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Proposed Changes to the Inspection Strategy for Fire Alarm Systems: Empirical Analysis of Weak Points and Technical Influencing Factors

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Abstract: Fire alarm systems are an important part of the safety concept in complex buildings. For this reason, there are high availability requirements for the systems, which must be sustained by a maintenance concept. A shortage of skilled workers and rising costs in the construction and operation of buildings are pushing these concepts ever further. This study deals with proposed changes to the maintenance strategies to achieve cost and time savings in addition to an improvement in quality. As a first part of the work, the current state of research on developments in fire alarm systems and their maintenance and inspection concepts is analyzed within a literature review. The results serve as a basis for further research, which is based on a qualitative content analysis of expert interviews and standardized surveys to identify the weaknesses in current inspection strategies and future factors influencing the methods and technology of inspections through technical innovations. As a data basis for this study, expert interviews were conducted with experts from manufacturers, industry associations, and standards bodies in order to determine the possible influencing factors. To determine their relevance for the inspection, more than 40 experts were surveyed about testing the systems. The presented results show that new technical risks, such as cyber threats and networked plant structures, are insufficiently covered by current inspection strategies. Furthermore, inspection steps can be substituted by new technologies. The most important influencing factors that can be identified here are automatic self-test functions of components and remote inspection techniques of the systems. Finally, the results are discussed within the framework of a PESTEL analysis. In conclusion, it can be stated that the integration of identified impacts in future inspection strategies brings time and efficiency benefits in the operation of systems.

Keywords: maintenance; inspection; fire alarm system; defects; quality; weakness analysis

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1. Introduction

In complex or public buildings, fire detection and alarm systems significantly contribute to the protection of people and animals [1]. These systems meet the requirements of building regulations by identifying fires in their early stages, locating the hazardous event, notifying emergency services (such as the fire department, police, or rescue services), alerting individuals in the area of potential danger, and managing other components of the building's technical apparatus related to fire prevention. To achieve these protection goals, the systems must fulfill comprehensive availability requirements [2]. It is important to understand that system maintenance makes a significant contribution to system availability. In addition to the further technical development of algorithms to optimize the functions of fire alarm systems, the further development of maintenance approaches is, therefore, a second focus that can improve the safety of people and the environment in buildings [3]. The relevance of maintenance is already known today and is considered in numerous European regulations. These specifications describe standardized requirements for the operation, maintenance, servicing, and regular testing of systems [4,5].

1.1. State of the Art

At the European level, the CEN TS 54-14:2018 and the DIN VDE 0833 series of standards, particularly DIN VDE 0833-1, are decisive regarding the maintenance of hazard detection systems. DIN 14675-1 further specifies the special testing criteria and procedures in Germany. In addition to these normative specifications, there are also legal requirements for the regular testing of fire alarm systems. These include the testing regulations of the respective federal states in Germany, the specifications regarding the personnel requirements for the testing personnel deployed, and the testing principles as a basic document for the content of tests by recognized experts [4].

Current regulations contain predefined steps and cycles for maintenance procedures and test contents, regardless of the risk factors, such as system size, environmental conditions, construction class of the protected object, size of the building, or age of the system. The current normative maintenance approaches, therefore, apply to all fire alarm systems to the same extent. This is a purely preventive maintenance approach divided into various responsibilities [6,7]. The responsibilities are divided between the system operator (first-party inspection), external specialists for fire alarm systems (second-party inspection), and independent recognized experts (third-party inspection). This separation in the concept of inspection responsibilities is based on the principles of ISO 9001 for the auditing of quality systems and provides quality assurance across multiple levels of responsibility and expertise [8].

As already mentioned, the rigid current framework of test specifications for fire alarm systems is a purely deterministic test model. Probabilistic adjustments with regard to the risk factors—for example, due to system-internal aspects such as the age of the system or due to system-external influencing factors such as the building structure and the protection objectives of the fire alarm system—are currently not implemented in the regulations.

This poses several problems. For example, the strict testing and maintenance requirements for fire alarm systems make them difficult and costly to operate, especially in low-risk properties. In addition, the standardized methodology—characterized by random sampling and snapshots—does not ensure that the tests meet the essential protection objectives that fire alarm systems are supposed to fulfill for large, important infrastructure facilities, such as airports, hospitals, and train stations. This problem is particularly critical because safety-relevant facilities in buildings are usually inactive; so, it is not clear from their normal operating status how well they will function in an emergency. Hence, there are special quality requirements for the maintenance of these systems [9]. Thus, the current framework for the inspection and maintenance of fire alarm systems presents several challenges.

Looking at the current state of research, which is described in more detail in the next section, the research in the field of fire alarm systems focuses almost exclusively on the technical development of the systems. The further development of maintenance and servicing approaches is only considered in a very small part of the research. One example of this is given by the study by Kamran et al. in [10]. Here, as in many other research projects, the authors analyzed how the use of machine learning can optimize fire detection in mine fires. What is not considered here is that the effectiveness of fire detection systems—even if they are based on highly innovative machine-learning approaches—requires proper maintenance. This is because, if essential components do not work due to a lack of maintenance, the technology and algorithms are limited in their effectiveness. These maintenance concepts represent a significant part of the safety and availability of the systems and are of similar relevance to the actual technical development.

1.2. Motivation and Objectives

The inadequate consideration of the relevance of this sub-area of research into fire alarm systems is the motivation and background for the study presented here. There is a growing gap in the research into how the technical development of fire alarm systems also requires maintenance measures to be adapted to maintain safety in operation in the long term. This work is intended to contribute to narrowing this research gap.

