Analysis of the Reliability of Automatic installed Fire Detection and Fire Alarm Systems

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Abstract

Automatic installed fire detection and fire alarm systems are used for a fast and reliable detection of fires in an early stage. Faults can impair the systems' operational readiness. This paper examines the availability – as a specific reliability characteristic for repairable systems – of installed fire detection and fire alarm systems (standard-compliant, commissioned and maintained by certified installers), which are in real use. The results confirm previous findings and go more in-depth on the system size, temporal behaviour over the years, and the area of application of the analysed systems.

Keywords: Reliability, availability, characteristics of systems performance, fire detection and fire alarm systems, fdas, statistical analysis, risk analysis

Introduction

Automatic installed fire detection and fire alarm systems (FDAS) are used to detect fires reliably and as quickly as possible. An installed FDAS essentially consists of fire detectors, alarm installations and fire control and indication equipment [1], or according to Schlosser, Hartwig & Berger [2] of fire control and indication equipment and the periphery [3]. As well as a voluntary decision by the site operator to use a FDAS, there are usually also building law requirements, results of a risk assessment, or insurance agreements, which require a FDAS for the achievement of safety objectives. Early fire detection and measures derived from this such as information for responding services, the warning of people, the activation of other fire protection systems and the permitting of easy access for the fire services, the locating of the fire outbreak, and the tracing of the spread of fire bring decisive advantages for the effective protection of people, property and the environment [3], [4].

In order to ensure early fire detection, fire alarms analyse parameters typical of fires and pass these on to the fire control and indication equipment. The alarm and fault states of the systems are determined from the input signals and if necessary corresponding output signals are sent, in order to initiate measures automatically and quickly.

Installed FDAS, like other technical systems of this kind, have a failure probability, referred to as availability in the case of repairable systems [5]. There already exist papers on the availability of installed FDAS, which, however, refer to either a special area of application (nuclear power station, [6]), to other overall systems and/or country-specific boundary conditions (cf. [7], [8] with refer to [9]; see also [3]) or which have results with a basis that is not, at least in part, recorded or which can no longer be comprehended from the publications (cf. [10], [11], [12]).

Table 1 shows different analyses on the availability of FDAS, sometimes with availability parameters.

This paper examines the availability of installed FDAS, in real use [13] - which are standard-compliant, commissioned and maintained by certified installers. We have analysed the status messages, which provided indicate how long the FDAS have been in operation and in a faulty or alarm state. In the analysis described here, the operation data from 19 installed FDAS is analysed, in use, about their lifecycle, size and kind of areas of use, and regarding their availability and number and duration of faults. These 19 systems result from an analysis of system data from very many systems. In these systems selected for the analysis, which form a cross-section of different areas of use and system sizes from the available inventory of systems. It was observed that the state messages for the selected systems are available without interruptions and are – with understandable exceptions – comprehensive. This paper will show that the achieved value is able to be generalised, that under given conditions the values are able to be raised over years of use and the availability will be combined with the probability of occurrence of fire to deducing a reliability in case of fire.

Table 1. Published results on the availability of installed FDAS.

Source	Methodical approach	Availability [%]
Staimer, A., Festag, S. & Münz, F. (2012)	Empirical, faults lead to non-availability	99.83 - 99.97
Staimer, A., Klein, W. & Montrone, F. (2007)	Empirical, non-secured operation leads to non-availability	99.99
Staimer, A., Klein, W. & Montrone, F. (2007)	Model-based, system regarded as not available, if more than one assembly / function group fails	99.97 - 99.98
PD 7974-7 (2003)	Unknown	90.00
Forell, B. & Einarsson, S. (2016)	Empirical, scheduled routine tests of several individual components	Failure rate of individual components; e.g.: average failure rate of optical fire detectors with $1.05 \cdot 10^{-9}$ - $4.23 \cdot 10^{-7}$ h^{-1}
Bukowski, R., Budnick E. & Schemel C. (1999)	Empirical reliability analysis of individual components	Reliability of fire detectors over 10 years with 69.3 -87.5
Association of TUEV e.V. (2016)	Tests of installed for specific constructions grouped into fault-free, minor faults and major faults in initial tests (EP) and scheduled routine tests (WP)	When systems with major faults regarded as not available: EP: 86.1 WP: 85.3

