SOLUTIONS FOR REDUCING (MINIMIZING) FIREFIGHTING TRUCK REPAIRS IN EU COUNTRIES AND IN LATVIA IN PARTICULAR

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Abstract. This research project aims to develop innovative approaches, reducing firefighting truck repairs in the EU countries, focusing on Latvian State Fire and Rescue Service (hereinafter - SFRS). The study comprehensively analyses existing maintenance, repair, and training procedures to identify potential optimization strategies. Employing both qualitative and quantitative methods, the research meticulously evaluates the efficiency of current procedures in maintaining and repairing fire engines, providing a thorough and holistic understanding of existing processes, potential issues, and overall efficiency. Additionally, the study conducts an in-depth analysis of technological innovations to identify and evaluate the potential benefits of improved diagnostic systems, materials, and other technological approaches that could minimize the need for repairs. This aspect includes a comprehensive economic analysis to assess the cost-benefit ratio associated with implementing these innovations. The obtained results offer not only a detailed understanding of existing problems but also propose comprehensive solutions for minimizing fire truck repairs. This valuable information serves as a foundational basis for future improvements in both academic and practical realms, thereby enhancing the safety and efficiency of the fire service in Latvia and other EU countries. This extensive and in-depth research contributes significantly to advancing the field, fostering a proactive and innovative approach to firefighting truck maintenance and repair, ultimately improving the overall effectiveness and resilience of fire services within the European Union. In conclusion, the findings underscore the paramount importance of sustained innovation for the continuous enhancement of firefighting operations and ensuring the safety of communities.

Keywords: fire safety, SFRS, rescue machinery, fire truck, fire-fighting vehicle, engines.

Introduction

Newly developed concepts of security and risk management, hereafter collectively referred to as New Security Paradigms (NSPs), have challenged established practices and invite stakeholders to view their roles and security initiatives from different angles [1].

The concept of New Security Paradigms (NSP) has challenged established practices and called for a re-evaluation of roles and security initiatives from different perspectives [2]. These paradigms have introduced competing explanations and causal relationships for safety culture, emphasizing the need to balance various tensions, competing demands and irresolvable dichotomies [3]. The introduction of new security paradigms has prompted rethinking of security management tools and their impact on resilience, supporting a proactive risk-based approach to prevent or control risks before they cause harm [4]. The transition to new security paradigms has emphasized the importance of traceability in the development of safety-critical software, emphasizing the need to ensure traceability from requirements to implementation in such systems [5].

While it is recognized that organizations are almost always under-resourced, it is assumed that these same organizations will find the necessary resources to effectively and sustainably implement all the changes and additions supported by each NSP, several of which indicate the need for extensive organizational reconfiguration and restructuring [1].

Traditional security management tools have been criticized for focusing on operational constraints. However, [4] argues that despite the fact that these tools emphasize limiting activities, they have a positive effect on the overall adaptability of the system. They discuss the impact of security management tools on resilience and highlight the lack of descriptions of new security management tools or recommendations for modifying existing tools based on the principles of the Resilience Engineering paradigm. In addition, [6] highlights the importance of security management tools in constructing and developing security arguments, further supporting the idea that traditional security management tools contribute positively to system adaptability. The above references provide evidence that challenges common criticisms of traditional security management tools and highlights their positive impact on overall system adaptability.

The concept of security includes various dimensions, and its definition has been the subject of scholarly debate. Baldwin [7] highlights the limited attention paid to conceptual issues in security research, stressing the need for a comprehensive understanding of the term. The authors in [8] delve into the contextual aspect of security by asking how to distinguish when a situation is about security. The authors emphasize the complexity of defining security and the need to take into account different perspectives, epistemological criticisms and contextual interpretations in the understanding of the concept and provide an insight into the multifaceted nature of security.

For example, vehicles and vehicle repair and maintenance play a crucial role in ensuring national road safety. The quality of technical maintenance and repair directly affects the safety and efficiency of road vehicles [9]. The complexity of modern vehicle designs and the introduction of new maintenance strategies and diagnostic methods make it necessary to improve maintenance and repair systems [10]. Brake defects, including brake misadjustment, are a major factor in crashes and can significantly affect the overall braking performance of vehicles [11]. Implementation of better safety maintenance strategies and technologies can improve vehicle safety [12]. In addition, the use of safety devices and diagnostic terminals can improve the efficiency of maintenance and repair systems [13].