To optimize the inspection concepts for fire alarm systems, this study provides an overview of the weak points of the existing concepts. The influence of technical developments in fire alarm systems on maintenance is being investigated. Based on the identified technical innovations and possible influencing factors, general guidelines for the optimization of inspection concepts are presented. The innovative contribution of the approach is to find new, more effective methods for using technology in maintenance approaches to protect people, the environment, and material assets from threats. In particular, new methods for risk-based inspection and vulnerability analyses are to be taken into account. The results of the investigations presented here can serve as a basis for this.

In the following, the current state of research in the field of fire alarm systems is first analyzed in a critical literature review. This serves to identify the research gap. Based on this, the methodology used to investigate the weakness and possible technical influences on the inspection strategy for fire alarm systems is explained. After the subsequent presentation of the results, the influences are discussed, and the results are summarized.

2. Literature Review/Background

As mentioned, the current requirements for fire alarm system maintenance are characterized by rigid legal and normative specifications. These rigid requirements no longer reflect current technologies and are leading to increasing problems in numerous areas [11]. During the following literature review, it will first be shown which current studies on defect/weakness analyses of fire alarm systems are known. In addition, the state of research will be shown concerning the current scientific work on fire alarm systems. Based on these explanations, the resulting research gap is highlighted, which is to be narrowed with the presented study.

An important starting point, which provides indications of weak points in the current maintenance strategy of fire alarm systems, is the statistics of the TÜV association in Germany on the defects found in fire alarm systems. The results illustrate why there is a need for optimization in the maintenance of fire alarm systems. On average, for the years 2012–2022, technical experts at TÜV were only able to certify defect-free fire alarm systems in terms of effectiveness and operational safety in accordance with building laws for 28.9% of systems tested in periodic inspections; on average, 52.1% of the systems were found to have minor defects, and approximately 19.0% of the systems were found to have significant defects that affected the reliable functioning of the safety systems [12]. These statistics are presented in Figure 1.

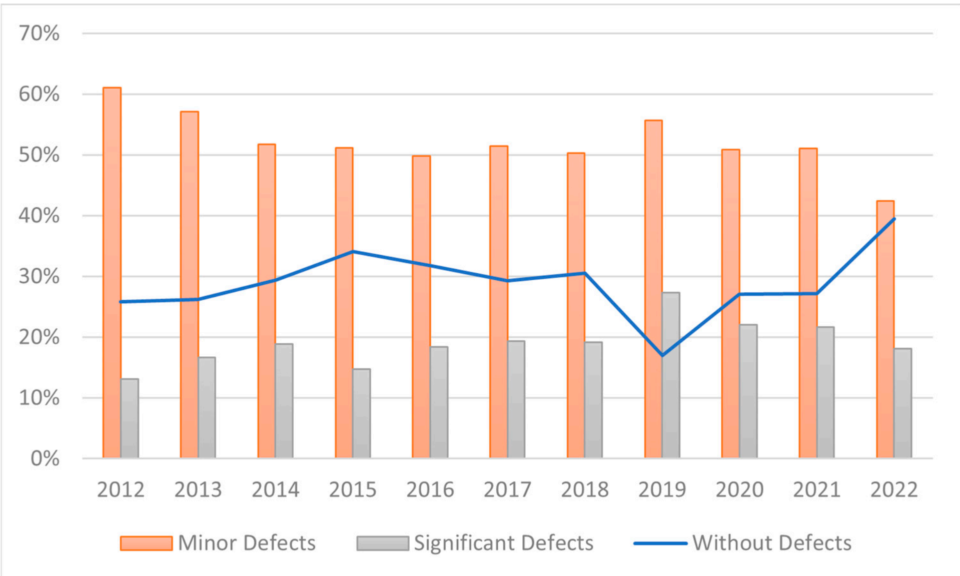

Figure 1. Defect statistics for inspections of fire alarm systems in the annual “Baurechtsreport” of the TÜV Verband [13].

While the statistics show that a large number of defects in fire alarm systems can be traced back to the operation of the systems, the current research work deals little with this consideration. There is a large body of research on the technical advancement of fire detection technology in the field of fire alarm systems and their related components. The studies especially focus on the sensor technology employed, the fire parameters investigated, and the algorithms for assessing the systems [10,13–18]. Furthermore, research has been conducted on the systems' power supply and availability [19,20]. Many studies, either theoretically or through the use of individual system examples, have calculated the availability of systems based on the likelihood of the failure of the individual assemblies [20–26]. Several studies have pushed the boundaries of IoT and AIoT technologies in the creation of new fire alarm systems [14,16].

In contrast to this branch of research, which focuses strongly on the technology of fire alarm systems, the area of operation and maintenance of the systems can be found in studies on the occurrence of false alarms and their background in various European countries [27,28]. At present, the research on fire alarm system maintenance and servicing is concentrated on remote services [12]. It is also addressed how BIM and augmented reality can be used for optimization [29], and there are research results suggesting a data-driven online detection of anomalies in smoke sensors for the predictive planning of maintenance measures [30]. Studies have also considered comparable risk-based maintenance systems. For example, Sobral and Ferreira analyzed optimized maintenance of a fire extinguishing system [9].

The evaluation of the existing research on the maintenance of fire alarm systems reveals a gap with regard to the focus on improving the quality of maintenance systems. In particular, there are deficiencies in the inspection of fire alarm systems for the preventive detection of defects. The present work intends to narrow this research gap.

