14th Annual International Conference on Industrial Engineering and Operations Management
Dubai, United Arab Emirates (UAE), February 12-14, 2024
Publisher: IEOM Society International, USA DOI: 10.46254/AN14.20240016
Published: February 12, 2024

Systemic Approach for Risk-Based Third-Party Inspections of Fire Alarm Systems

Stefan Siegfried Veit
Doctoral Student, Faculty of Electrical Engineering
University of West Bohemia
Pilsen, Czech Republic
TÜV SÜD Industrie Service GmbH
Munich, Germany
veit@fel.zcu.cz, stefan.veit@tuvsud.com

Frantisek Steiner
Professor, Faculty of Electrical Engineering
University of West Bohemia
Pilsen, Czech Republic
steiner@fel.zcu.cz

Abstract

The proposed conference paper addresses a systemic approach for risk-based third-party inspections of fire alarm systems. In the first part of the article, there is a comprehensive literature review of what the status is regarding current research on the use of risk-based inspection methodology on fire alarm systems. This is followed by an explanation of the chosen methodology. The paper then evaluates and presents the results of expert interviews with manufacturers of fire alarm systems as well as the results of surveys among recognized experts for the inspection of fire alarm systems in Germany. The evaluation is carried out by means of a qualitative content analysis. Using the results from these surveys as well as the findings on defect occurrence-statistics from previous work by the authors, a systemic approach for the risk-based test content to be selected for third-party inspections of the systems by technical experts is then presented. The results serve as a basis for an optimized inspection concept to increase efficiency in the operation of the systems while maintaining or improving availability. Furthermore, suggestions are made as to which inspection contents must be included or given increased attention due to technical innovations as well as a changed risk situation. The last part of the conference contribution is a discussion of the results and a summary of the most important findings.

Keywords
Risk based inspection, testing, fire alarm system, safety, building.

1. Introduction

Fire alarm systems play an essential role in ensuring the safety of people and animals in complex or publicly used buildings (Merschbacher, 2018). In terms of building code requirements, these systems fulfill the tasks of detecting fires in the formation phase, localizing the dangerous event, alerting emergency services (e.g., fire department, police, rescue service), warning people in the danger zone, and controlling other fire protection-relevant parts of the technical building equipment.

To reach these protection goals, the systems must meet comprehensive availability requirements. For this reason, there are numerous national and European regulations that define the operation, maintenance, inspection, and regular testing of the systems with regard to their proper condition (Gerber, 2019).

In complex building structures, where the legislator places particularly high demands on the availability and fault-free condition of the fire alarm systems, third-party inspections of the system by experts are required at regular intervals in addition to the classic maintenance measures.
The large number of required testing and maintenance measures with the additional third-party inspections result in high costs. On the one hand, these measures require a high level of staffing by highly qualified experts, while on the other hand they cause increased operating costs for the building owner and, finally, they also contribute to deficits in sustainability due to the resulting emissions.

In terms of cost reduction in the building industry as well as the green deal, it is a declared goal to reduce the effort for tests and inspections. However, the availability of the affected systems must not suffer as a result. Predictive, risk-oriented planned individualized inspection plans can contribute to this but have not yet been developed for these systems.

This type of maintenance is called Risk-Based Inspection (RBI). The approach is well known from the process industry and has been successfully applied to the operation of power plants and production facilities in the petrochemical industry for decades. For reasons of safety for the environment, personnel and sustained high availability of production, maintaining the technically sound condition of this equipment has traditionally played an important role in these plants. To keep the costs of maintenance low in this price-sensitive market, the methodology of "Risk-based Inspection (RBI)" was introduced in the American region in the 1990s. The underlying logic is that most risky components are concentrated in a limited area of an investment. It is therefore necessary to prioritize the inspection and maintenance of these assets and allocate additional resources. These additional costs can be offset by lower maintenance costs for other lower-risk assets (Bhatia et al., 2019; Faber, 2002).

To evaluate an RBI inspection approach for fire alarm systems, the risk factors that influence the availability of fire alarm systems must be known. Furthermore, a distinction must be made as to which qualitative availability requirements are to be placed on different application areas and fire alarm systems. The author identifies these influencing factors from the results of his previous research and presents a proposal for a risk-based inspection approach for third-party inspections of fire alarm systems within the scope of the article.

1.1 Objectives

This study is presented here and aims to present a systemic approach for the planning and implementation of risk-oriented third-party inspections. The aim of the paper is first to present the current state of research in the mentioned topic area in a comprehensive literature review. The foundations of the risk-based approach to third-party inspection are provided by the results of expert interviews, expert surveys, and a quantitative study of the frequency of occurrence of defects in fire alarm systems.

