From Concept Design to Validation and Verification: Case Study of a Modern and Integrated Fire Protection System for Application on Rolling Stock

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Summary
The paper investigates the design and development of a modern fire protection system for rolling stock application, based on case studies taken from the author's real experience in project management of several fire protection systems all over the world.

Keywords: fire protection, fire detection, firefighting, fire safety, rolling stock, design, water mist, aerosol, gas, nitrogen

1. Introduction

A lot have been done since the first fire protection systems for rolling stock applications, dating late 90s[2], did appear on modern rail vehicles. Technologies have been improved, architectural solutions converge to common and standardized layouts, and the regulatory framework is taking shape day after day. Still, design and development of active fire protection systems for rolling stock are often a not well known topic within the railway industry, traditionally focusing on more substantial subsystems like bogies or brakes.

The goal of this paper is therefore to „jump in" the world of the designer (might it be a sales manager, or a company, or a consultant, or a system engineer of a vehicle manufacturer) of the fire protection system, to have an introductive view of which tasks, which challenges, which criteria are given and must be followed to realize a modern active fire protection system for rolling stock application.

The approach we will follow is based on the well-known „V-process" (Figure 1), adopted as project management tool by most of the manufacturing companies dealing with system engineering, design and development. However, this paper will focus in only one first part of the v-process, from concept to system verification

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[2] Barbagli M., „*Impianti di e controllo / estinzione incendio: tecnologie e caratteristiche*", May 22nd, 2013, Convegno CIFI Lotta al Fuoco, Bologna, Italy.

and validation. Although of primary interest too, operation and maintenance will be at this stage superseded focusing on the design phase.

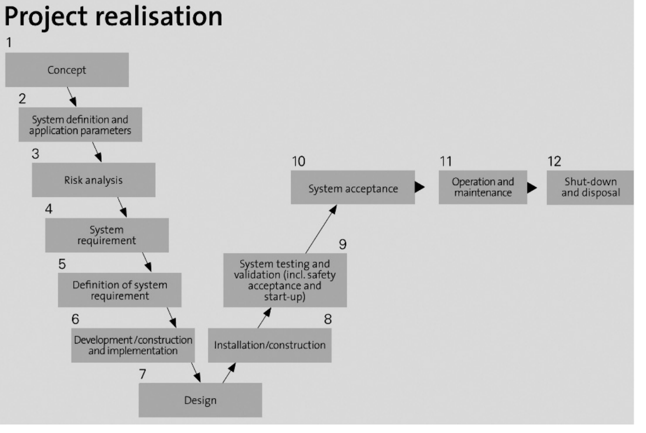

Fig. 1. V-process of project management

Following the v-process starting from concept, we can structure the paper on following main parts:

- Concept design;
- Detail design;
- System validation and homologation.

Examples from real industrial experience of the author will be used to ease the presentation and give a direct application case.

2. Concept Design

The definition of concept design can be extremely varied, based on the input data available. The input data are a big variable itself: often they are very few, or very imprecise, or dramatically confusing. Seldom input data tells us exactly what we need to know to draft a concept of a fire protection system for a train. The valid definition of which are the necessary input data is up to designer's skills, experience, understanding and full-view of the project to identify which data are necessary to acquire.

Let's take an example on how to define and choose the right fire detection system for an application in a double deck passenger coach. The coach used for example is a typical UIC (Union Internationale des Chemins de Fer) double deck coach, as it can be seen in Figure 2.

Fig. 2. Coach used for the example is a traditional UIC double-deck coach

The vestibules are located between the two-level part and the extremities, and include in their volume the stairs to the upper level. The extremities, over the bogies, are realized as separated volumes from the vestibules. The coach can be connected and disconnected in service for changing train formation or shunting a defective unit.

The requirement from the customer is of a smoke detection system for passenger areas and vestibules. At train level, the information about system status (operational, alarm, failure) must be forwarded between the coaches, to be announced in the driver's desk of the locomotive. Eventually, the customer expresses his preference for a system which can ensure easier maintenance and lower life cycle costs (LCC). As a typical concept design case, the task is to choose the right technology and to design the system according to the layout and the specification coming from the customer, and to integrate this into our scope and costs.

Some requirements are direct and clear like the smoke detection system, information forwarded between coaches, possibility of integration of a firefighting system. Some requirements are hidden and it is up to designer's experience and skills to detect and raise them. For example, the experience could highlight the need of an independent system, because the coach must be connected and disconnected during service. In that way, during operation it will be possible to de-couple and re-assembly together the coaches of the train without the need to reset or adapt the fire detection system.