To achieve the objectives, this study focuses on identifying the current weak points based on the existing approaches for the maintenance of fire alarm systems. This approach is new in the sense that the work deals with how the maintenance approaches for fire alarm systems must develop further in order to do justice to the technical developments of the existing research work. The aim is to optimize the overall quality and availability of the operation of the systems by combining the further technical development of the fire alarm systems from the existing research work and the further development of the maintenance approaches presented here.

3. Materials and Methods

A mixed-methods approach was chosen to address the research questions. The combination of individual methods is given in Figure 2. The basis and starting point of the work are the literature review on current methods, contents, processes of system maintenance, applicable regulations, and developments presented in the previous chapters.

The findings of the literature review were supplemented by guided interviews with experts. According to Bogner and Kaiser [31], the expert interview is particularly suitable for ascertaining hard facts that cannot be obtained from other sources.

When selecting interview partners, care was taken to select a mixed group of experts from the construction sector and those who worked in the field of fire alarm system manufacturers. To determine the participants in the expert interviews, inquiries were made to the market-leading manufacturers of fire alarm systems and the DKE standards committee DKE/K 713. As part of the inquiries, the objectives/focus of the research project were described, and suggestions for appropriate participants in the interviews were made. From a total of 10 proposed participants, 7 were selected based on their expertise and knowledge. Care was taken in the selection process to invite experts from various manufacturers and industry associations (VDE, VdS, DKE) to obtain answers from different perspectives on the subject of the research. The backgrounds of the interviewed experts are detailed in Table 1.

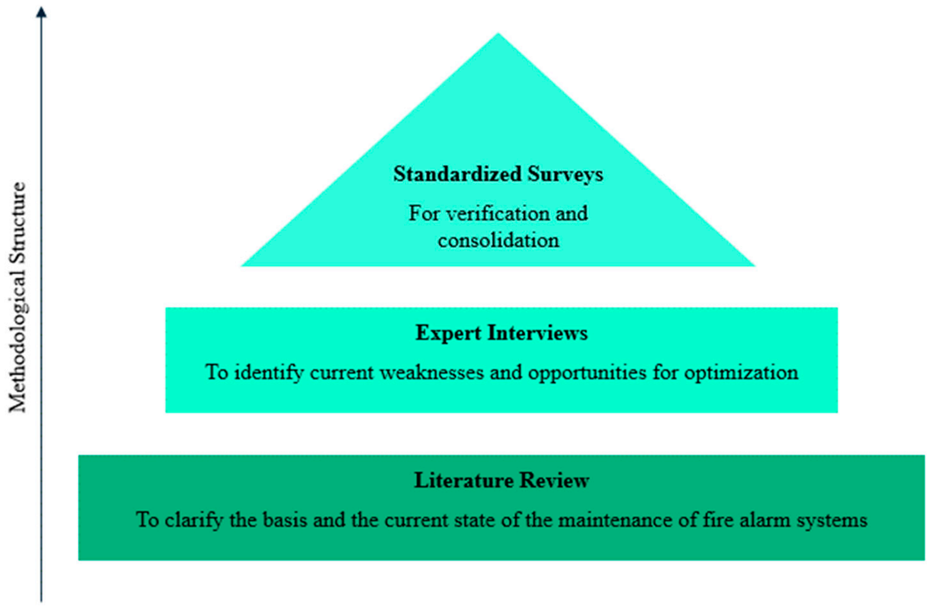

Figure 2. Combination of methods used to address the research question.

Table 1. Selection and background of the participants in the expert interviews.

Interview No.	Background of Interview Partner	Institutional Classification
1	Product manager for fire detection technology, company representative in standardization committees of ZVEI, DIN, VDE, EN	Bosch AG, Grasbrunn, Germany (Manufacturer of FAS)
2	Product manager for fire alarm technology, member of the fire alarm committee of the German Association of Cities	TELENOT ELECTRONIC GMBH, Aalen, Germany (Manufacturer and installer of FAS)
3	Sales manager of fire detection and alarm systems	Bosch AG, Grasbrunn, Germany (Manufacturer of FAS)
4	4.1 Head of standards and guidelines in product management 4.2 Product manager building law/ national standardization	Honeywell Analytics AG (ESSER), Munich, Germany (Manufacturer of FAS)
5	5.1 Portfolio manager installer/B2B business FAS 5.2 Team leader plant installation	Bosch AG, Munich, Germany (Installer of FAS)

The expert interviews were conducted as part of the online meetings. Each interview lasted between 60 and 90 min and took place in the period from September 2022 to January 2023. All interviews were conducted as guided expert interviews using identical, pre-prepared guidelines.

The objective in developing the question guideline was to determine both technical and process-oriented knowledge. A framework was defined for this purpose, which followed the following structure according to Bokrantz et al. [32]:

- Warm-up, introductory questions about the expert as a person;
- Component and system level (technical background);
- Company level (manufacturer or operator level);
- Extra-company level (cross-company topics, legal changes).

The first step was a brief introduction to the subject of the research and the aim of the study. This was followed by an examination of the components/systems at higher levels up to the extra-company level, where the focus was on cross-company issues/changes. The interviews were recorded during the online meetings for further analysis and transcription.

The transcription was summarized in tabular form for each question in order to compare the results.

The expert interviews were evaluated using a qualitative content analysis according to Mayring, and the results were analyzed according to an inductive coding guide. The experts' statements were qualitatively standardized as part of a coding guide. This standardization was used to conduct a consensus analysis of which influencing factors were named by several of the experts surveyed. This consensus analysis forms the starting point for the standardized interviews and provides a basic set of possible weaknesses in the current inspection strategies as well as technical innovations that could have an influence on the inspection strategies. The evaluation was carried out using the Microsoft 365 framework by using MS Forms, MS Word (Version 2404, Build 17531.20000)., and MS Excel (Version 2404, Build 17531.20000).