Evolutionary algorithms face several challenges in fleet maintenance planning. One of the challenges is the heterogeneity of the fleet, which consists of different types of vehicles with different characteristics and usage patterns [14], such as electric vehicles with limited driving range and charging infrastructure [15]. Another challenge is the lack of data on newly added vehicles, which makes it difficult to accurately predict their maintenance needs [16] and optimize maintenance schedules based on the predicted damage distribution of vehicle components [16]. In addition, the complexity of the problem requires the use of specialized multi-objective evolutionary algorithms, such as the diversity indicator-based multi-objective evolutionary algorithm (DI-MOEA) [17]. The goal of these algorithms is to generate solutions in the waypoint region where there are balanced trade-offs between conflicting objectives [18]. In addition, the optimization process must consider real-world constraints such as customer time windows and limited charging station capacities [19]. In general, challenges in using evolutionary algorithms for fleet maintenance planning are related to addressing the unique characteristics of different vehicle types, optimizing maintenance schedules based on damage distribution, and considering real-world constraints.

The aim of the research project is to develop innovative approaches to reduce the need for fire truck repairs in the EU countries, in the context of the Latvian SFRS situation.

The research used an analytical approach that includes both qualitative and quantitative methods.

In the course of the research, an analysis of the report data of CTIF - the International Association of Fire & Rescue Services World Fire Statistics Center for the year 2021, which has been published in 2023, has been performed. After a careful selection of data, an analysis of statistical data on 27 whales has been carried out, which provides a broad representation of the research scene, providing information on the researched topic. Quantitative data have been critically evaluated based on the collected data.

This study has used both Scopus and Web of Science databases, after careful data extraction records that provide information on the researched topic were selected.

In general, the study included not only quantitative data, but also qualitative and content aspects.

Data analysis

Research in the field of fire truck transport has become a major focus of academic and industry attention, and this interest has been growing over the years. In the last five years, the number of articles published in this field has experienced a significant increase, which indicates a rapid development and intensive research work devoted to improving the efficiency and safety of firefighting transport. Research has been carried out in various scientific fields, including engineering, environmental sciences and technology, proving the diversity of researcher interests and cross-border cooperation. According to the analyzed data, it becomes clear that most of the publications that were selected for this study are related to engineering.

At the beginning of the analysis, the data on the number of inhabitants in each country, which is reflected in Figure 1, has been analyzed.