From the data presented, it is derived which test contents must be considered more intensively in the influence of which risk factors during testing or can be neglected due to influencing factors.

The goal is a final discussion of the results to determine whether the risk-based influences on testing that are considered can optimize efficiency, save resources, and ultimately ensure that availability requirements are met.

2. Literature Review

From the general economic pursuit of efficiency and effectiveness comes the desire of every plant operator to achieve a balance between the benefits or advantages of inspections and the associated costs and expenses (Bhatia et al., 2019). Risk-based inspections are one approach to meeting this aspiration. The underlying logic is that most high-risk components of a system are concentrated in a limited area of a facility. Inspection and maintenance of these assets must therefore be prioritized, and additional resources must be allocated. These additional costs can be offset by lower maintenance costs of other lower risk assets (Shin et al., 2020).

The RBI methodology, which is now practiced and standardized, originated in the Americas, and was designed for use in the petrochemical and process industries. The corresponding approaches are largely standardized. Corresponding projects were carried out in the late 1990s and early 2000s (Bhatia et al., 2019; Cordis, 2023; Faber, 2002).

If we now consider the state of research on applying risk-oriented maintenance approaches as well as the resulting method framework to other fields and systems, we find that there are various current research approaches in this regard.

First, with respect to application cases considered here in the field of buildings, it can be stated that there is a large body of work dealing with risks to people in buildings and building structures. For example, Van Weyenberge, Deckers et al (2019) are concerned with the development of a method for assessing the life safety level of persons in buildings in the context of fire safety design. As part of the work, a computationally efficient quantitative risk assessment procedure was developed to evaluate the fire safety level based on the probability of failure and individual and social risk. Van Coile, Hopkin, et al. (2019) state in their work that probabilistic risk assessments are a necessary approach to provide an objective safety basis for atypical fire protection structures. As part of their research, they have developed an objective measure of adequate safety and propose this as a standard against which the adequacy of fire protection designs can be measured. This recognizes that what constitutes acceptable safety is subjective and may change over time. Similar research approaches are presented by Kong, DP., Lu, SX. and Ping, P. (2017). Sabapathy, Depetro et al. (2019) demonstrate the application of a similar approach to the performance-based design of a six-story commercial building with an open stairwell connecting four floors in a case study. Detailed event trees supported by statistical data and analysis are used to calculate the corresponding probabilities.

If we consider research related to building safety equipment in addition to the application of risk-based approaches to the design of building structures, which is relevant here, we can find numerous papers in the area of reliability analysis of fire alarm systems and other safety-related equipment (Gupta et al.; Jafari et al., 2020; Qu et al.). Highlighting an concrete example, Pas and Klimczak (2019) study various operational and reliability parameters of some fire alarm systems with different functional architectures. The considered systems were operated in a specific environment with a large traffic area and can be divided into three categories: concentrated, diffuse, and mixed. The studies refer to the actual results of the operational process tests, such as the duration of repairs and damages. In this way, it was possible to establish correlations that allow defining the operational and reliability parameters for a fire alarm system (FAS) operating under the selected study conditions. In another work Klimczak, Pas et al. (2022) deal with indicators of reliability of FAS. Diagrams of energy balance development for selected operational and reliability parameters were also developed. Festag (2016; 2018) investigated the false alarm rate of fire alarm systems in different countries in Europe in two publications. In the field of maintenance and servicing of fire alarm systems, research is currently focusing on remote services (Pfeiffer, 2022). In conclusion to the thematic focus of fire alarm systems, it can be stated that numerous studies deal with new technologies such as AIoT as well as Iot for this use case (Jones, 2012; Mondal et al., 2023).

Furthermore, however, one notes that for the concrete application of risk-based inspection approaches to parts of the technical building equipment, only few works have existed so far. Sobral and Ferreira (2016) address the application of RBI to automatic fire extinguishing systems in. Their research discusses the importance of testing, inspection and maintenance procedures related to fire sprinkler systems and proposes a methodology based on international standards and supported by testing/inspection reports to adjust the frequency of these actions according to the degree of deterioration of the components and considering safety aspects.

Overall, based on the structured literature review conducted, it can be stated that there is no specific research to date on the application of RBI in the field of fire alarm systems. However, the research presented has shown all the more that the maintenance of precisely this type of system is of particular importance. The reason for this is that these systems are usually in a dormant state, so that their functionality in an emergency is not known.