Methodology

In the technical standards (according to DIN 14675-1:2020 [15] with reference to the products according to DIN EN 54 series [1]) the passing on of fault messages to a continuously staffed occupied centre, such as a commissioned installation company, is required for FDAS (cf. DIN VDE 0833-1:2014 [16]). The status reports received at such an installation company for alarm systems are recorded and saved. For the investigation, access to such information was gained via the systems of certified installers. Consistently high quality is ensured and assumed due to the evidence of standard-compliant work in the maintaining of the systems in accordance with DIN 14675 [15]. The status messages provided indicate how long the FDAS have been in operation and in a faulty or alarm state. For this analysis 19 systems were selected from a pool of systems. The 19 systems form a cross-section of different areas of use and system sizes from the available inventory of systems. In the analysis described here, the operation data from 19 installed and operating FDAS is analysed, about their life-cycle, size and kind of areas of use, and regarding their availability and number and duration of faults.

There are times systems like FDAS must be tested and maintained and in these processes the fire alarm control panel may also send failure messages. These messages need to be identified so that they can be excluded for the calculation of the availability. They have therefore been tracked down and assessed - using the work performance records produced by the maintaining installation company - as operational periods (or as faults without functional relevance, respectively). In addition to these faults, other faults are produced by improvements, repairs and (additionally for systems required by building codes) inspections in tests by other experts (cf. DIN 31051:2012-09 [17]). These faults are not functionally relevant either. Work causing these faults is not carried out entirely regularly and cannot be readily deduced from the performance records analysed here. Only the scale of these faults in the totality of faults is estimated based on an analysis of the triggers for fault messages. These faults are included in the availability parameters determined in the following.

The whole data record produced supplies information about the point in time and duration of fault messages - but without specification of the fault message. The proportion of downtime of the life-cycle yields a parameter for non-availability. Inversely, availability can be calculated according to equation 1. There are faults that influence the functionality of the installed FDAS and there are minor faults that influence the proper functioning of the system insignificantly, such as e. g. the failure of a fire detector (because a single fire detector would not set a whole protection sector unsafe, but a failure of e.g. many detectors or a control element would do so). Regarding the analysed faults, based on the data, no statements can be made about the impairing of the system’s functionality, which is why the parameters derived here are conservative.

$$Availability = V = 100 - \left(\frac{\Sigma(Downtime[min])}{Life\text{-}cycle\ time\ [min]} * 100\right) [\%] \qquad \text{(Eq. 1)}$$

Equation 1 can be used to calculate the desired availability parameters from the ascertained downtimes. Several availability parameters result for each system:

A) *The availability (total,n_i) refers to the availability of a system over its total life-cycle time* ($A_{t,ni}$). The values calculated for the examined systems (N=19) are combined in a parameter of *availability (total,N)* over the arithmetic average ($A_{t,N}$). The availabilities ($A_{t,ni}$) of the individual systems continue to be suitable for the deeper analysis of other characteristic system parameters.

B) *Availability (averaged annual values,N) represents a value for the availability of a specific system ($A_{Y,N}$) averaged over several years. An individual annual value corresponds to the availability over 365 days ($A_{Y,ni}$).* These values are in particular drawn upon for the studying of availability in the course of time over the years. Due to calculative "smoothening effects", the *availability* ($A_{Y,N}$) may vary slightly from the *availability* ($A_{t,ni}$) of the same system.

The analysed systems continue to be examined as regards their operating conditions, structure and other characteristics by surveying of the maintainers, in order to make it possible to assign characteristic availability parameters based on individual operating characteristics. Modernising measures and expansions were outlined in these characteristics as well as the technology built in. Based on the performance records for the systems, the triggers for the faults continue to be analysed for a year (02/2017-02/2018) and will be scaled. Resulting out of this investigation additional faults will turn out as functionally not relevant. The value of availability will be cleared from this scale of not relevant cases. After combining the probability of occurrence [18] of a fire there will result a value of reliable detection of an event of fire.

Selected Results

Generalised Availability ($A_{t,N}$)

Figure 1 shows how availability (total) appears, taking into account the availability values of the analysed installed FDAS, and the associated distribution over the number of systems. The consideration of the availability ($A_{t,ni}$) of all 19 analysed systems yield an averaged availability ($A_{t,N}$) of 99.2724 %. As one can see, the derived total average value (red straight line) lies within the confidence interval or below it. This means that it is to be assumed that the total average value no longer changes substantially (see red dotted curve) if other systems are incorporated into the analysis and the parameter value is conservative. For this reason, the value of 99.2724 % is generalised for this kind of system[1].