In accordance with the chosen methodology of the scientific work described in Figure 1, standardized surveys were conducted to verify and substantiate the above findings. These serve to determine and quantitatively evaluate the relevance of the individual influencing factors identified in the expert interviews. The participants in the survey were selected based on the field of activity of inspecting fire alarm systems. Only experts who carry out professional inspections of fire alarm systems themselves were surveyed. The professional experience of the respective experts was also queried and is listed below. The survey was conducted via MS Forms as part of a total of 2 training days of the inspection experts. The two survey dates took place between February and April 2023. Both open and closed questions were asked in order to verify the results. The experts were present on-site and had no preparation for the survey before the event. As part of the survey, the author presented the question verbally and explained the background to the topics in question in response to questions. The experts responded independently and without coordination, each individually with the tool used.

Finally, a total of 47 experts took part in the survey. Of these, 39 participants were recognized by the responsible building supervisory authority with regard to their professional qualifications as experts in building law, while eight participants worked as experts without recognized qualifications in building law.

The surveyed experts' years of professional experience in the field of fire alarm technology were as follows:

0 years: 1 participant (2%)
1–3 years: 5 participants (11%)
3–5 years: 3 participants (4%)
5–10 years: 18 participants (38%)
>10 years: 21 participants (45%)

This distribution ensures comprehensive expertise in the field of fire alarm technology.

The standardized surveys were evaluated quantitatively. The questions with predefined selection options were evaluated quantitatively in a direct manner, whereas a qualitative content analysis was carried out for the open questions according to Mayring's methodology. The quantitative analysis was carried out by coding the responses. The coding guide was again created inductively as part of the analysis. The evaluation was carried out using the Microsoft 365 framework by using MS Forms, MS Word, and MS Excel.

The combination of the methodology with the mixed-methods approach described is relevant from other areas of technology with similar approaches to the further development of existing regulatory requirements and content. For example, in the area of the further development of Industry 4.0 and cyber security, corresponding methods of expert interviews and surveys were used to point out the relevant weaknesses and challenges [33–35]. The objectives of the aforementioned studies are similar to the problems considered here.

Both the expert interviews and the surveys took place in the context of a larger scientific study with further questions from the field of fire alarm system inspections. The aim of this larger study was to collect further statistical data on the operation and defects of fire alarm systems, which will be published in future papers.

4. Results

This chapter presents the results of the research. In accordance with the structure presented in the methodology section, the existing contents of the inspection of fire alarm systems from the literature review are outlined first. In the second part, the main weaknesses in relation to this content are presented based on the results of the investigations. The third part presents the influence of technical innovations that will probably change the inspection of fire alarm systems in the future.

4.1. Existing Approaches of Fire Alarm System Inspections

The existing system for inspecting fire alarm systems is based on different responsibilities. Inspections are divided into first-, second-, and third-party inspections in terms of the content and personnel involved.

4.1.1. Regular Inspections by the System Operator (First-Party)

The overall responsibility for unrestricted operation of the fire alarm system lies with the system operator in accordance with the applicable normative requirements. In accordance with CEN TS 54-14, DIN VDE 0833-1, and DIN 14675, the system operator is obliged to carry out regular inspections in the security area. The aim of this is to determine whether parts of the fire alarm system are affected by influences outside the hazard detection system that cannot be detected and reported or evaluated by the system's own functions. These not-automatically detectable defects can be, for example, changes in the furnishing of rooms that conceal detectors or changes in the use of the room that require other fire detectors.

The following contents must be considered:

- The monitoring task(s) specified in the documented safety concept;
- The use of the room;
- The room layout;
- The organizational resources available on-site for emergency services, e.g., fire department route maps;
- The environmental conditions;
- The proper installation of all system components;
- The external damage and soiling of all system components;
- The completeness and accuracy of the operating logbook.

4.1.2. Inspections by Specialist Companies (Second-Party)

As the operators of fire alarm systems are not experts in the respective systems themselves, the technical regulations for the operation of the systems provide rules for regular inspections by an approved maintenance company. These inspections, referred to here as external inspections, are divided into quarterly and annual inspections and serve as a starting point for any necessary repair and maintenance work. In the course of this work, only diagnostic processes were deliberately considered—not repair and maintenance work. For this reason, these are not covered in this paper. According to the specifications of DIN VDE 0833-1:2014-10, the following functional tests must be evaluated at least quarterly as part of the recurring tests:

- Monitoring of external connections with non-destructively testable detectors by triggering one non-destructively testable detector per monitored transmission path;
- Monitoring of external connections of transmission devices by triggering transmission devices;
- Signaling devices;
- Signaling and/or actuating devices in or outside control centers;
- Switching devices;
- Control devices in connection with transmission devices, alarm devices;
- Power supply systems;

- Fault forwarding to the remote authorized location in the case of a non-permanently manned location on site.

The following additional functional tests must be carried out at least once a year:

- Tripping of all non-destructively testable detectors, including the associated indication of message origin;
- Monitoring of external connections that only contain non-destructively testable detectors;
- Triggering of devices in connection with control devices.

4.1.3. Third-Party Inspections by Recognized Experts

Statutory third-party inspections by recognized experts are required for fire alarm systems that have particularly high safety requirements due to the building structure or use [4]. The inspection contents in Germany are defined in the inspection principles published by the IS-Arge Bau (2011). In accordance with the requirements, experts focus on a total of four basic subject areas. The breakdown and the required inspection content are shown in Figure 3.

