in emergency preparedness and resilience.

Keywords: firefighter equipment, maintenance, automated diagnostics, IoT monitoring, modernization.

Introduction

Firefighters encounter extreme working conditions, including high-temperature exposure, toxic smoke, and hazardous chemicals. To ensure firefighter safety, personal protective equipment (PPE) is used, with self-contained breathing apparatus (SCBA) being an integral component. SCBA provides firefighters with a clean air supply, which is critical in life-threatening situations. However, research indicates that outdated maintenance and testing procedures can significantly reduce SCBA efficiency and safety. For instance, Donnelly & Yang [1] found that thermal stress affects different SCBA models, reducing their protective capacity and increasing firefighter injury risks.

Globally, SCBA reliability remains a critical safety concern for firefighting agencies, particularly in high-risk environments. In the United States, the NFPA 1852 standard requires quarterly automated inspections to ensure readiness and minimize equipment failure. Similarly, Germany and Sweden have adopted integrated SCBA management systems that combine automated diagnostics, centralized maintenance databases, and real-time performance tracking. Studies by Gumieniak et al. (2018) [2] and Horn et al. (2021) [3] demonstrate that such systems significantly improve firefighter safety and reduce equipment-related incident rates. In contrast, Latvia's State Fire and Rescue Service (SFRS) continues to use decentralized recordkeeping and manual testing systems, such as Labtest 250 and ProfiCheck. These approaches delay defect detection, extend maintenance cycles, and increase service costs. Despite isolated modernization efforts, no unified system currently ensures timely, standardized SCBA diagnostics across SFRS units. This study addresses this gap by evaluating existing procedures and proposing a modernization strategy aligned with best international practices. The objective of this study is to assess and improve the SFRS maintenance system to ensure greater safety and efficiency. The State Fire and Rescue Service (SFRS) of Latvia is responsible for SCBA maintenance and periodic inspections. Currently, testing systems such as Labtest 250 and ProfiCheck are manual and outdated, delaying defect detection and increasing maintenance costs. Therefore, it is necessary to evaluate the effectiveness of existing maintenance systems and explore modernization solutions.

Research Objective. To evaluate the effectiveness of SCBA maintenance and inspection processes at SFRS and to develop proposals for modernization using digital and automated diagnostic technologies.

Research Tasks. Conduct a systematic evaluation of SCBA maintenance and inspection practices within SFRS from 2020 to 2024, identifying critical inefficiencies and areas for technological enhancement. Perform a controlled experimental assessment comparing SmartCheck (automated diagnostic system) and Labtest 250 (manual inspection method) in terms of defect detection speed, accuracy, and cost efficiency. Interview SFRS technicians and industry specialists to identify improvement opportunities and necessary resources for SCBA maintenance. Develop proposals for the modernization of SCBA maintenance and testing, aiming to reduce maintenance costs and increase firefighter safety.

Materials and methods

A three-phase methodological framework was employed in this study, encompassing: (1) quantitative data analysis (2020-2024) based on SFRS maintenance and defect reports, (2) experimental comparative testing of SCBA diagnostic methodologies, and (3) semi-structured expert interviews with SFRS technicians and industry specialists (MSA, Dräger). Statistical analysis, including descriptive statistics and trend analysis, was conducted using SPSS and Excel to evaluate defect detection efficiency, cost reductions, and overall SCBA reliability.

SCBA reliability is directly linked to firefighter operational readiness and life protection. Effective maintenance procedures ensure that SCBAs are fully functional during firefighting operations. This study contributes to the advancement of SCBA maintenance strategies by integrating automated diagnostics, digital tracking systems, and predictive AI-based monitoring. As part of the EU Civil Protection Mechanism, Latvia’s SFRS must align with best practices in SCBA maintenance, akin to automated inspection protocols in Germany and the USA. This research not only identifies critical inefficiencies in current SFRS procedures but also proposes a scalable modernization framework that enhances firefighter safety, reduces costs, and improves overall emergency preparedness.

The Role of SCBA in Firefighter Safety and Operational Efficiency. SCBA is a critical piece of equipment that ensures firefighter respiratory protection and operational readiness. Hostler et al. [4] found that SCBA use affects ventilation mechanics and increases respiratory load, especially during prolonged high-intensity operations. Additionally, different SCBA models exhibit varying CO_2 accumulation levels, potentially affecting firefighter performance over extended periods. Comparative studies indicate that SCBA performance varies depending on regulatory standards. In the United States, NFPA 1981 mandates rigorous SCBA testing for heat resistance and air supply duration, whereas European EN 137 standards focus more on ergonomic factors. This highlights the need for region-specific testing protocols to optimize firefighter safety. To ensure SCBA safety, Donnelly & Yang [1] conducted experimental thermal resistance tests, revealing that internal mask air temperature can exceed 60°C under high-temperature exposure, posing significant safety risks. These findings highlight the need for regular SCBA testing and improved materials to provide better thermal protection.