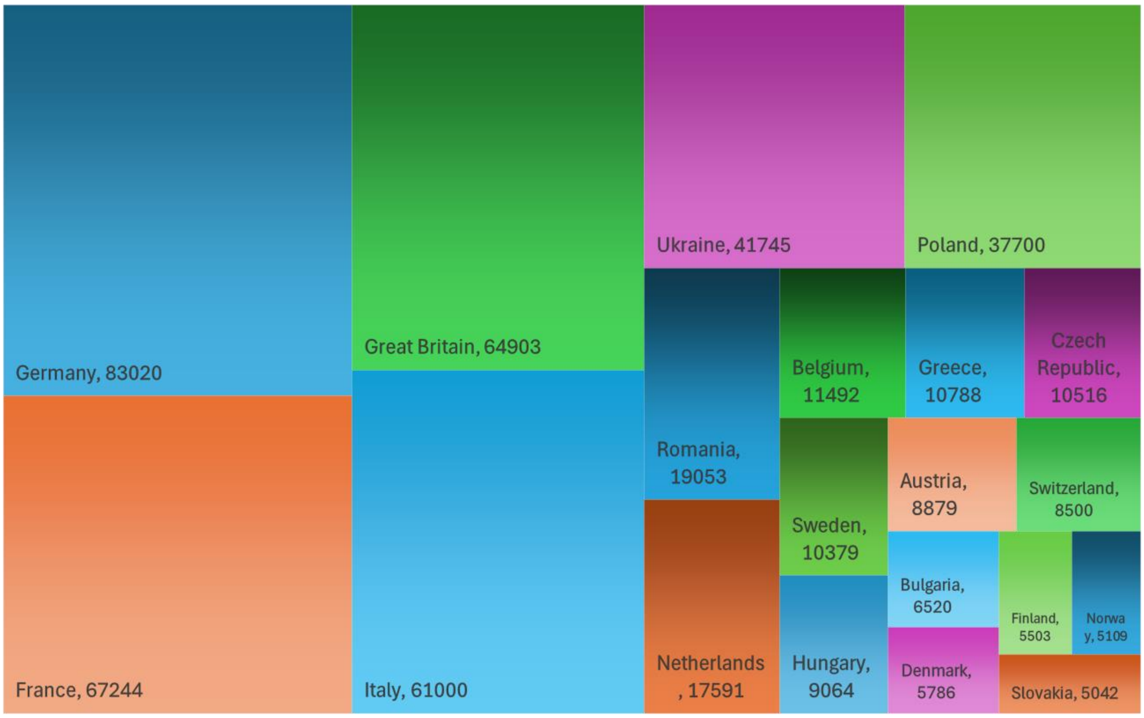

Fig. 1. **Number of inhabitants in the countries according to CTIF data**

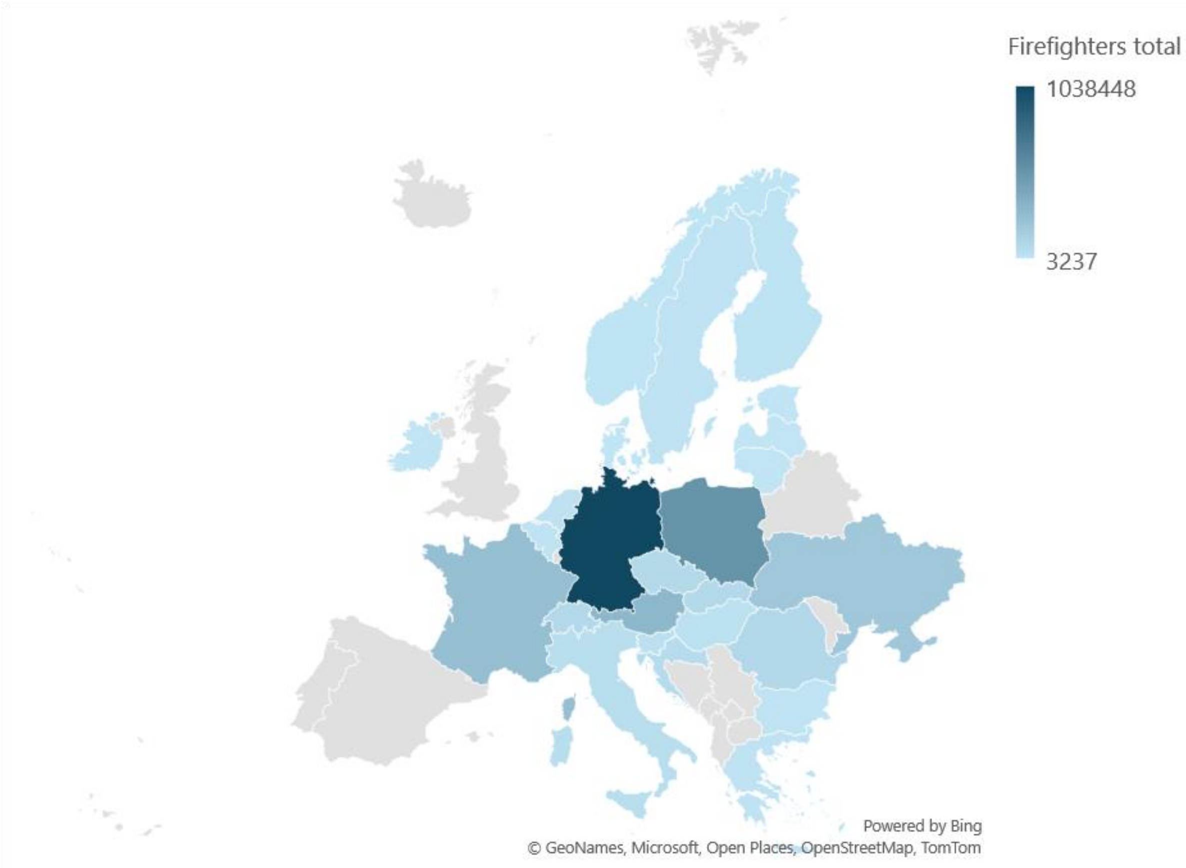

Fig. 2. **Number of firefighters in the countries according to CTIF data**

Figure 2 graphically represents CTIF statistical data on the total number of firefighters in each of the analyzed countries, this is an essential aspect of the analysis that helps understand the situation as a whole. On the other hand, Figure 3 shows the data on the number of fire stations in each of the districts.