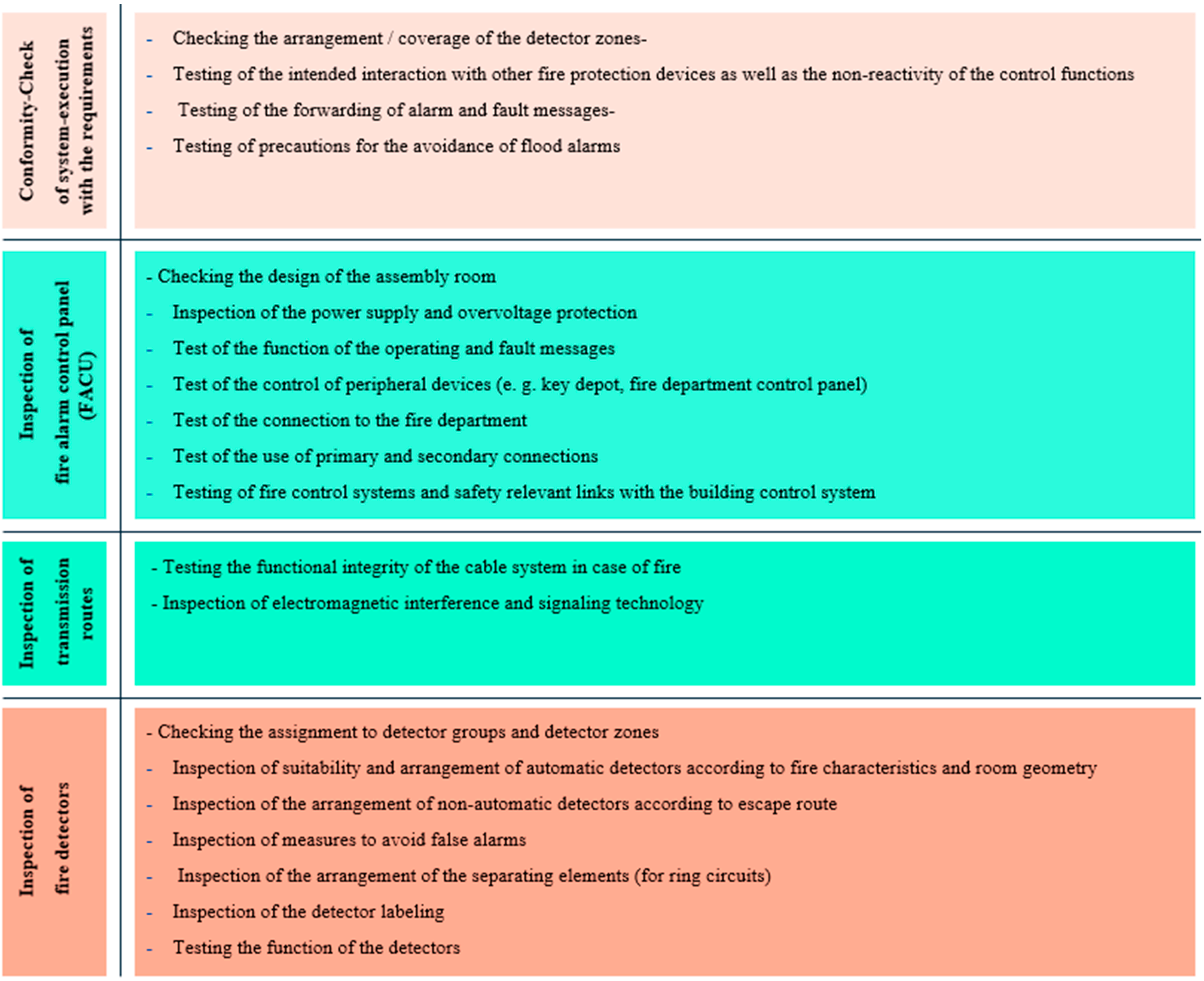

Figure 3. Current inspection content of external monitoring according to testing principles in Germany.

Currently, the basis of the test content is a conformity and functional test. As part of this test step, independent experts assess whether the fire alarm system complies with the minimum requirements under public law and functions as intended; this is conducted on the basis of both building regulations and normative requirements.

The above results show the current requirements for the inspection of fire alarm systems. The test contents for first-, second-, and third-party inspections are shown. In accordance with the selected methodology and the structure of this study, the weaknesses of this existing methodology are presented below based on the results of the evaluation of the expert interviews and the standardized surveys.

4.2. Weaknesses in the Current Inspection Methodology

- Weak points in the current inspection methodology were determined from the expert interviews and the standardized surveys. These weak points are illustrated graphically in Figure 4.
- According to the experts, the lack of inspection content with regard to cyber security represents the greatest weakness. The respondents felt that cyber security is a cross-cutting issue that needs to be considered in general.

