Mission Effectiveness and Failure Rates Drive Inspection, Testing, and Maintenance of

Fire Detection, Alarm, and Signaling Systems

W hen a fire alarm system fails, it impacts mission effectiveness. The degree of impact depends on the role or mission of the alarm system in the overall fire safety mission.

The first type of potential failure is when a system that has been designed and installed to meet specific objectives fails to meet those objectives. The failure may be the result of an operational failure or fault, or it may result from changes in the environment or hazards that affect the system's ability to meet its objectives. The second failure mechanism is when the objectives of the fire alarm system have not been properly matched and integrated with the overall fire safety mission. A third type of failure is when a system "fails positive" due to false or nuisance alarms. Fire protection engineers can have a measurable impact on each of these potential failure mechanisms. Next to mission definition and integration, a program of system inspection, testing, and maintenance (ITM) has the greatest potential to assure system success or failure. In addition, an ITM program can identify when a system has not been properly integrated into the overall fire safety mission.

In a survey of the operational status of 46,339 fire alarm systems conducted by the California State Board of Fire Services,[1] 73% of the respondents cited lack of maintenance for the cause of system failures. Another survey[2] showed that actual equipment problems with smoke detectors, smoke alarms, and control panels were comparable for new systems (less than one year) and

existing/old systems (one year or more). The numbers showed a trend towards higher numbers of failures in older systems for conditions such as "in alarm" or "in trouble" that would be discoverable during routine ITM. A false/nuisance alarm survey showed that 72% of all unwanted alarms could be prevented in the design and installation stages of systems.[3]

Components and assemblies tend to follow the typical "bathtub" failure rate curve as shown in Figure 1. Following the infant mortality phase, the statistical or "intrinsic" failure period is relatively flat, constant, and long until the wear-out or end-of-life phase is reached.

Some manufacturers use 100% burn-in programs to eliminate infant mortality for certain products. In other situations, Quality Control (QC) or Quality Assurance (QA) programs use statistical sampling and analysis to reduce infant mortality by reducing manufacturing defects and by assuring the quality and reliability of the components used to make the product. At the other end of the curve, system changes, upgrades, building renovations, and other factors tend to result in "retirement"[4] of systems and components before the end-of-life or wear-out phase is reached. Thus, the infant mortality phase can be reduced or nearly eliminated and the end-of-life phase cut off, resulting in a relatively flat failure rate over the life of the product. From a component and system product standpoint, today's fire alarm systems are very reliable. In the case of smoke detectors, the statistical failure rate is less than 3.5 or 4.0 failures per million hours (of operation), depending on how the number is determined.[5]

Other fire detection devices, fire alarm appliances, and more complex systems such as control units, which often include customizable software and modular components, do not require computation of failure rates by the listing laboratories as do
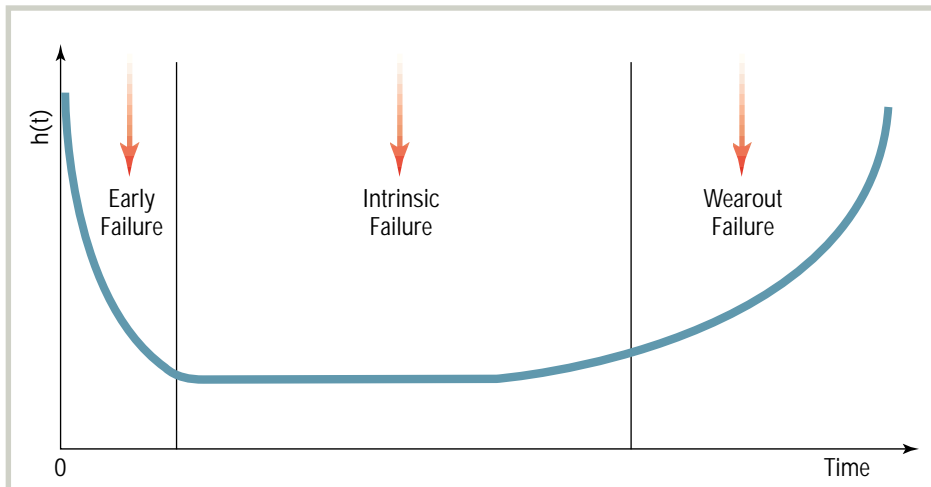
Figure 1. Bathtub Curve[6]

Early
Failure

Intrinsic
Failure

Wearout
Failure

smoke detectors and smoke alarms. In addition, while individual devices, appliances, and subsystems (modules) use manufacturing controls, QA, and QC programs to reduce or eliminate infant mortality, the installation process and assembly of a complete system introduces new failure modes that effectively reintroduce the infant mortality section of the bathtub curve for the overall system.