Thus, there is a research gap in the mentioned field, which shall be reduced by the shown work. In particular, this research gap consists in the fact that, based on an empirical analysis of the practical operating behavior of fire alarm systems in buildings, it is not known where particularly critical or non-critical system assemblies are located, which would therefore have to be considered in particular or in less depth in the course of an RBI approach. In addition, the influencing factors have not been conclusively analyzed. This research work aims to narrow this gap somewhat.

3. Methodology

The chosen method for evaluating the systemic approach for risk-based third-party inspections of fire alarm systems presented in this article is based on the previous preventive inspection contents explained in the introduction based on the current normative and regulatory requirements. The process is graphically illustrated in Figure 1.

First, an investigation is carried out to determine which additional risk factors resulting from new technological influences and experience values must be dealt with in the course of the inspections. These influencing factors are evaluated by means of expert interviews with manufacturers of fire alarm systems and a survey of recognized experts in the field of inspection of such systems.

The additional consideration of these inspection contents initially results in a comprehensive and complex inspection framework, which at the same time provides the starting point for the consideration of risk-oriented optimization measures of the inspections. Here, influencing factors from two perspectives are considered. On the one hand, the risk factors from operational experience are taken into account. For this purpose, findings from previous scientific work of the authors on the frequency distribution of occurring errors are used and their influence on the test contents is presented. In particular, it is considered under which influencing factors which classes of defects occur more or less frequently. In addition, risk-based influencing factors are examined from the perspective of experienced test engineers and included in the systemic approach with regard to their influence. These factors are identified from expert interviews and surveys. From the totality of these findings, risk priority factors can be determined in the final part of the document in a qualitative sense as the product of the probability of occurrence, the potential extent of damage and the probability of detection.

The test contents and processes optimized under this aspect then form the systemic approach for risk-based third-party inspections of fire alarm systems, which is discussed in the following.

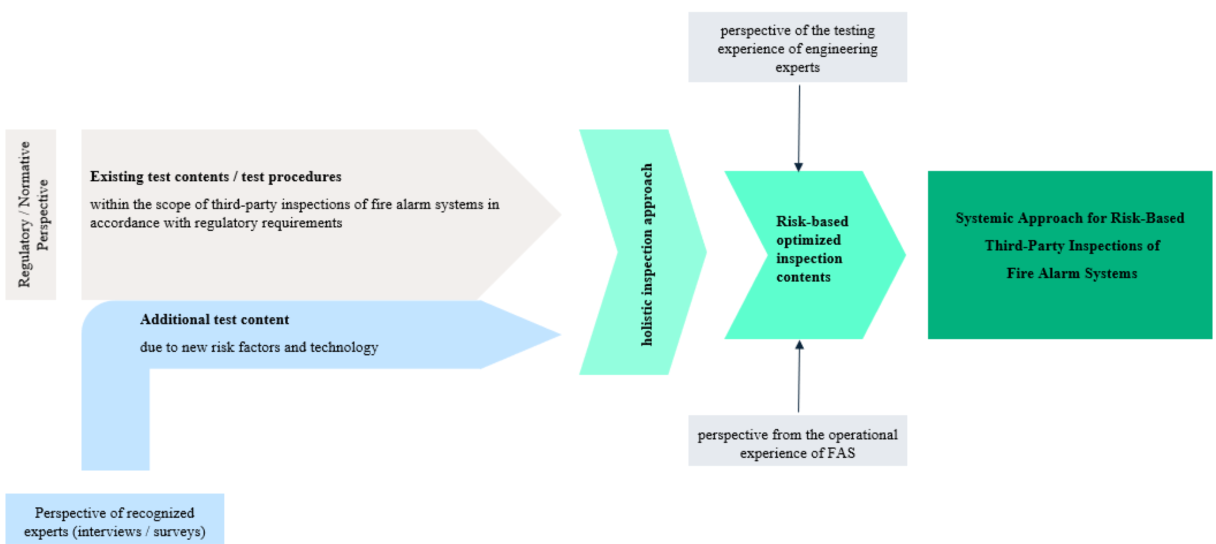

Figure 1. Methodical procedure for the development of a systemic approach for risk-oriented third-party inspections of fire alarm systems

4. Results and Discussion

4.1 Background situation, current regulatory requirements

In accordance with the methodology chosen for this paper, the work begins with an analysis of the current requirements for test content in third-party inspections of fire alarm systems in Germany. The corresponding requirements are given in the inspection principles, which are published by the IS-Arge Bau (2011). In accordance with the requirements, the experts' activities are focused on a total of four fundamental topics. The breakdown and the required test contents are shown in Figure 2. In Germany, the frequency of tests and the specification of which fire alarm systems are to be tested by recognized experts are defined by the legislator within the framework of the building regulations of the federal states. It can be stated that tests of fire alarm systems are generally required before commissioning, after significant technical changes to the system (e.g., replacement of the fire alarm control panel), after structural changes and recurrently in a cycle of three years. Systems in most special buildings are subject to testing, especially if the systems are required due to the use of the building (sales premises, places of assembly, etc.) or due to compensation for other structural deviations (e.g., flammability of the structural envelope).