The maximum value across all systems is 99.9394% (System I) and the minimum value 96.4947 % (System H), which deviates substantially from

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[1] Automatic installed FDAS based on quality products (i.e. products of well-known manufacturers that meet the requirements of the applicable body of rules that are harmonised and mandated for Europe), which are set up in compliance with standards and maintained by certified installers.

the distribution of the other system values. The boxplot in Figure 1 shows the distribution around the median (99.4430 %) in the range between the upper (99.6445 %) and lower quartile (99.1271 %). The development of the confidence interval is compared to the distribution of the generalised availability ($A_{t,N}$).

Considering the finding that 10.41 % of the faults arise due to work on the systems carried out by third parties (on top of the further cleared irrelevant periodically occurring messages), it can be concluded that the availability parameters derived here for these systems are conservative. By correcting the measured data with this scale there arises a corrected Generalised Availability **($A_{t,N,corr.}$)** of **99.3496 %.**

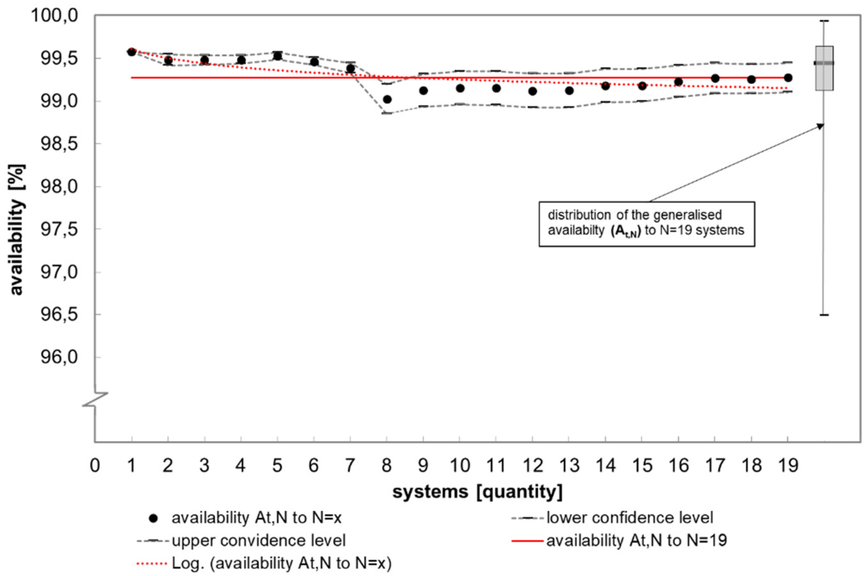

Fig. 1. Availability of the analysed FDAS ($A_{t,ni}$), the confidence interval and the generalised availability ($A_{t,N}$) as an average (red straight line) and as a distribution (box-plot).

Availability ($A_{Y,ni}$) over the time course of the systems

Repairable systems are to be subjected to maintenance measures. With the aim of high availability over time, these systems are inspected, serviced and when necessary repaired (DIN VDE 0833-1:2014). The following presentation in Figure 2 shows the distribution of availability based on the annual values of the systems ($A_{Y,ni}$) over the operation time in years, although fewer system values are available from the documentation of the analysis as the years go by (which can be seen from the x-axis caption and the falling variance).

Across the first four years, the median shows an increase to a high value of 99.8776 %. Between the upper and lower quartile, the distribution of values sinks over time. In the first few years, data is only available on some systems from the time after commissioning. Experience has shown that the fault rate decreases sharply in this period, due to subsequent improvements to the system, which is expressed in stabilised, higher availability values. The distribution stabilises in the first few years, and the high median and lower dispersion remains into the next year. At the start, all 19 systems provide data for analysis. In years three and four, data on 18 systems is analysed. In year 5, another two systems fall out of the analysis (n = 16). Year 6 still provides values on 12 systems, while in year 7 only 8 systems provides information about availability, and in year 8 only 4 systems did. In years 9 and 10, only one system is still supplying a parameter. Accordingly, a distribution cannot be derived in the last years.