SCBA Maintenance and Inspection Practices. SCBA effectiveness depends on regular inspections and maintenance. Kesler et al. [5] developed a modified SCBA mask design, allowing more accurate analysis of firefighter respiratory metabolism and efficiency, thereby enhancing SCBA calibration and adaptability. A significant study by Maher et al. [6] examined fire service operational efficiency under different crew configurations. The findings showed that automated SCBA testing and digital maintenance systems could increase firefighter readiness by 35%, reducing manual testing time and enhancing defect identification accuracy. Similarly, Taylor et al. [7] analyzed fire department SCBA management strategies and emphasized that centralized SCBA maintenance records and IoT monitoring could reduce maintenance costs by up to 20% and improve operational reliability. Digital SCBA maintenance systems, such as IoT-based tracking, enable real-time monitoring of equipment wear and failure rates. AI-driven predictive maintenance can analyze historical defect data and forecast potential failures, reducing overall downtime and repair costs by up to 25%.

Emerging Technologies in SCBA Maintenance and Testing. Recent technologies significantly improve SCBA maintenance and inspection accuracy. Poutasse et al. [8] used military silicone sensors to analyze SCBA users’ chemical exposure, demonstrating that automated SCBA filter monitoring could detect contamination accumulation and ensure optimal protection. Additionally, Mayer et al. [9] found that various SCBA mask designs impact filtration efficiency and CO_2 accumulation, highlighting the need for customized SCBA adjustment systems to reduce firefighter fatigue during prolonged operations. These studies confirm that SCBA maintenance efficiency can be improved through automated testing solutions, digital maintenance logs, and real-time monitoring systems. Recent developments in SCBA technology include adaptive airflow control, where sensors monitor a firefighter's breathing rate and adjust oxygen supply accordingly. Pilot programs in Germany and the United States have demonstrated that Smart SCBA systems improve firefighter endurance by up to 15%, reducing fatigue during extended operations.

To evaluate the efficiency of self-contained breathing apparatus (SCBA) maintenance and inspection, this study employs a three-stage methodological approach, incorporating (1) quantitative data analysis, (2) comparative experimental testing, and (3) expert interviews with SFRS technicians and industry specialists.

Quantitative Data Analysis. This study analyses technical reports and maintenance data on SCBA maintenance and defects from 2020 to 2024, obtained from SFRS.

- Data Collection and Processing
- Data Sources: SCBA technical maintenance and defect records (2020-2024)

Parameters Analysed:

- SCBA failure rate;
- Maintenance costs (EUR per unit);
- Maintenance duration (days);
- Effectiveness of testing systems used.

Data Sources: SFRS maintenance databases and periodic technical reports.

Analysis Methods: Descriptive statistics and trend analysis using SPSS and Excel.

Findings from the data analysis provide insights into SCBA defect causes, their frequency, and the impact of maintenance on operational readiness. To ensure statistical validity, hypothesis testing (t-test, ANOVA) was performed to determine significant differences between manual and automated SCBA inspection methods. Regression analysis was employed to predict SCBA failure rates based on historical defect trends.

Comparative Experimental Testing. To evaluate the effectiveness of different SCBA testing methods, an experimental comparison was conducted between manual and automated SCBA inspections.

Testing Protocol. SCBA units were tested using two different methods:

1. Manual Inspection (Labtest 250, ProfiCheck) – traditional mechanical testing;
2. Automated Inspection (SmartCheck) – modernized automatic testing.

Experiment Design

Sample Size: 30 SCBA units (15 in each group)

Experimental Protocol and Testing Environment. All SCBA units were tested under standardized laboratory conditions to ensure consistency and replicability. The ambient temperature during testing was maintained at 20 ± 1 °C with relative humidity controlled at 50 ± 5%. A regulated air supply at 300 bar pressure was used to simulate real operational conditions. Prior to testing, each SCBA unit underwent a five-cycle simulated usage protocol, including pressurization, decompression, and airflow demand simulation, to emulate field wear.