In this regard, the existing content currently represents a broad content of fire alarm system testing that is representative of all systems. Since the definition of these test contents, there have been numerous technical innovations in the industry, so that the test contents can also be adapted based on operational experience and considering new technical possibilities. These circumstances are considered within the scope of the study through the expert interviews conducted.

Test contents of third-party inspections of fire alarm systems by recognized experts in Germany

Conformity-Check of system-execution with the requirements	**Inspection of fire alarm control panel (FACU)**	**Inspection of transmission routes**	**Inspection of fire detectors**
- Checking the arrangement / coverage of the detector zones- - Testing of the intended interaction with other fire protection devices as well as the non-reactivity of the control functions - Testing of the forwarding of alarm and fault messages- - Testing of precautions for the avoidance of flood alarms	- Checking the design of the assembly room - Inspection of the power supply and overvoltage protection - Test of the function of the operating and fault messages - Test of the control of peripheral devices (e. g. key depot, fire department control panel) - Test of the connection to the fire department - Test of the use of primary and secondary connections - Testing of fire control systems and safety relevant links with the building control system	- Testing the functional integrity of the cable system in case of fire - Inspection of electromagnetic interference and signaling technology	- Checking the assignment to detector groups and detector zones - Inspection of suitability and arrangement of automatic detectors according to fire characteristics and room geometry - Inspection of the arrangement of non-automatic detectors according to escape route - Inspection of measures to avoid false alarms - Inspection of the arrangement of the separating elements (for ring circuits) - Inspection of the detector labeling - Testing the function of the detectors

Figure 2. Overview of the current test contents of third-party inspections of fire alarm systems by recognized experts in Germany.

4.2 Evaluation of the additionally demanded test contents

To achieve the objectives of the work presented here, the first step of the work is to use expert interviews and surveys to determine what additional factors would need to be considered when technical experts inspect fire alarm systems. In accordance with the methodological procedure described in Figure 1, this involves an evaluation that is intended to integrate any missing / insufficiently considered inspection content into an overall scope that is later optimized in terms of its efficiency based on identified risk factors.

A qualitative content analysis of the statements made by a total of 5 experts from the expert interviews and 47 recognized experts questioned in a survey summarizes these additional aspects into a total of three additional key points of the audit. These are shown in Figure 3.

Additional test contents according to statement / opinion of the technical experts		
Assessment of the operational quality of the system	**Evaluation of the software integrity of systems programming and parameterization**	**Testing of the full function of fire controls over the entire functional chain**
Evaluation - of operator behavior - the implementation of maintenance and servicing measures - the elimination of defects,- the measures for system optimization regarding quality criteria.	- Evaluation of measures to prevent undetected / unknowing / malicious changes to the software as well as the parameterization of the system. - Identifiability of changes in the system parameterization and programming compared to previous tests.	- Evaluation of the fire controls over the complete functional chain of the system, regarding the requirements of the overarching safety-related system function and the fail-safety / availability of the system interfaces.

Figure 3. Overview of additional test aspects according to the assessment of technical experts.

4.3 Determination of risk-priority ratios

After analyzing the additional test contents required from an expert's point of view, the next step is to identify the risk factors where faults occur in a fire alarm system and lead to a possible damage event or malfunction of the system. In order to be able to derive a prioritization of the test contents depending on the risk, risk priority factors are formed from these factors together with the detection probability of the respective defects. An evaluation is carried out in two steps. In the first step, it is analyzed how different risk factors influence the frequency of occurrence of defects in the fire alarm system. The identification of these factors was described in detail in a previous paper by the authors. From a sample analysis of test reports of third-party monitoring of fire alarm systems, defect categories were formed whose frequency of occurrence was statistically evaluated. From this, trends could be derived, which are summarized in Figure 4. Here it is shown in which areas of a fire alarm system defects occur with increasing or decreasing frequency, depending on the influencing factors of system age, system size and the environmental conditions to which a system is exposed during operation.

These factors have a direct influence on risk-oriented test contents, because the more frequent or the more probable the occurrence of defects in a certain system area is, the more important it is to consider this area in terms of content during tests.