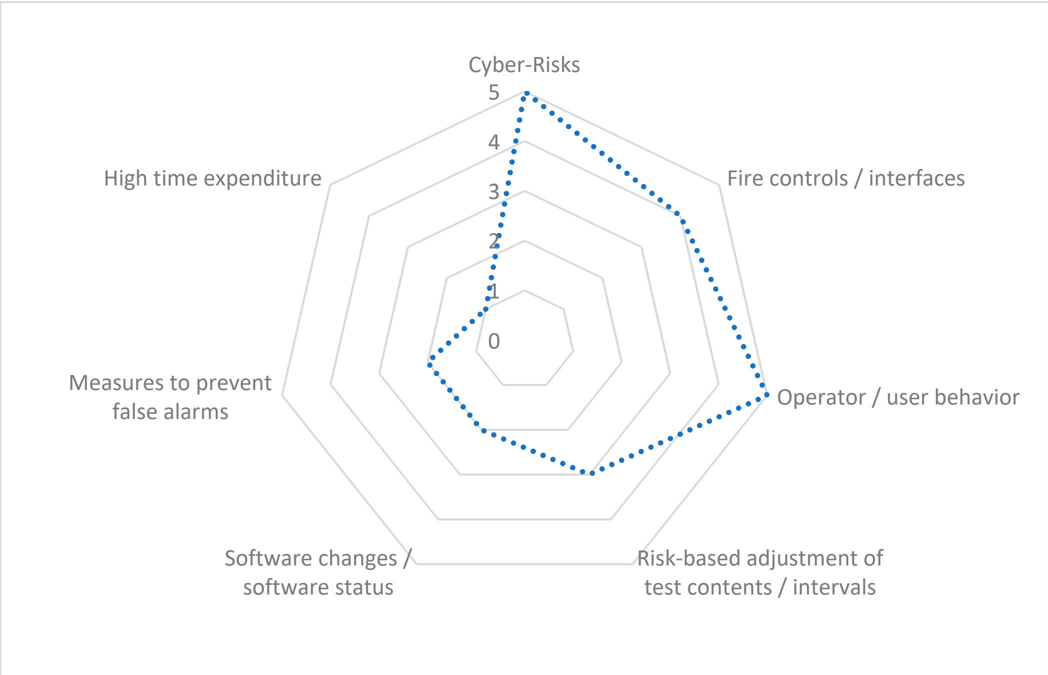

Figure 4. Graphic representation of the relevance of the weaknesses identified via qualitative content analysis of the standardized surveys and expert interviews. The numbers in the figure indicate the relevance with which the experts rated the individual topics. 0 = no relevance, 5 = highest priority.

The survey also revealed that there are currently no assessment mechanisms for the quality of fire alarm system operation and operator behavior. In the standardized survey, when asked which topics the experts felt were being neglected in current testing, 68% of the respondents answered "user/operator behavior". The experts also expressed a desire for a tamper-proof, end-to-end digital logbook that would enable the complete recording of any misconduct during system operation.

As a medium priority, according to the ranking of the qualitative analysis, the experts also noted the lack of testing of complex fire control systems and of comprehensively networked systems. In this regard, the experts criticized the fact that, despite the increasing degree of system networking, the focus of maintenance and testing is usually on individual systems or the testing of a standalone system, while interfaces to other systems are insufficiently considered.

With the same priority, the experts also perceived weaknesses in the adaptation of test cycles and test content to operational experience and risks. For example, systems are currently tested across the board without taking into account the defects identified in the system. According to the experts, the possibility of risk-based adjustments is missing.

In addition but less frequently, the experts also identified weaknesses in the detection and documentation of changes in system software and the avoidance of false alarms. Both points were reported as sometimes being neglected. Table 2 lists the results regarding weaknesses in the methodology and content of maintenance and inspection measures.

Table 2. Presentation and prioritization of weak points in the current maintenance content and methodology for fire alarm systems.

Weakness in the Current Inspection System	Type of Vulnerability (Content-Related, Methodical)	Priority/Relevance
Lack of consideration of cyber risks	content-related	very high
Insufficient treatment of fire safety controls/interfaces	content-related/methodical	high
Lack of evaluation of operator/user behavior	content-related	very high
Rigid test intervals without risk-based adaptation of test content/intervals	methodical	medium
Lack of treatment of software changes/software version	content-related	medium
Insufficient evaluation of measures to prevent false alarms	content-related	medium
High time expenditure for testing due to partially excessive test content for modern systems	methodical	low

The interviews revealed that there are not only weaknesses in the current scope of testing but also an excessive amount of testing that could be reduced. The experts agreed that "There are test contents that can be omitted or are no longer up to date in modern fire alarm systems (e.g., ring bus technology, detectors with automatic fault detection) without any relevant effect on the quality of the test statement". Hence, existing maintenance and testing can be reduced without any relevant loss of quality in newer systems that meet the defined minimum technical requirements. The other results show where the existing inspection content can be adapted accordingly.

4.3. Influence of Technical Innovations on the Inspection of Fire Alarm Systems

Figure 5 illustrates the results of the qualitative content analysis on the influencing factors of technical innovations on testing content and methods for inspecting fire alarm systems. The results indicate a prediction that the future possibility of digital inspection logbooks and digital document storage will have the greatest influence on the maintenance and servicing of fire alarm systems. According to the experts, these options will help to create seamless and consistent documentation on the operation of fire alarm systems, including a transparent presentation of all operational events, such as false alarms, conversion measures, and software changes. These measures represent a gain in efficiency as interfaces between the testers' instances can be documented separately, thus avoiding duplicate tests.

According to the experts, efficiency is also enhanced by the new possibilities of remote access and remote maintenance. These technical innovations mean that many aspects of inspections can be carried out and documented remotely, minimizing maintenance costs and, at the same time, significantly increasing the depth of random inspections due to the reduced effort involved. However, the experts also agree that, in addition to remote maintenance, on-site inspections will continue to be necessary, especially to identify deviations or problems that cannot be detected by the new (automatic) self-test functions.

The experts reported that the intelligent self-test functions of fire detectors will mean that on-site testing with test gas or external smoke and heat generators will no longer be necessary in the future. This change offers the opportunity to significantly reduce the time required for on-site testing. Some experts went even further in their assessment. Two of the experts maintained that the identified technical innovations will also reduce the need for on-site specialists. Remote access on-site could make it possible for individual test steps to be carried out remotely by laypersons or together with a specialist. This was also discussed by the experts in official panel discussions and is considered an effective means of combating the shortage of skilled workers [12].