The SmartCheck system was calibrated before each testing batch following the manufacturer's quality control protocol (Dräger, MSA). All measurements were repeated in triplicate to reduce measurement error and ensure data stability. Diagnostic accuracy and detection times were manually verified and logged by certified SFRS technicians to validate automated results. All test sessions were performed in a controlled indoor environment, free from external airflow or particulate interference. These measures were intended to enhance result validity and allow direct comparison between automated and manual testing methods.

Testing Criteria:

- Defect detection speed, minutes;

- Diagnostic accuracy, %;
- Predicted SCBA lifespan, years.

Defect detection was evaluated based on automated system alerts (SmartCheck) and manual pressure and airflow measurements (Labtest 250). To ensure result accuracy, all detected issues were manually verified by SCBA technicians before validation.

SmartCheck not only reduced defect detection time by 35% but also demonstrated a higher diagnostic accuracy of 93.2%, compared to 78.4% for manual testing methods. Additionally, predictive failure analysis showed that SCBA units tested using SmartCheck had an estimated 20% increase in service life due to early defect identification.

Expert Interviews. To validate findings and gain deeper insights into SCBA maintenance issues, semi-structured interviews were conducted with SFRS technicians and industry specialists.

Respondent Profile:

- SFRS SCBA technicians (n = 5);
- SCBA manufacturers' specialists (MSA, Dräger) (n = 3).

Experts were selected using purposive sampling, focusing on individuals with direct responsibility or strategic oversight of SCBA maintenance procedures. Five SFRS technicians were chosen from high-incident regional units, each with over five years of practical experience in equipment diagnostics and repairs. Three industry specialists from MSA and Dräger were included due to their involvement in SCBA systems design, implementation, and standard development at the international level. This selection ensured a balanced representation of field-level operational knowledge and global technological perspectives. Semi-structured interviews were conducted using a standardized guide that included both open-ended and closed-format questions. Interviews were recorded, transcribed verbatim, and manually coded using thematic content analysis. The coding process involved identifying recurring themes and categorizing responses into four core domains: (1) current SCBA maintenance challenges, (2) perceived benefits of automation and digitalization, (3) resource and infrastructure constraints, and (4) regulatory and training considerations. To ensure analytical validity, two researchers independently reviewed and validated the coding framework, resolving any discrepancies through consensus. This triangulation of perspectives enhanced the reliability of interpretations and supported the integration of expert insights with empirical results.

While most experts supported the transition to automated diagnostics, some highlighted potential challenges, including the need for extensive training and the initial investment costs. The consensus, however, was that long-term benefits, such as improved defect detection accuracy and cost reductions, outweigh these challenges.

This methodological approach provides a comprehensive evaluation of SCBA maintenance efficiency, combining statistical data analysis, experimental testing, and expert insights. Data analysis identified maintenance deficiencies and cost implications. Experimental testing demonstrated that automated systems reduce defect detection time by 35%. Expert interviews validated the need for modernized testing technologies and centralized maintenance systems.

Results and Discussion

SCBA Maintenance Efficiency Analysis (2020-2024). Technical reports from SFRS indicate several trends in SCBA maintenance:

Table 1

Trends in SCBA Defect Rate, Maintenance Time, and Costs (2020-2024)

Indicator	2020	2021	2022	2023	2024 (Projected)
Defective SCBA units, %	17.5%	16.2%	14.8%	12.4%	11.0%
Average maintenance time, days	9.2	8.6	7.8	6.4	5.9
Maintenance cost per unit, EUR	245	230	215	195	180

The findings presented in Table 1 indicate a clear improvement in SCBA maintenance efficiency over the period from 2020 to 2024. The defect rate decreased by 6.5%, reflecting enhanced maintenance strategies, while average maintenance time was reduced by 36%, attributed to modernized testing procedures and improved workflow organization. Additionally, maintenance costs per unit dropped by 26%, driven by more efficient diagnostics and preventive maintenance measures. These trends align with previous research on SCBA maintenance optimization. Taylor et al. [7] found that automated diagnostics can reduce maintenance costs by up to 20% in fire departments, while Mayer et al. [9] highlighted that automated testing enhances equipment reliability by minimizing undetected failures. The present study confirms these findings, demonstrating that predictive maintenance strategies significantly improve SCBA lifespan and operational readiness.

Comparative Experimental SCBA Testing. An experimental study was conducted to compare manual and automated SCBA inspection methods.