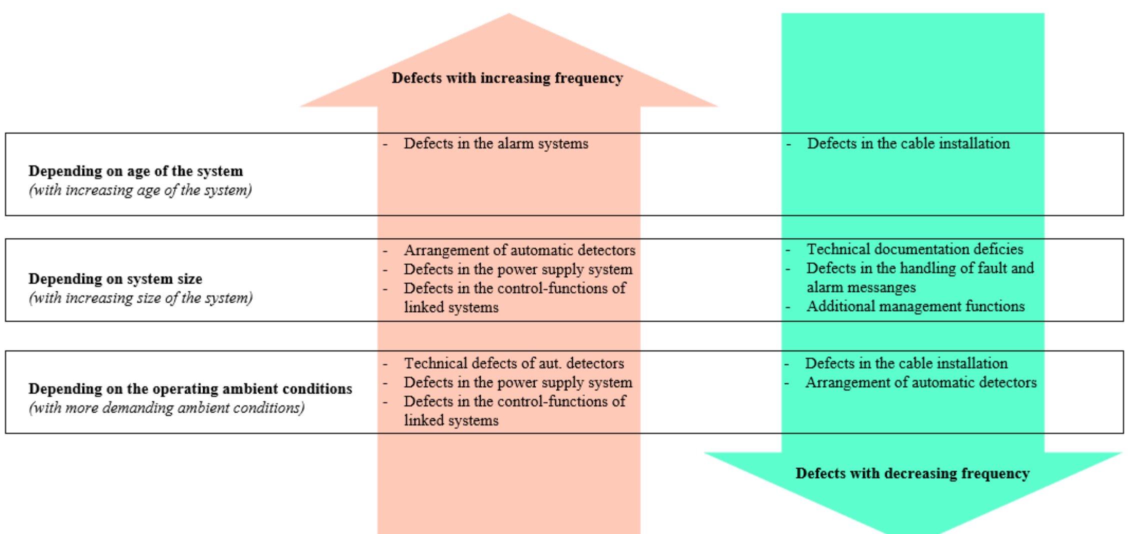

Figure 4. Overview of the influence of internal risk factors on the frequency of occurrence of defects in fire alarm system assemblies.

In a second step, a qualitative assessment of the potential extent of damage and the probability of detection of defects is made. For this purpose, coding codes according to Table 1 are introduced in order to be able to make a classification according to dedicated qualitative factors for each defect category. The results of this evaluation are shown in Table 2.

Table 1. Importance of the qualitative risk classifications and criteria for the assignment to the respective categories

Category / Classification	Potential extent of damage in the event of defects	Probability of detection of defects in system operation
1	Defects of this category have no direct influence on the effectiveness and operational safety as well as the function of the fire alarm system. The protection goals of the system are not influenced.	Defects in this category could be detected without much effort by the operator of the system during the daily inspections / walk-throughs.
2	Defects in this category do not directly affect the effectiveness and operational safety of the fire alarm system. Influences on subsequent functions in the operational processes outside the safety-related systems are possible. The protection goals of the system are not significantly impaired.	Defects in this category can be detected by the system operator during normal maintenance activities, e.g. when operating the system. No special tests and inspections are required to identify corresponding defects.
3	Defects in this category have an indirect influence on the effectiveness and operational safety of the fire alarm system. For example, damage can increase the times for alarm detection or reduce the maintenance of functions in the event of fire or damage. The protection goals of the system can be partially impaired.	Defects in this category can be identified by the operator of the system or by specialists in the operation of the system during inspections of the hazardous area. These defects can also be identified during structural measures, which can be the starting point for inspections.
4	Defects in this category directly affect the effectiveness and operational safety of the fire alarm system. These deficiencies result in a violation of the protection goals when the system is required, or the system no longer fulfills its intended purpose.	Defects in this category cannot be detected by simple visual inspection during walk-through inspections. Specific tests / inspections by qualified personnel are required to identify defects in this category.
5	Defects in this category directly affect the effectiveness and operational safety of the fire alarm system. These deficiencies result in a violation of the protection goals. Malfunctions can cause additional hazards and risks due to the affected system parts / defects.	Defects in this category cannot be detected by simple visual inspection during walk-through inspections. Specific tests / inspections by qualified personnel are required to identify defects in this category. In order to assess the complete functional chain, interdisciplinary expert knowledge from different departments is also required.

The product formed from the potential extent of damage and the probability of detection is referred to as the "specific risk coefficient" in this paper. This coefficient forms the starting point for the further formation of the risk priority numbers. These are then system-dependent and must be determined on a case-by-case basis. They are based on the findings from Figure 4, since different probabilities of occurrence of defects can be assumed depending on the operational environmental conditions, the system age as well as the system size.

Table 2. Qualitative determination of risk coefficients for the need for additional inspections by system assembly / defect categories.