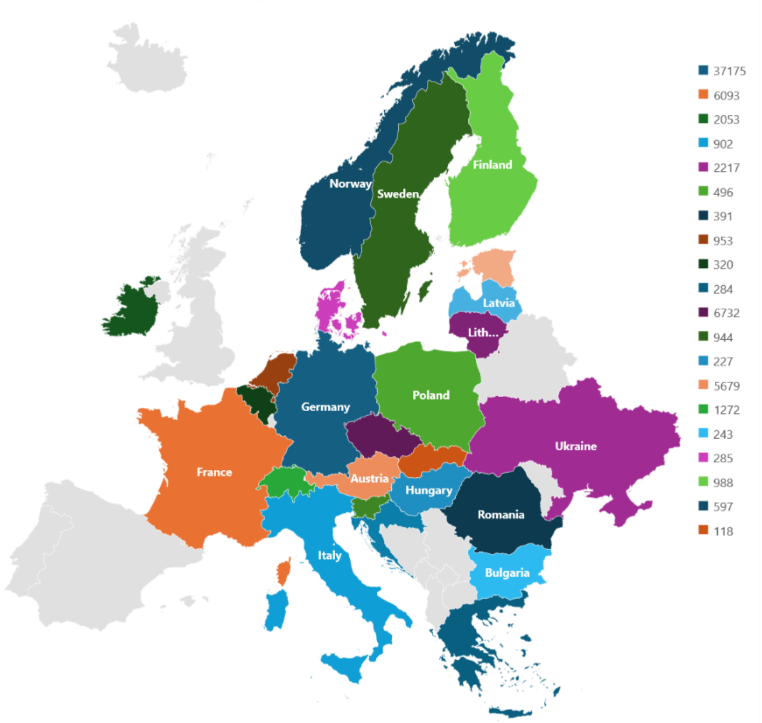

Fig. 3. **Number of fire stations in the countries according to CTIF data**

Analyzing firefighting resources based on CTIF statistics, it was found that Germany has the largest population (83 020 thousand) and the number of calls per year (4 279 393). The highest number of fire stations (37 175), fire trucks (41 064) and firefighters (1 038 448) among the countries is included in the analysis.

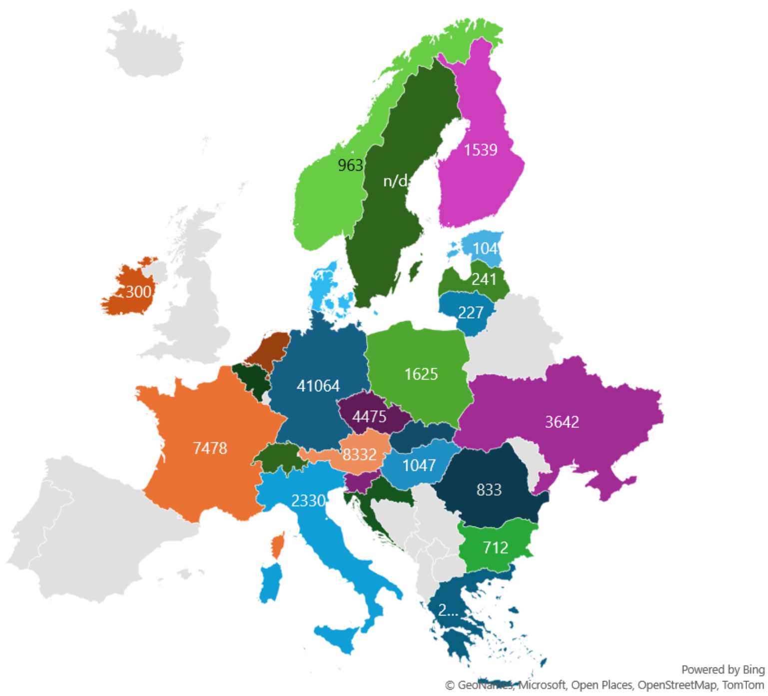

Fig. 4. **Number of fire trucks in the countries according to CTIF data**

The most important aspect of the research analysis is the number of tank trucks in the countries (Fig. 4) and the total number of calls in the countries (Fig. 5), which allows to calculate the hypothetical average arithmetic load for one tank truck and perform a comparative analysis (Fig. 6).