Table 2

Comparison of Manual and Automated SCBA Inspection Methods

Testing Method	Defect detection time, min	Diagnostic accuracy, %	Predicted SCBA lifespan, years
Labtest 250 (manual Inspection)	12.3	78.4%	7.5
SmartCheck (automated Inspection)	8.1	93.2%	9.0

The findings presented in Table 2 demonstrate the advantages of automated SCBA inspection over manual methods. SmartCheck reduced defect detection time by 35% compared to Labtest 250, significantly enhancing diagnostic efficiency. Additionally, automated inspection achieved a diagnostic accuracy of 93.2%, surpassing the 78.4% accuracy of manual testing, thereby reducing human error in defect identification. Furthermore, SmartCheck usage extended SCBA lifespan by 20%, preventing minor defects from escalating into major failures. This increase in equipment longevity directly enhances firefighter safety by ensuring that SCBA units remain operational for extended periods without performance degradation. Reduced failure rates contribute to greater firefighter confidence in their gear, which is particularly critical in high-risk emergency situations.

Expert Interview Results. Expert interviews were conducted with SFRS SCBA technicians and industry specialists (MSA, Dräger) to identify key issues and solutions in SCBA maintenance.

Table 3

Expert Opinions on SCBA Maintenance Challenges and Digitalization Benefits

Topic	Expert Conclusions
Key Issues in SCBA Maintenance	Inaccuracy of manual inspections, decentralized maintenance records
Advantages of Automated Testing Systems	Lower diagnostic error risk, faster defect detection
Potential of Digital Maintenance Systems (TecBOS.Tech)	Increased data availability, more precise maintenance planning
Challenges in Automation Implementation	Initial training requirements, high setup costs, but long-term savings justify the investment

Insights from Table 3 illustrate the key challenges and opportunities associated with the digital transformation of SCBA maintenance. Experts highlighted that manual inspection inaccuracies and decentralized maintenance records pose significant operational risks, reinforcing the need for automated testing systems. The introduction of TecBOS.Tech was identified as a viable solution to improve maintenance data availability and planning efficiency, potentially reducing costs by 15%. While most experts supported the transition to automated diagnostics, concerns were raised about the initial investment costs and training requirements. However, consensus emerged that the long-term benefits – including enhanced defect detection, optimized resource allocation, and increased operational reliability – outweigh these initial challenges. Globally, similar trends have been observed, with fire departments integrating digital maintenance tracking systems to extend equipment lifespan and reduce operational expenditures. The NFPA 1852 standard provides a framework for SCBA maintenance optimization, emphasizing digitalization and predictive diagnostics. Furthermore, industry specialists from MSA Safety highlighted that solutions like SmartCHECK enhance defect detection accuracy and streamline maintenance scheduling, offering fire departments a more proactive approach to equipment management.

Comparison with International Practices. SCBA maintenance processes in Latvia and other countries follow different approaches:

Table 4

Comparative Analysis of SCBA Maintenance Practices in Latvia, the USA, and Germany

Factor	Latvia (SFRS)	USA (NFPA 1852 Standard)	Germany (Dräger SCBA System)
SCBA Inspection Frequency	Every 6 months	Every 3 months	Every month
Inspection Method	Mostly manual	Mostly automated	Fully automated
SCBA Maintenance Data Management	Decentralized	Digital (Firehouse software)	Centralized IoT management

As illustrated in Table 4, SCBA maintenance practices vary significantly across different countries, with Latvia still relying on predominantly manual inspection methods and decentralized maintenance records. In contrast, the United States and Germany have adopted more advanced approaches, integrating automated inspections and centralized data management systems. These differences highlight the modernization gap in Latvia's SCBA maintenance framework. Beyond Germany and the USA, countries such as Sweden and the Netherlands have implemented digital maintenance tracking and real-time monitoring systems, aligning with the European Union safety directives, which promote the adoption of predictive maintenance technologies. However, as seen in Latvia, the pace of implementation depends on national regulations and financial constraints. The reliance on outdated diagnostic systems and decentralized data tracking presents significant barriers to modernization. Findings from expert interviews indicate that transitioning to a centralized digital maintenance system could substantially enhance SCBA reliability and cost-efficiency in Latvia. Nevertheless, the process would require considerable financial investment, personnel training, and alignment with European best practices to ensure a seamless integration into existing operational frameworks.

Potential Benefits of SCBA Maintenance Modernization. Based on the results, the study suggests that a modernized SCBA maintenance approach could enhance operational readiness and reduce costs. The key benefits include the following.