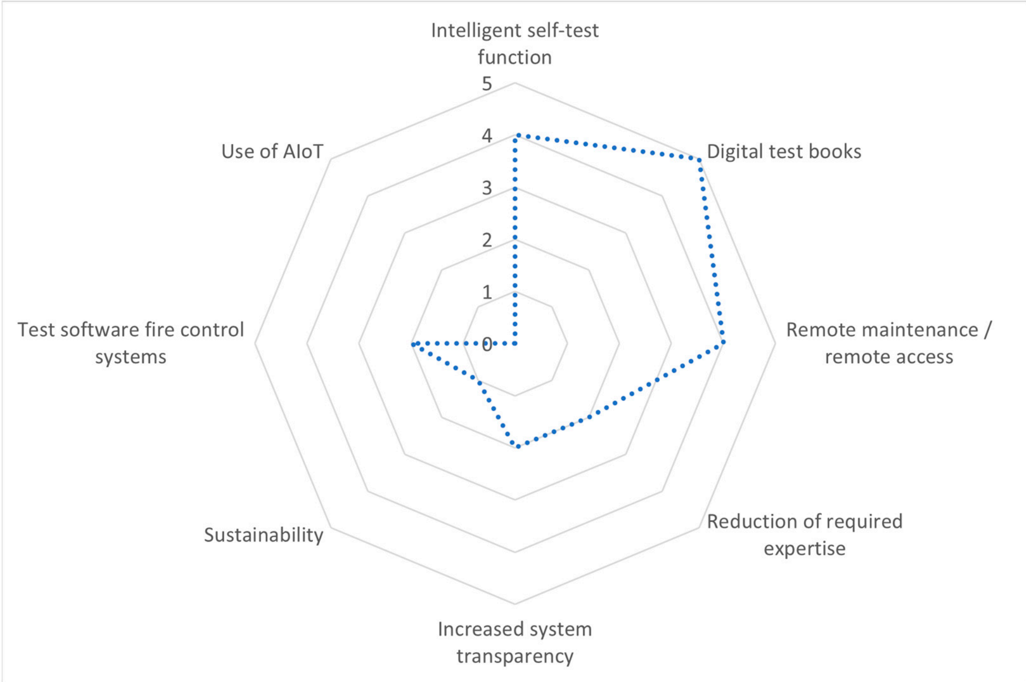

Figure 5. Relevance of the identified influences of technical innovation on the inspection of FAS. The numbers in the figure indicate the relevance with which the experts rated the individual topics. 0 = no relevance, 5 = highest priority.

In addition to the calls for technical innovations in the maintenance and inspection of fire alarm systems, the experts also expressed criticisms and rejections of individual trends, such as the use of AI. The respondents agreed that the use of AI for maintenance and inspection is currently a marginal phenomenon that will initially play a subordinate role. The experts viewed AI critically, particularly in individual discussions, and expressed doubts as to how a system response to AI solutions can be effectively predicted and tested in terms of system availability and operational reliability.

One topic the interviewed experts did not clearly assess was the use of software for digital testing and documentation of fire safety system inspections. These software solutions offer, for example, the possibility of digitally and intelligently evaluating and documenting the function of fire protection controls when a fire detector is triggered by sensors in the building. According to the experts, this can be an effective means of testing complex fire control matrices, but it only shifts the test steps in the direction of an order check of the programming/parameterization of the software. This additional software also requires the stored functions to be regularly checked for correct operation. Software validation plays an important role in this regard. In addition, the integrity of the recorded sensor data must be checked for plausibility and relevance; this, in turn, represents an additional testing effort, which may have an effect on the test but does not necessarily lead to optimization of the test quality or a reduction in testing time. In this respect, however, it should be noted that the test time on-site can be significantly reduced, and even disruptive fire controls that cannot be tested during normal operation can still be subjected to a test.

Table 3 summarizes and qualitatively evaluates the influencing factors that emerged from the qualitative content analysis of the expert interviews and surveys.

Table 3. Compilation of the influencing factors of technical innovations on the content and methodology of the inspection of fire alarm systems.

Technical Innovations with an Influence on the Methods and Content of the Maintenance and Servicing of Fire Alarm Systems	Type of Innovation (Content-Related, Methodical)	Priority/Relevance
Intelligent self-test function for FACU and components	content-related/methodical	high
Digital test logs with complete and integrated documentation of operating behavior	content-related	very high
Remote maintenance/remote access to the FAS	methodical	high
Reduction in the required expertise of on-site personnel	methodical	medium
Increased system transparency through optimized display/documentation	methodical/content-related	medium
Optimization of sustainability through reduction in test scopes	methodical	low
Testing software to support/document the testing of FAS	methodical	medium
Use of AIoT for the testing/evaluation of FAS	methodical	very low

With the corresponding contents of the technical influencing factors on the contents of inspection strategies as well as the previous identification of the corresponding weak points, all influencing factors on the future optimization of the inspection strategy of fire alarm systems can now be presented. In the following section, the necessity of incorporating the adjustments into the inspection strategy of fire alarm systems and the relevance of the results are discussed.

5. Discussion

As part of the discussion of the results, it will be considered why further development of the inspection strategies for fire alarm systems is necessary. The results are presented using the PESTEL methodology [10]. The PESTEL method is a strategic tool that helps to analyze the external environment and identify the macroeconomic factors that influence the area under investigation. It examines the influencing factors from political, economic, social, technological, ecological, and legal perspectives.