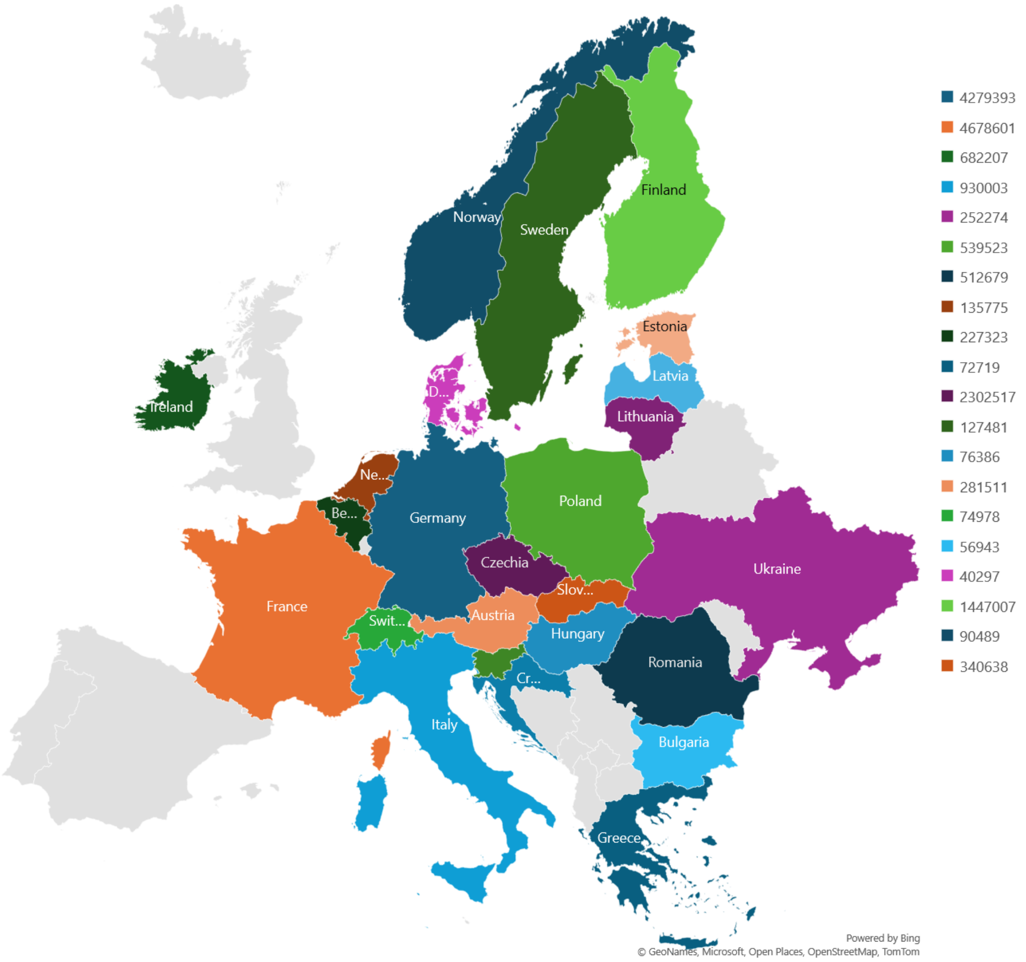

Fig. 5. **Number of calls in countries according to CTIF data**

The visual reflection of the obtained calculation data showed a rather significant difference between the possible workload for one tank truck in each country, ranging from 13,3 calls in Croatia to 970,5 calls in Slovakia. In Latvia, this hypothetical number of calls per tank truck, which the authors of the study have chosen as a parameter to determine the wear and tear of tank trucks based on their load, is 83,7 calls per tank truck, while in Germany it is 104,2 calls per tank truck.

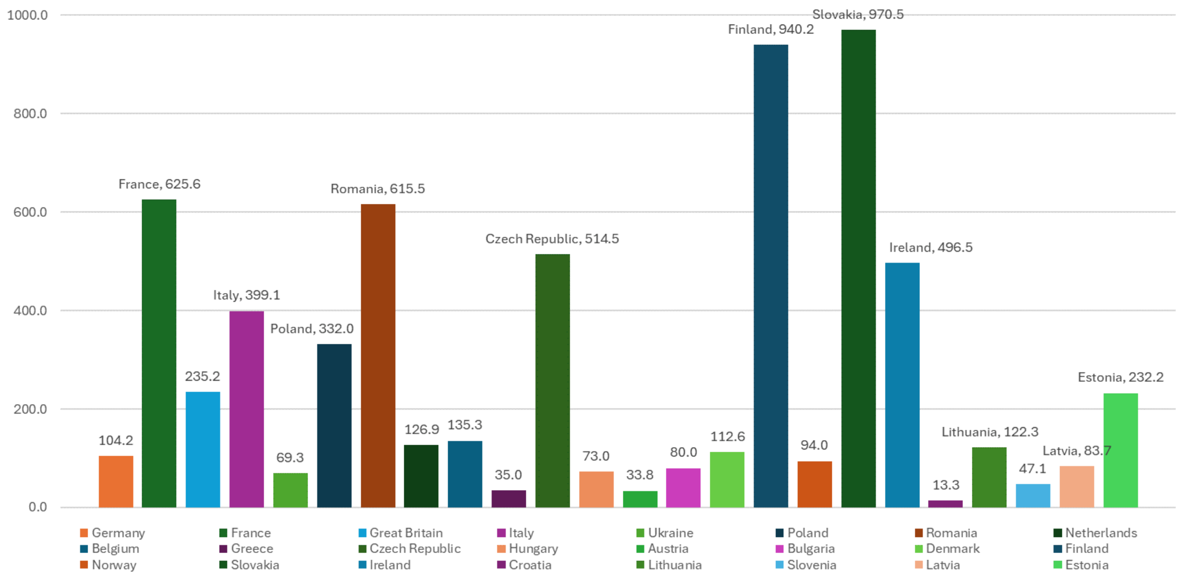

Fig. 6. **Hypothetical number of calls per fire truck, CTIF data**

To analyze the number of repairs and technical maintenance of fire tankers of the Latvian State Fire and Rescue Service (SFRS), the authors of the study summarized the number of repairs and technical maintenance carried out in a two-year period - 2022 and 2023 (Table 1).