When systems undergo ITM at frequent intervals, the failures are discovered. If the faults are fixed, time out of service is minimized. The time out of service is equivalent to the time it takes to discover a fault and the time needed to repair or correct the fault.

In a paper addressing the need for functional testing of smoke detectors and smoke alarms,[7] Hjalmar N. Nelson, Jr., showed statistically that component reliability has less of an impact than inspection and test frequency on the mean time out of service, or unprotected time. For example, a smoke alarm in service for ten years and having a failure rate of 4.0 failures per million hours would have an estimated time out of service of 33.5 weeks over the ten-year period if the unit were tested only once per year and replaced within two weeks if found defective. Halving its failure rate to 2.0 failures per million hours would result in an estimated time out of service of 30.6 weeks over ten years of service life – a reduction of 20 unprotected days.

However, increasing the test interval to twice per year instead of once per year lowers the unprotected time from 33.5 to 17.9 weeks – a reduction of 109 days of unprotected time. These examples assume a "quiet failure", i.e., unsupervised, no-trouble signal. They also assume a nonrepairable failure resulting in a new unit being in place within two weeks of the failure being found by testing or inspection. Nevertheless, these calculations show the tremendous importance of ITM.

It is clearly more cost-effective for overall mission reliability to implement a well-designed program of ITM. Entire industries and professional organizations specialize in how to determine the necessary intervals for ITM. For an excellent discussion of performance-based reliability, mission effectiveness, and ITM frequencies related to fire detection and alarm systems, see the *NFPA Fire Protection Handbook.*[8]

Looking at the big picture, failure rates and, hence, calculated ITM frequencies are not available for complete system installations. The frequencies specified in *NFPA 72, the National Fire Alarm Code*,[9] do not have a known failure-rate basis that can be used in performance modeling – at least none that has been quantified or documented. However, new data[10, 11] suggest that design, installation, and the installed environment of a complete system have a large impact on the failure rate and mission effectiveness. Knowing the failure rates of individual components is not sufficient to predict failure rates for completed systems. Manufacturing and production methods may reduce infant mortality of components, but design and installation introduce new, cumulative failure modes that can be uncovered and corrected only through thorough ITM programs.

How do ITM programs affect failure rates, the probability of success, and overall mission effectiveness?

INSPECTION

The first evaluation of a physical system – as opposed to a design or plan – is performed by conducting an inspection. During system installation and following its completion, inspections are performed to determine if the installation conforms to the intent of the design. During the rough-in stage, it is easy for the engineer to check wire sizes, circuit loading, and terminations as well as the quantity and location of fire-detection devices and alarm appliances. At the same time, the designer has the opportunity to see the physical environment of the system and to evaluate conditions that may not have been apparent during the design stage. For instance, the shape of complex ceiling geometries combined with air supply and return registers may warrant changes to detector layouts in order to enhance actual fire detection or to reduce maintenance costs and prevent nuisance alarms.

After installation, periodic inspections are necessary to identify changes in the environment that might also affect system performance. For example, the construction of a wall to subdivide a room may leave a space without adequate smoke detection or sprinkler coverage. Similarly, noise-generating equipment may affect occupant notification or the intelligibility of voice communications.

TESTING

Manufacturers can do 100% testing of production and 100% burn-in to nearly eliminate infant mortality, but faults will

still be introduced by the system design and installation. Therefore, codes require a 100% acceptance test of the installed system and reacceptance testing when a system is altered.