From a political perspective, there is pressure to ensure a secure building infrastructure. On the one hand, this is achieved through the basic technical requirements of the systems themselves as well as the requirements for maintenance and servicing. At the same time, there is a political need to keep the operating costs of buildings low. Thus, the requirements must not be exaggerated [36].

From an economic viewpoint, there is also great interest in the test content and methods for the maintenance of fire alarm systems. The current preventive maintenance strategy for fire alarm systems, with its fixed and rigid test cycles, incurs high costs for system operators and sometimes leads to downtime if systems cannot be operated due to the tests. False alarms also cause high costs due to operational interruptions [27,28]. Optimizing maintenance strategies makes it possible to increase efficiency and minimize costs [6,9,12].

There is also an interest in changing maintenance concepts from a social perspective due to general demographic changes in Germany and Europe, which are likely to exacerbate the shortage of skilled workers. The high degree of specialization of the technical experts needed also affects the operation and maintenance of safety systems. To guarantee a high-quality inspection of all affected fire alarm systems, it is, therefore, essential to make efficient use of specialist knowledge. Optimization of maintenance concepts can make it possible to divide work according to the qualifications of the personnel such that technical expertise can be used as time-efficiently as possible, taking advantage of all technical possibilities. This works, for example, in such a way that experts access the systems remotely and instruct non-experts on-site to take action [12].

From a technical viewpoint, the further development of maintenance concepts is driven by new possibilities for self-diagnosis of systems and the methodology for carrying out maintenance and inspection measures. These possibilities are currently not optimally utilized due to the rigid requirements of the legal framework. In addition, there are weaknesses in the existing inspection content that do not fully detect defects in areas that are not currently inspected.

As part of the European Green Deal, there is an interest in all areas of the economy in reducing CO_2 emissions and prioritizing sustainability. Excessive and inefficient inspections and maintenance measures cause excess emissions [37]. Any increase in efficiency in this area is, therefore, also an improvement in terms of eco-efficiency and sustainability goals, especially if preventive maintenance extends the service life of systems and components.

From a legal perspective, building operators have an interest in legal certainty during operation. Only through concrete specifications for the maintenance of fire alarm systems and a defined legal framework can operators reliably prove that they are considering all relevant measures to maintain the operational readiness of the system.

The discussion according to the PESTEL methodology reveals that, from all the perspectives of this kind of analysis used, high demands are placed on a rapid-change process with regard to maximizing quality and efficiency in maintaining fire alarm systems.

In terms of content, the investigations revealed the following points that should be taken into account in the further development of inspection strategies:

- As the results of the literature review have shown, there is currently a great deal of research into optimizing fire detection systems themselves and the algorithms used for fire detection. With regard to the optimization of maintenance and inspection concepts, there is currently little relevant work that goes beyond reliability analyses. There is potential for future work in this area.
- The results of the expert interviews and surveys support that the current inspection methods for fire detection systems have weaknesses, especially with regard to protection against cyber risks and the evaluation of the operating and operator behaviors of the systems.
- The influence of technical innovations provides new opportunities for optimizing fire alarm system inspection concepts. Addressing these influences could reduce the effort and costs of inspections while, at the same time, increasing quality.
- The results reveal both weaknesses and opportunities with regard to the maintenance of fire alarm systems based on an empirical analysis of the current situation. There is, thus, the potential to develop an optimized maintenance approach within the framework of future research that also accounts for the prerequisites for the successful implementation of optimizations.
- The results are highly generic. In order to evaluate specific influencing factors in more detail, it is necessary to substantiate the results. There are opportunities for this in future studies.

When critically examining the results of this study—particularly with regard to the optimization of maintenance strategies—it is important to note that the general conditions/environmental conditions under which fire alarm systems are operated are also taken into account in addition to the general content considered. For example, the investigations have shown that cyber risks are currently only given little consideration in the context of the tests [13]. In the context of operational framework conditions, this point certainly only applies to systems with correspondingly vulnerable interfaces and the technical possibility for remote services. Systems without interfaces, for example, would not be affected by this, meaning that a case-by-case assessment is always required. The results presented serve as an initial basis for the further development of future maintenance strategies. In order to obtain a complete picture, numerous other factors still need to be taken into account and investigated.

6. Conclusions

This paper presented possible changes to fire alarm system inspections. This paper offered an empirical analysis of the weak points and influencing factors in new technical developments and used a qualitative content analysis to determine the corresponding findings.

The interviewed and surveyed experts reported the relevant influencing factors in the inspection of fire alarm systems in a practical manner. In summary, cyber security and the quality of the operation of fire alarm systems are currently receiving too little attention. However, new technical developments, such as digital test books and self-diagnostic functions, can simplify many aspects of inspection. In particular, the newly created possibilities for remote access to fire alarm systems will have a significant influence on the methodology and content of inspections. In the future, numerous aspects of previous on-site inspections will be carried out via remote functions, documented in a digital logbook, and, thus, become increasingly efficient. It will also be possible for on-site inspections to be carried out remotely by less-trained personnel under the guidance and supervision of specialists.

In conclusion, the results highlight numerous avenues for optimizing the inspection of fire alarm systems. A comparison with studies from other technical areas—for example, the investigation of future developments in the field of PV systems—shows that the chosen methodology is suitable for identifying the corresponding weak points and technical influencing factors [33]. This underlines the relevance of the results and their generic character for generalized applicability. Future research should deepen these aspects, explore various possible approaches, and develop them into a generic maintenance concept for fire alarm systems.

In the future, not only the technology of the fire alarm systems themselves but also the technology of their inspection, maintenance, and servicing must be further developed and optimized in order to successfully guarantee a high level of system availability in the long-term.

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