Table 1

Repairs and maintenance in 2022-2023, SFRS data

Year	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**	**Total**
2022	46	57	64	95	66	59	57	55	29	78	65	51	**722**
2023	54	42	85	87	46	55	50	0	51	112	57	37	**676**

In the graph, which has been built based on the collected data, you can see a significant increase in the number of repairs and maintenance between spring and autumn. In August 2023, the repair works were not carried out due to insufficient funding.

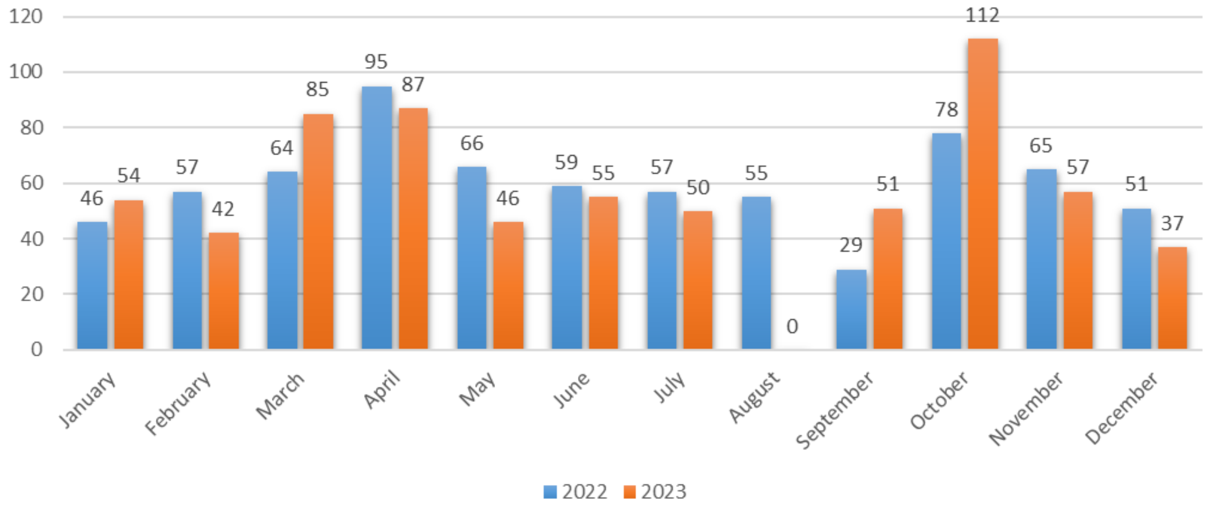

Fig. 7. **Repairs and maintenance in 2022-2023, SFRS data [23]**

A significant increase in the number of tank truck repairs and maintenance in the middle of spring and autumn can be justified both by the planned seasonal maintenance of tank trucks received in the fall and by the increase in the number of seasonal calls in spring.

Table 2

Warranty repairs and maintenance in 2022, SFRS data [23]

2022	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**	**Total**
Fire truck IVECO FF150	9	10	18	18	12	10	8	20	9	24	12	10	**160**
Fire truck MAN TGS	2	3	4	1	3	0	1	1	0	1	1	0	**17**

Warranty repairs are carried out as needed and their number did not differ significantly over the years. A sudden increase in the number of warranty repairs indicates the processes of eliminating uniform defects of the new equipment.

During the active operation of fire trucks, deficiencies appear in a shorter period of time, while if the operation of a fire truck is lower, then the same deficiencies appear after time. The authors recommend, as far as possible, to choose deployment locations for warranty fire trucks with a large number of calls, as well as to ensure the redeployment of fire trucks, taking into account their involvement in active events. Some of the warranty repairs are related to errors made by the human factor, so personnel training must be provided in full and in accordance with the requirements and recommendations of the fire truck manufacturers.