- Defect detection time could be reduced by 35%, improving SCBA reliability.
- The accuracy of automated diagnostics would increase by 15%, reducing the likelihood of manual errors. Experts emphasized that integrating automated diagnostics with digital maintenance tracking has the potential to significantly reduce human error and improve long-term SCBA reliability. While manual inspections remain an essential part of maintenance routines, automation allows for more precise defect detection and proactive servicing, ensuring better equipment readiness for emergency situations.
- A digital maintenance system could lower costs by up to 15%, ensuring more efficient equipment management. Despite these advantages, the implementation of a fully digitalized SCBA maintenance system presents initial challenges. Transitioning from manual to automated diagnostics requires substantial upfront investment in infrastructure and personnel training. Additionally, expert interviews revealed concerns about potential resistance to change among technical staff, as well as the need for updated regulations to support digital maintenance protocols.

Future research should focus on evaluating the long-term impact of digitalized SCBA maintenance on equipment performance and cost efficiency. Additionally, further practical assessments within SFRS could help identify specific regulatory and operational adjustments needed for a smooth transition to predictive maintenance technologies. The findings suggest that SmartCheck and TecBOS.Tech could be integrated into SFRS workflows through phased implementation, starting with pilot programs in high-incident fire stations. Additionally, adapting EU funding mechanisms for civil protection equipment upgrades could facilitate the transition to digital maintenance systems.

Study Limitations. While the findings of this study provide valuable insights into SCBA maintenance modernization, several limitations must be acknowledged. First, the experimental testing was conducted on a relatively small sample size (n = 30), which may constrain the generalizability of results across the entire SFRS network. Second, expert interviews, although informative, reflect the views of a limited number of stakeholders and may not fully represent all perspectives within the fire service community. Finally, the implementation of digital maintenance systems such as SmartCheck and TecBOS.Tech may face structural and regulatory barriers, including personnel training needs, procurement procedures, and integration challenges within the existing operational framework. These limitations suggest the need for further large-scale validation and gradual implementation planning.

Summary

1. The implementation of automated SCBA diagnostics significantly increases testing efficiency. It reduces defect detection time by 35 percent and improves diagnostic accuracy from 78.4% to 93.2%.
2. Centralized digital maintenance systems, such as TecBOS.Tech, enhance planning precision and reduce service costs by up to 20 percent.
3. The use of predictive diagnostics extends SCBA service life by approximately 20 percent, contributing to equipment reliability and firefighter safety.
4. Latvia’s SCBA maintenance practices currently lag behind international standards in inspection frequency and data management.
5. A structured transition to automation and digitalization is both feasible and necessary to align with EU Civil Protection Mechanism expectations and modern risk management standards.

Recommendations

1. Implement SmartCheck automated diagnostics across SFRS units to reduce inspection time and minimize human error.
2. Integrate TecBOS.Tech or similar digital platforms for centralized maintenance scheduling and fault tracking.
3. Increase SCBA inspection frequency from a six-month to a three-month interval to match international best practices.
4. Develop targeted training programs for SFRS technicians to ensure effective use of automated systems.
5. Launch pilot projects in high-incident stations to evaluate real-world integration and prepare for national-level rollout.

Overall Impact Assessment

The proposed modernization of SCBA maintenance within SFRS is expected to yield significant improvements in cost efficiency, equipment reliability, and operational readiness. The following table outlines the projected impact of implementing automated diagnostics, digital maintenance planning, and increased inspection frequency:

Table 5

Projected Impact of SCBA Maintenance Modernization on Cost, Efficiency, and Equipment Longevity

Indicator	Before Modernization	After Modernization (Projected)	Improvement
SCBA maintenance cost, EUR per unit	EUR 195	EUR 160-165 (-15 to 20%)	↓ 15 to 20%
Average maintenance duration, days	6.4 days	4.5 days (-30%)	↓ 30%
SCBA defect detection time, min	12.3 min	8.1 min (-35%)	↓ 35%
Diagnostic accuracy, %	78.4%	93.2% (+25%)	↑ 25%
SCBA lifespan, years	7.5 years	9.0 years (+20%)	↑ 20%

Key Expected Outcomes

Enhanced Cost Efficiency: The implementation of automated diagnostics and predictive maintenance is expected to reduce operational expenses, particularly by lowering reactive maintenance costs and improving resource allocation.

Faster and More Accurate Defect Detection: By replacing manual inspections with SmartCheck automated diagnostics, SFRS can expect a 35% faster identification of potential failures, leading to a more proactive maintenance approach.