	Defect-Category	Potential extent of damage in the event of defects	Probability of detection of defects in system operation	**Specific Risk coefficient for the need for additional inspections as the product of probability of detection and extent of damage**
DC.1	ADD. DEFECTS WITH INFLUENCE ON FIRE FIGHTING	1	3	**3**
DC.2	INFORMATION DEFECTS	1	3	**3**
DC.3	OTHER DEVIATIONS FROM TECHNICAL REGULATIONS	1	4	**4**
DC.4	DEFECTS IN CABLESYSTEM AND FIRE PROTECTION OF SYSTEM PARTS	3	4	**12**
DC.5	TECHNICAL DEFECTS OF AUTOMATIC FIRE DETECTORS	4	4	**16**
DC.6	DEFICIENCIES IN THE ARRANGEMENT OF AUTOMATIC DETECTORS	3	4	**12**
DC.7	TECHNICAL DEFECTS OF MANUAL FIRE DETECTORS	3	3	**9**
DC.8	DEFICIENCIES IN THE ARRANGEMENT OF MANUAL DETECTORS	3	2	**6**
DC.9	DEFECTS IN THE POWER SUPPLY	4	4	**16**
DC.10	DEFECTS IN THE FACU OPERATING AND DISPLAY EQUIPMENT	4	2	**8**
DC.11	ALARM DEFICIENCIES	5	4	**20**
DC.12	DEFICIENCIES IN THE CONTROL OF LINKED SYSTEMS	5	5	**25**
DC.13	DEFICIENCIES IN THE REACTION OF LINKED SYSTEMS	5	5	**25**
DC.14	DEFICIENCIES IN THE HANDLING OF FAULT MESSAGES	3	3	**9**
DC.15	DEFICIENCIES IN THE TRANSMISSION OF ALARM MESSAGES	4	5	**25**
DC.16	DEFICIENCIES IN ADDITIONAL MANAGEMENT FUNCTIONS	2	1	**2**

4.4 Derivation of a systemic approach

From the totality of the results of the investigations presented so far, a systemic approach for risk-oriented third-party inspections of fire alarm systems can be derived. For this purpose, the existing inspection contents from Figure 2. are combined with the additionally required inspection contents in Figure 3. The contents of the individual headings of the inspection are evaluated qualitatively regarding the required inspection depth under the influence of the presented risk coefficients. The external risk factors to be used in individual cases, which consider the probability of defects occurring, are included individually to be able to determine a risk-oriented test plan for each system on a case-by-case basis. This results in an overall inspection that is tailored to the content of each individual case by means of risk priority factors. Figure 5. shows an overview of this systemic approach.

The framework conditions of the chosen approach are based first on the fact that the tested plant was put into operation without any defects. Under this assumption, it is assumed that defects resulting from errors in the planning, project planning or installation of the system are not present. The systemic approach taken is applied to recurring tests at regular intervals because of this determination. Based on this assumption, some contents could be deleted from the test contents shown in Figure 2. This concerns the tests to investigate the use of primary and secondary lines, which are usually not changed after the system has been commissioned in the normal operational scope. Furthermore, the tests for the arrangement of isolating elements have been deleted. The background to this optimization is the technical further development of fire alarm systems, which has led to corresponding separating elements being integrated in each bus subscriber (detector) in today's systems. For this reason, according to the experts, an assessment of the requirement can be dispensed with.

The approach taken first divides the inspection contents regarding the inspection depth to be selected within the scope of the third-party inspections or the required scope of random samples. As described, this classification is based on the risk coefficients determined from the extent of damage and the probability of detection during operation of the system.

To be able to adapt the approach taken individually to the systems to be inspected, the effect of further risk factors such as the system age, the system size and the operational environmental conditions is also specified for each inspection content. In each case, an indication is given of how the scope of the inspections is to be adapted about the specific inspection contents in each case if the influence of the risk factors changes.

For example, it can be deduced from Figure 5 that when testing the alarm function, the depth of the inspection must be increased as the system age increases, while regarding handling fault messages, low inspection depths are required as the system size increases. With the aid of this systemic approach, the test content can be individually determined and adapted according to the existing system based on the risk assessment of the expert. It should be noted that the operational experience values and the operational quality of the system have a particular influence on the determination of the test cycle of the system. If the operating quality is low - e.g., due to a lack of maintenance measures - more frequent third-party inspections are required. If the system is operated conscientiously, the inspection cycles can be extended accordingly.