Table 3

Warranty repairs and maintenance in 2023, SFRS data [23]

2023	January	February	March	April	May	June	July	August	September	October	November	December	Total
Fire truck IVECO FF150	19	26	21	12	12	12	14	-	12	14	3	16	161
Fire truck MAN TGS	0	2	14	6	1	1	0	-	1	1	3	0	29
Fire truck Scania P370	-	-	-	-	-	-	-	-	-	-	0	1	1
Fire truck MB Unimog	0	4	4	1	7	10	2	-	4	7	6	1	46

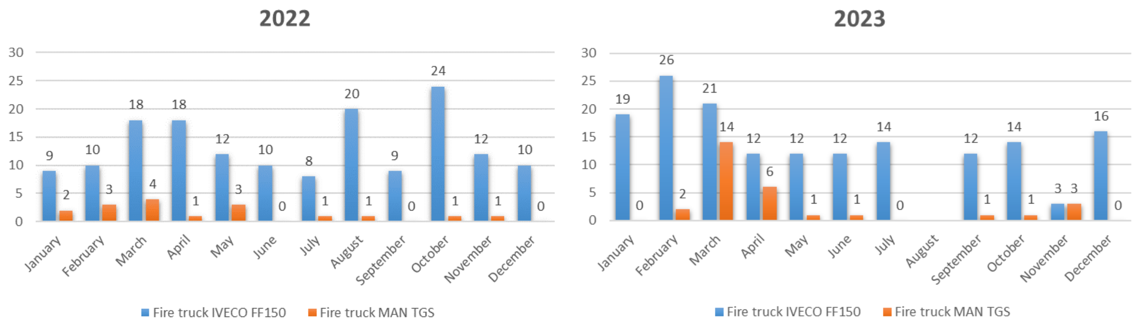

Fig. 8. **Warranty repairs and maintenance in 2022-2023, SFRS data [23]**

Of particular importance for ensuring sustainable operation of fire trucks and reducing repairs is the provision of high-quality technical maintenance of fire trucks in full at the start of operation of the fire truck, as part of the repairs are related to untimely detection of problems. High-quality technical maintenance cannot be ensured if the responsible technical staff is not properly trained and certified. By implementing comprehensive instructions for personnel, for technical maintenance, and by using appropriate maintenance materials, the number of fire truck repairs will be reduced.

Maintenance of firefighting vehicles in appropriate technical condition is a serious and relevant topic not only in Latvia. For example, in the city of Sofia, like the Latvian SFRS, only one functioning auto-repair center operates, which is extremely insufficient to ensure the maintenance and repair of the entire fleet of the General Directorate of Fire Safety and Civil Protection. For this purpose, a study has been conducted on the number of firefighting vehicles in MAI, as well as their distribution on the territory of the Republic of Bulgaria. The main goal is to improve the maintenance and repair system of all firefighting vehicles in the country by building new specialized service centers. They should be located on the national territory in such a way that each of them could cover several regional directorates of Fire Safety and Civil Protection. The optimal number and placement of such centers is determined using a mathematical model of the cluster coverage problem [20]. In Bulgaria, a study of the refusals of firefighting vehicles received during accidents by the institutions of the Main Directorate "Fire Safety and Citizen Protection" of the Ministry of the Interior was carried out. Statistical data on types of failures, time and place of their occurrence and consequences were analyzed [21]. Iliev concluded that, considering the need to continuously maintain fire trucks in operational readiness, organizing their technical maintenance and repair, the possibility of using mobile services should be provided, which would allow adequate actions to be taken to eliminate the consequences of failures and accidents. This service must be available 24 hours a day, 365 days a year and must be provided by personnel with the necessary skills and professional qualifications [21]. On the other hand, researchers in Slovenia and Lithuania have conducted a study to find out whether the scientific literature in the field of maintenance of heavy trucks corresponds to the current trends in the development of technical maintenance. For this purpose, models related to fleet maintenance were analyzed in terms of cost optimization, decision-making support and improvement of employee technical maintenance competence. The analysis emphasizes the lack of research in the researched area and highlights the scientific gap in the development of methodological approaches to improve the competence of truck drivers as an important unit in the process of detecting and eliminating technical problems [22]. In Ukraine, an article has been written about the actuality of determining the effectiveness of the reasoned system of maintenance and repair of motor vehicles. The authors of the article emphasize that the improvement of the road transport maintenance and repair system is one of the main ways to increase the efficiency of road transport companies, which can also be applied to the organization of road transport repair and maintenance of rescue services. This is due to the high growth rate of the work performed, the significant complexity of the design of modern vehicles and the variety of implementation of new maintenance strategies and diagnostic methods. Substantial complications in the design of components and aggregates of modern motor vehicles, the increase of their functions, more demanding operating modes of components, aggregates, etc. – significantly aggravated the problem of traffic safety, which is largely related to the quality of maintenance and repair. The urgent need to improve the maintenance and repair system is related to changes in the technical condition of automobile equipment and requirements for maintaining the working condition of vehicles during operation. Analysis of existing maintenance and repair strategies has shown that each has its own advantages and disadvantages. Combining the advantages of each strategy and eliminating the shortcomings will lead to the creation of a mixed maintenance and repair system, which, along with high-quality staffing of repair companies and equipping them with modern diagnostic equipment, will increase the readiness, technical efficiency, and quality of operational efficiency of road transport, reduce maintenance and repair costs at a certain level of reliability [9]. Rikunovs and Kuzhelovych concluded that the application of a mixed technical maintenance and repair system, as well as high-quality staffing of automotive companies with qualified repair specialists and equipping them with modern diagnostic equipment will lead to an increase in the main efficiency indicators of this system. A set of measures to ensure the effectiveness of the combined maintenance and repair system should include:

- development of requirements for technological processes and maintenance methods;
- verification of compliance of control parameters with the established requirements;
- timely detection of possible deviations;
- prompt prevention of damages and breakdowns of road transport nodes and aggregates by implementing optimal maintenance measures [9].