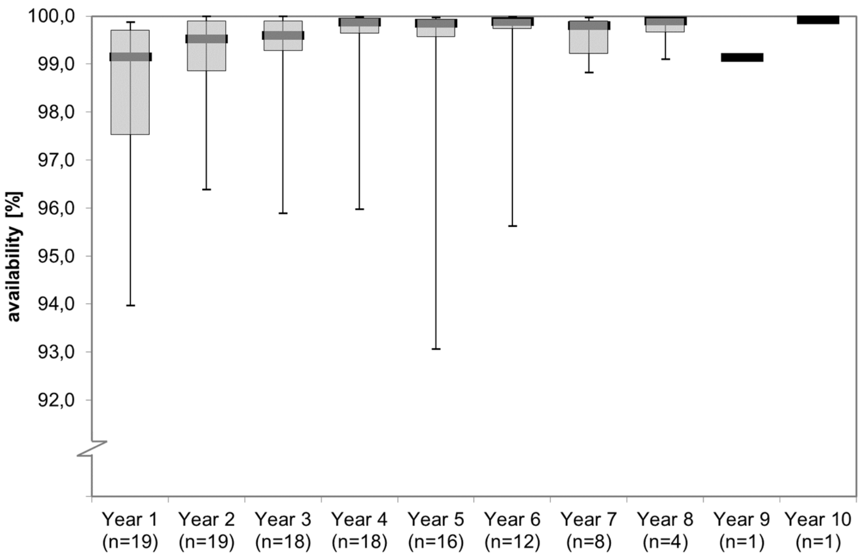

Fig. 2. Availability of the systems ($A_{Y,ni}$) over ten years.

The analysed systems, in addition, partly subjected to a change process. Modernisation measures have also been carried out on the systems in the context of upgrades and modifications.

Reliability in Case of Fire

For Risk Assessments of buildings, the generalized availability of FDAS will be combined with the probability of occurrence of fire by Fault Tree Analysis (FTA). The probability of occurrence of fire is determined on $p_{FIRE} = 1{,}2*10^{-3}$ [18]. In FTA the probability of occurrence of a fire p_{FIRE} and the probability of a not available but installed FDAS $p_{FDAS\ not\ available}$ will be multiplicated. According to FTA the probability of a fire and an installed - but not available at moment - FDAS is calculated in Equation 2.

$$p = p_{FIRE} * \ p_{FDAS\ not\ available} = p_{FIRE} * [(100\ \% - A_{t,N,corr.}): 100]$$

$$= 1{,}2 * 10^{-3} * 6{,}51 * 10^{-3} = 7{,}812 * 10^{-6}$$

(Eq.2)

Conclusion

The results from the analysis of 19 automatic FDAS, in real use, which have been set up in compliance with standards from quality products and maintained by certified installers are evidence of an averaged availability ($A_{t,N}$) of 99.2724 %. After analysing the fault reasons the availability also can corrected to 99.349 %. With respect to the availability values and the variance across the analysed systems, the results achieved here are generalised for the type of systems.

In the examination of the availability parameters over the years of operation, an increase of availability and a decreasing variance around the median can be observed across the distribution of the systems. Such a progression requires not only the correct and standard-compliant planning and setting up of automatic installed FDAS, but also high-quality maintenance. Under the conditions of certified construction, maintenance and modernisation in compliance with standards and using quality products the high availability can be reached and even improved over the time of use. By this high availability the probability of a not available FDAS in case of fire can be hold on a low level of $7{,}812*10^{-4}$ %.

For Risk Assessments this study gives a generalised value of availability and - by combination with the probability of occurrence of a fire - a probability of an installed but not available FDAS of $7{,}812*10^{-6}$.

For further works, this study provides numerous data and a basis for the analysis of further parameters. The data even show indications that the type of building use has an influence on the system's availability [13], [14]. These indications should be analysed with a higher number of FDAS. In the context of further works, deeper questions may be treated, e. g. whether specific conditions of use have a significant influence on the fault durations and/or availability. With further system data, it is intended to examine the evidence of the influence of the type of building use on the occurrence of faults.

In addition, the analysis presented here provides fault root-causes that should be further analysed in order to approximate the availability parameters even more closely to the functionally relevant system values. It is intended to continue the work on this subject.

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