Systemic approach for determining risk-oriented inspection content of third-party inspections

Conformity-Check of system-execution with the requirements

Test density	Content	R.A.	R.S.	R.E.
Content with high test density as well as high test depth *(Sampling rate 70 - 100 %)*	- Testing of the intended interaction with other fire protection devices as well as the non-reactivity of the control functions	↔	↑	↑
	- Testing of the forwarding of alarm messages	↔	↓	↔
Contents with medium test density as well as medium test depth *(Sampling rate 30 - 70 %)*	- Checking the arrangement / coverage of the detector zones-	↔	↑	↓
	- Testing of precautions for the avoidance of false alarms	↔	↔	↑
Content with low test density as well as low test depth *(Sampling rate 10 - 30 %)*	- Testing of the forwarding of fault messages	↔	↓	↔

Inspection of fire alarm control panel (FACU)

Test density	Content	R.A.	R.S.	R.E.
Content with high test density as well as high test depth *(Sampling rate 70 - 100 %)*	- Inspection of the power supply and overvoltage protection	↔	↑	↑
	- Test of the connection to the fire department	↔	↓	↔
	- Testing of fire control systems and safety relevant links with the building control system	↔	↑	↑
Contents with medium test density as well as medium test depth *(Sampling rate 30 - 70 %)*	- Checking the design of the assembly room	↔	↔	↔
Content with low test density as well as low test depth *(Sampling rate 10 - 30 %)*	- Test of the function of the operating and fault messages	↔	↓	↔
	- Test of the control of peripheral devices (e. g. key depot, fire department control panel)	↔	↔	↔

Inspection of transmission routes

Test density	Content	R.A.	R.S.	R.E.
Content with high test density as well as high test depth *(Sampling rate 70 - 100 %)*				
Contents with medium test density as well as medium test depth *(Sampling rate 30 - 70 %)*	- Testing the functional integrity of the cable system in case of fire	↓	↔	↓
	- Inspection of electromagnetic interference and signaling technology	↓	↔	↓
Content with low test density as well as low test depth *(Sampling rate 10 - 30 %)*				

Inspection of fire detectors

Test density	Content	R.A.	R.S.	R.E.
Content with high test density as well as high test depth *(Sampling rate 70 - 100 %)*	- Testing the function of automatic detectors	↔	↔	↑
	- Testing the function of alarm devises	↑	↔	↔
Contents with medium test density as well as medium test depth *(Sampling rate 30 - 70 %)*	- Checking the assignment to detector groups and detector zones	↔	↑	↓
	- Inspection of suitability and arrangement of automatic detectors according to fire characteristics and room geometry	↔	↑	↓
Content with low test density as well as low test depth *(Sampling rate 10 - 30 %)*	- Inspection of the detector labeling	↔	↔	↔
	- Testing the function of manual detectors	↔	↔	↔
	- Inspection of the arrangement of non-automatic detectors according to escape route	↔	↔	↔

Evaluation of the software integrity of systems programming and parameterization

Test density	Content	R.A.	R.S.	R.E.
Content with high test density as well as high test depth *(Sampling rate 70 - 100 %)*	- Evaluation of measures to prevent undetected / unknowing / malicious changes to the software as well as the parameterization of the system.	↔	↑	↔
Contents with medium test density as well as medium test depth *(Sampling rate 30 - 70 %)*	- Identifiability of changes in the system parameterization and programming compared to previous tests.	↔	↑	↔
Content with low test density as well as low test depth *(Sampling rate 10 - 30 %)*				

Testing of the full function of fire controls over the entire functional chain

Test density	Content	R.A.	R.S.	R.E.
Content with high test density as well as high test depth *(Sampling rate 70 - 100 %)*	- Evaluation of the fire controls over the complete functional chain of the system, regarding the requirements of the overarching safety-related system function and the fail-safety / availability of the system interfaces	↔	↑	↑
Contents with medium test density as well as medium test depth *(Sampling rate 30 - 70 %)*				
Content with low test density as well as low test depth *(Sampling rate 10 - 30 %)*				

Assessment of the operational quality of the system according to determine the interval until the next periodic inspection

Evaluation of operator behavior, the implementation of maintenance and servicing measures, the elimination of defects and the measures for system optimization regarding quality criteria.

↑ Increase of test density / test depth
↓ Decrease of test density / test depth
↔ No influence on test density / test depth

R.A. – Influencing factor of the system age - consideration with increasing system age
R.S. - Influencing factor of the system size - consideration with increasing system size
R.E. - Influencing factor of the operating / environmental conditions- consideration with increasing exposure

Figure 5. Proposal of an systemic approach for determining risk-oriented inspection content of third-party inspections

4.5 Discussion

1. The analyses presented, which form the basis of the specific risk factors and risk priority factors identified, show that a risk-oriented differentiation of the inspection content within the scope of third-party inspections is possible in principle and that it is therefore also possible to differentiate the inspection depth to be selected and the scope of the inspections. This forms a basis for a risk-based inspection approach.