The analysis, focused on the assessment of costs and benefits, assumed that the implementation of innovative technologies will contribute to the reduction of the frequency of repairs throughout the European Union. The introduction of these technologies is projected to be gradual, with increasing benefits achieved over time. Data analysis revealed significant differences between different EU member states, which, according to the authors, could be explained by several factors. For example, climatic conditions affecting the need for repairs, and differences in the level of infrastructure and technological development of countries. It was pointed out that financial resources and political decisions can significantly influence the pace and efficiency of innovation implementation.

During the study, the organizational and financial differences of fire services in EU member states were examined. It is recognized that these differences can significantly affect the feasibility of the proposed solutions. The researchers identified several factors.

- Differences in organizational structure. Differences between centralized and decentralized fire services can significantly affect the innovation implementation process.
- Differences in funding models. The different sources of funding, which can be the state budget, municipalities, or private funds, affect the amount of available resources and investment priorities.
- Differences in economic situation. Economically stronger countries could innovate more effectively compared to less developed countries.

In order to facilitate the implementation of the proposed solutions, the authors consider it important to develop customized plans that meet the specifics of each country, strategies that correspond to the structure and funding model of the fire service of a specific country, to promote the exchange of knowledge and best practices between countries to improve the adaptation of solutions, and to use the EU funding opportunities to support the specific needs of different countries. Such an approach could help overcome organizational and financial barriers, promoting a wider adoption of the proposed solutions throughout the European Union.

Conclusions

As a result of the research, it has been established that at the given time in the state fire and rescue service, the organization of technical maintenance and repairs of fire trucks is carried out using only Microsoft Office programs, which significantly limits the possibilities for planning work and predicting, for example, the wear and tear of fire truck units, which is calculated based on the involvement of the fire truck intensity, mileage, start of operation and other relevant aspects in operative work.

1. The authors conclude that, based on the shortcomings discovered during the research, it is useful to introduce a unified information system that would track the entire history of the fire truck, including repairs and maintenance.
2. In addition, introducing a control mechanism will ensure timely technical maintenance. GPS transmitters on each tank truck will provide mileage control and the collected data will serve as a basis for planning and organizing the replacement of fire truck tank units.
3. Regular training of the technical staff will increase the quality of the technical maintenance and repairs.

The study identified several areas where further research would be needed to reduce fire truck repairs.

- Durability of materials: research is needed on new, more durable materials that could reduce wear and tear and the frequency of repairs.
- Diagnostic Technologies: further investigation into improved diagnostic systems to detect potential problems at an early stage.
- Automation and robotics: investigate the possibilities of automation and robotics that could improve fire truck maintenance and repair.
- Energy efficiency: research into energy efficiency improvements that could reduce operating costs and the need for repairs.

During the research, it was found that there are several technological and organizational aspects that could affect the efficiency and costs of maintaining firefighting vehicles, but considering the rapid development of technology, they require in-depth research of each individual aspect. For instance:

- Firefighting tactics: how the development of different firefighting tactics can affect the wear and tear of cars.
- Organizational culture: how organizational culture and approach to maintenance can affect the frequency and effectiveness of repairs.

In the opinion of the authors, these aspects require more detailed research to fully understand and develop comprehensive solutions to reduce fire truck repairs. Further research in these areas could help develop more effective and sustainable maintenance protocols.

It is important to emphasize the importance of the development of artificial intelligence (AI) in further research on the issue of reducing fire truck repairs. AI technologies can offer several benefits, such as: predictive maintenance: AI could help develop algorithms that can predict potential problems before they occur, allowing for preventative repairs and reducing unexpected breakdowns; automated diagnostics: AI can improve the accuracy, speed and efficiency of diagnostic systems by reducing human error and repair time; Optimized resource management: AI can analyze large amounts of data to optimize repair and maintenance schedules, material orders and personnel work allocation.

According to the authors, the development of AI is particularly important because it can significantly improve the efficiency of fire truck maintenance and reduce costs. Future research is planned to include AI application scenarios to fully understand its potential and implementation opportunities in fire services.

Author contributions

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

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