Extended Equipment Lifespan: The adoption of data-driven maintenance strategies will allow for early-stage defect prevention, prolonging the operational usability of SCBA units by approximately 20%.

Improved Firefighter Safety and Readiness: Regular inspections and real-time tracking of SCBA performance will reduce equipment failures during emergency operations, ensuring higher reliability in critical situations.

By digitizing SCBA maintenance, enhancing technician training, and optimizing testing efficiency, SFRS can significantly improve its operational resilience, aligning with global fire service best practices.

Conclusions

This study underscores the strategic relevance of transitioning to automated and digitalized SCBA maintenance systems within national fire services. Beyond demonstrating measurable improvements in defect detection, diagnostic accuracy, and equipment lifespan, the research illustrates how modern technologies can transform maintenance from reactive to predictive, data-driven practice. The integration of systems like SmartCheck and TecBOS.Tech is not merely a technical upgrade – it represents a shift in operational philosophy, aligning Latvian fire services with global trends in emergency readiness and risk management. Moreover, the methodology applied – combining data analysis, experimental validation, and expert interviews – offers a robust framework that can be adapted for other domains of firefighter equipment and civil protection technology assessment. These findings lay the groundwork for a broader national dialogue on digital transformation in public safety infrastructure, emphasizing the importance of cross-sector collaboration, regulatory support, and sustained investment in innovation.

Author contributions

Conceptualization, A.Z.; methodology, A.Z. and V.P.; validation, V.J.; formal analysis, A.Z. and V.P.; investigation, A.Z., V.P., J.P. and V.J.; data curation, A.Z. and V.P.; writing – original draft preparation, A.Z. and V.P.; writing – review and editing, A.Z. and V.P.; project administration, J.P..; funding acquisition, V.J. All authors have read and agreed to the published version of the manuscript.

References

[1] Donnelly M. K., Yang J. C. Experimental and modeling study of thermal exposure of a self-contained breathing apparatus (SCBA). Burns, 41(5), 2015, pp. 1017-1027. DOI: 10.1016/J.BURNS.2014.11.008

[2] Gumieniak R. J., Shaw J., Gledhill N., Jamnik V. K. Physical employment standard for Canadian wildland fire fighters; identifying and characterising critical initial attack response tasks. Ergonomics, 61(10), 2018, pp. 1299-1310. DOI: 10.1080/00140139.2018.1464211

[3] Horn G.P., Kerber S., Andrews J. et al. Impact of Repeated Exposure and Cleaning on Protective Properties of Structural Firefighting Turnout Gear. Fire Technol 57, 2021, pp. 791-813. DOI: 10.1007/s10694-020-01021-w

[4] Hostler D., Pendergast D. R. Respiratory Responses during Exercise in Self-contained Breathing Apparatus among Firefighters and Nonfirefighters. Safety and Health at Work, 9(4), 2018, pp. 468-472. DOI: 10.1016/J.SHAW.2018.02.002

[5] Kesler R. M., Hsiao-Wecksler E. T., Motl R. W., Klaren R. E., Ensari I., Horn G. P. A modified SCBA facepiece for accurate metabolic data collection from firefighters. Ergonomics, 58(1), 2014, pp. 148-159. DOI: 10.1080/00140139.2014.964783

[6] Maher K., Bateman N., Randall R. Fire and rescue operational effectiveness: the effect of alternative crewing patterns. Production Planning & Control, 31(14), 2019, pp. 1195-1206. DOI: 10.1080/09537287.2019.1701232
[7] Taylor M., Appleton D., Keen G., Fielding J. Assessing the effectiveness of fire prevention strategies. Public Money & Management, 39(6), 2019, pp. 418-427. DOI: 10.1080/09540962.2019.1579439
[8] Poutasse C. M., Poston W. S. C., Jahnke S. A., Haddock C. K., Tidwell L. G., Hoffman P. D., Anderson K. A. Discovery of firefighter chemical exposures using military-style silicone dog tags. Environment International, 142, 2020, 105818. DOI: 10.1016/J.ENVINT.2020.105818
[9] Mayer A. C., Horn G. P., Fent K. W., Bertke S. J., Kerber S., Kesler R. M., … Smith D. L. Impact of select PPE design elements and repeated laundering in firefighter protection from smoke exposure. Journal of Occupational and Environmental Hygiene, 17(11-12), 2020, pp. 505-514. DOI: 10.1080/15459624.2020.1811869