While the codes require complete testing of all devices and appliances, is it possible to test all possible failure modes and to calculate all success probabilities? Just consider a system requiring two detectors in alarm before an extinguishing system is discharged. The number of combinations of n things, taken r at a time, where order is not important, is:

$$C = (n, r) = \frac{n!}{r!(n-r)!}$$

For a system of four smoke detectors (n=4) taken two at a time (r=2), the number of tests required is six. For 10 detectors, 45 tests are required, and for 30 detectors, 435 tests are required. In addition, each detector must be tested by itself to verify that it works and alarms the panel as required, but does not activate the discharge circuit. It may be possible to use program analysis, sampling, and scenario testing to reduce the required number of tests. This would require more advanced statistical modeling.

Periodic testing over the life of a system is performed to discover faults that do not generate trouble signals and to possibly identify increased failure rates, which may signal the approach of end-of-life failure modes.

In addition to acceptance and periodic testing, fire alarm systems use electronic testing methods to identify faults that might affect mission effectiveness. Monitoring the integrity of installation conductors and power supplies is one form of automatic, internal testing as is automatic sensitivity testing of smoke detectors. However, this does not eliminate the need for functional tests, as there are silent modes of failure in all systems.

MAINTENANCE

There are two forms of maintenance required for fire alarm systems. The first is preventative maintenance intended to keep a system operational. This includes

the cleaning smoke detectors and the lenses of flame and spark detectors. The second form of maintenance involves the repair or replacement of devices, appliances, or components that have been identified as having failed or degraded. The combination of testing, integrity monitoring, and repair results in reduction, control, or even elimination of end-of-life failure rate increases.

CONCLUSIONS

The mean time to failure (MTTF) of fire alarm system components can be used by engineers and code committees to calculate ITM frequencies. However, considerable work is needed to model the contribution of design, installation, and environment on total system MTTF. Only then can statistical methods be used to model the reliability of fire detection, alarm, and signaling systems. Nevertheless, ITM programs are used to reduce infant mortality and to intervene before end-of-life failures become dominant, thus reducing the failure rate to a relatively constant, though unknown, rate.

Failure rate data are needed for all fire alarm system components, not just smoke detectors. This does not need to be manufacturer-specific since it has been shown that failure rate is less important than testing frequency on the out-of-service time. The data can be in the form of a range or a limit as we have for smoke detectors and smoke alarms.

At the same time, we need more data on installed systems. Combined with the component data, it is then possible to identify the root causes of failures (system design, integration, component design, performance, installation, maintenance, etc.) and their relative contribution to mission effectiveness. Then, engineers and code committees can better design and target ITM programs to maximize the probability of success. ▲

REFERENCES

1 "Report to the Legislature in Response to House Resolution No. 14, Fire Alarm Systems," December 30, 1983, Office of the State Fire Marshal, 7171 Bowling Drive, Suite 600, Sacramento, CA 95823.

2 Drouin, J.,"Simplex Safe Survey," Presentation to the Automatic Fire Alarm Association 1984 Annual Meeting, New Orleans, LA, Simplex, Gardner, MA.

3 NFPA 72 Fire Alarm Systems Seminar Workbook, National Fire Protection Association, Quincy, MA, 1990.

4 George, L., "The Bathtub Curve Doesn't Always Hold Water," Reliability Division, American Society for Quality, http://www.asqrd.org/articleBathtub.htm, 2002.

5 UL 268, "Smoke Detectors for Fire Protective Signaling Systems," Underwriters Laboratories, Inc. Northbrook, IL.

6 NIST/SEMATECH Engineering Statistics Internet Handbook, http://www.itl.nist. gov/div898/handbook/index.htm, 2002.

7 Nelson, H.N., Jr., "The Need for Full-Function Test Features in Smoke Detectors," Fire Technology, February 1979.

8 Cholin, J., "Fire Alarm Systems Inspection, Testing, and Maintenance," Fire Protection Handbook, 18th Edition, NFPA, Batterymarch Park, Quincy, MA, 1997.

9 NFPA 72, National Fire Alarm Code, National Fire Protection Association, Quincy, MA, 1999.

10 Brewster, B., BuildingReports.com, private communication, and QuickStats, Interim Device Report for Smoke Detectors, http://www.buildingreports.com, March 2002.

11 Cholin, J.M., and Moore, W.D., How Reliable Is Your Fire Alarm System?, NFPA Journal, Vol. 89, No. 1, pp. 49-53, January/February 1995.