2. The proposed systemic approach meets the fundamentals of risk-based inspection, which is since risks can be narrowed down to certain sub-areas of systems according to their priority, and thus areas of systems where there is an increased risk can be looked at with increased depth and effort. This additional effort can be saved when inspecting less risky system components. This approach can increase the overall efficiency and effectiveness of inspections and conserve resources and manpower.

3. The approach shown represents an open framework within which guidelines technical experts can vary the inspection content in the context of third-party inspections. The qualitative classification leaves room for discretion, which allows individual adjustments to be made based on the experience of the experts, but which correspond to a systemic framework.

4. Within the framework of the approach shown, the operating conditions or the operator behavior of the system are also considered through the influence on the cycle or the determination of the intervals of the recurring tests. This is an important aspect, which was mentioned by all the experts interviewed as a decisive influencing factor on the risk of system failures and defects.

5. Proposed Improvements

The studies presented in this article have shown that it is possible to successfully and systemically implement a risk-oriented inspection approach based on statistical studies of the frequency of occurrence of defects, the potential extent of damage, and the probability of detection.

The approach currently chosen only takes into account risk factors internal to the system, i.e. risks emanating from the fire alarm system. In addition to these influencing factors, it is also relevant from the authors' point of view to consider the influence of a fire alarm system in the construct of the overall fire protection measures of a building. For example, it is important to consider whether a system is used in a ground-floor kindergarten or a multi-story assembly center, or even in an infrastructure facility such as an airport or train station. This represents additional "external risk factors" whose influence on the choice of testing depth or a comprehensive risk-based deployment must be considered. This will be further investigated in future research activities.

6. Conclusion

In this study, we demonstrated a systemic approach for risk-based determination of the depth of inspection of third-party inspections of fire alarm systems. The approach presented is based on the prioritization of inspection contents or the inspection depth / number of samples of the individual inspection contents based on risk factors. As a basis for the work, the contents of the current tests were analyzed in accordance with the chosen methodology and, based on the assessment of technical experts, expanded to include additional test contents that have arisen, for example, due to technical innovations. The risk priority factors used to create a risk-oriented approach are based on the product of the probability of occurrence, the potential extent of damage and the probability of detection of defects in the course of plant operation. These factors were determined qualitatively and are presented in the article. The approach shown provides experts who perform third-party inspections of fire alarm systems with a guideline for the first time on how to systematically adjust the inspection depth on the basis of an individual risk assessment. This enables a more efficient execution of the inspection, which is optimized with regard to the effectiveness of the inspections.

In the context of planned future work, a deepening of the approach is planned. Especially with regard to further external risk factors, which are based on the individual protection goal of the fire alarm system as well as the building structures.

Acknowledgements

The research work as well as the project for the investigation of risk-based testing approaches for fire alarm systems, which forms the basis of the findings presented here, was supported by TÜV SÜD Industrie Service GmbH both by providing the necessary data from tests and inspection reports and by financial means.

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Biographies

Stefan Siegfried Veit is a PhD student at the University of West Bohemia in Pilsen, Czech Republic. As part of his academic education, he earned a Bachelor of Engineering degree in electrical and information engineering with a focus on communications engineering and a Master of Business Administration degree with a focus on environmental management. Stefan Veit is a recognized expert for fire alarm systems in Germany and works for TÜV SÜD Industrie Service GmbH as head of product and quality management in electrical engineering. He is also a group leader of the technical management in the real estate division. He has published both conference and journal papers. The paper he has written is part of his dissertation and presents initial partial results of the work.

Dr. Frantisek Steiner is an Associate Professor at the Faculty of Electrical Engineering of the University of West Bohemia. He was awarded an Ing. (MSc) degree in the field of Applied Electronics in 1996, a PhD degree in the field of Electronics in 2001 and an Associate Professorship in Electrical Engineering in 2008. He is the head of the Diagnostics and Testing Engineering Team at The Regional Innovation Centre for Electrical Engineering (RICE), deputy head of Department of Materials and Technology and head of Diagnostics Research Group at this department. His research fields include risk management, information security management systems, quality management systems and IT services management. Other areas of his research include diagnostics, testing of materials and electronic devices, and electronics technology. He is a supervisor of 15 Bc. and 47 MSc. theses successfully defended in 2000 – 2023. Currently supervisor of 3 Ph.D. students and supervisor of 5 defended Ph.D. students. He has published more than 125 papers and presented 45 contributions in 35 congresses.