The goal of fire detection in passenger areas is to ensure quick fire detection for protecting the safety of the passenger. The detection system must be able to define an alarm in early stage of the fire, when the level of smoke (with its main effects, reduction of visibility and toxicity of the atmosphere) and temperature is still enough low to maintain survival conditions in the passenger area. Therefore smoke detection is the suitable and safest technology.

Smoke detection systems are available in two technologies: point smoke detectors and smoke aspiration systems. A point smoke detector based system will keep LCC lower and easier maintenance[3], and a bus based system with addressable detectors and central processing unit (CPU) will allow an easier localization of failures and problems. So the sum of the given requirements tells us eventually how to draft our concept of fire detection system:

- Independent system with its own CPU in each coach;
- Point smoke detectors as detection technology;
- Bus – based system logic.

Of course, concept design has several limits: it is not precise, it lacks of integration details and likely of a finalized bill of materials. Probably the software specification is not yet set, and all system detail functionalities are not defined. But it is the first step for the designer, the sales manager, the consultant, who wants to put on paper the idea his customer is asking him to provide. Because of this limits, more details are needed from the two sides of the systems, in order to define the integration between the different interfaces. This phase of customization is called the detail design.

3. Detail Design

The detail design phase can be resumed on such question: how can we incorporate our concept onto a feasible and working system?

The detail design sets new targets and challenges:

- Detail layout of the detection system, with definition of the detection time.
- Calculation for the amount of extinguishing agent to be used and therefore stored.
- Analysis of available spaces and installation areas.
- Definition of the monitoring performances and of the interface communication with the train monitoring and control system.
- Finalization of a bill of materials.

For the purpose we will shift from the example of the previous project to an alternative one.

In this case we will analyse the detail design of a fire detection and firefighting system for technical equipment mounted on the roof of the train. Let assume the concept design phase did set following system concept layout:

- Fire detection system based on linear heat detection (LHD) technology. This technology is based on an electrically monitored metallic bifilar wire, melting

[3] Klinger M. (2013): *Modern Trends of Fire Protection in Rolling Stock 2013*, Problemy Kolejnictwa, Vol. 57, Issue 160, 77–97.

and sending an electrical signal in case of fire. The technology is strongly diffused in rolling stock applications due to robustness and value for money[4].

- Firefighting system based on aerosol generators. Aerosol generators are cartridges of specific chemical compounds, activated via a thermoelectric reaction in case of fire detection are. Due to this reaction the chemical compound expands and is sprayed from the cartridge to extinguish the fire.[5]

The technical equipment used for this example is a high tension (3 kV/1,5 kV) high-speed main circuit breaker with magnetic blow, with the breaker chamber in atmospheric air. As standard rail industrial productions the equipment assembly is contained in a metallic box mounted on the roof (Figure 3).

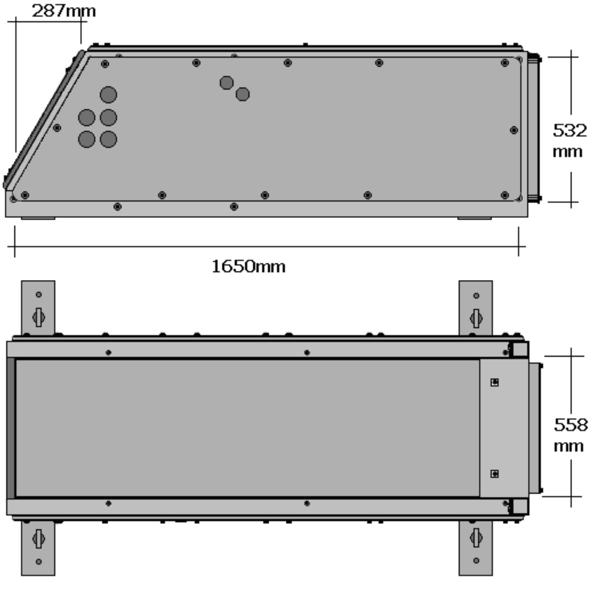

Fig. 3. Main circuit breaker used for the example

The detail design of the detection system is of dramatic importance, for the effectiveness of the complete fire protection system depends on the good working performance of detection subsystem[6]. The detail design of the fire detection system based on the LHD technology consists primarily in the definition of the temperature setting and of the cable's path. These must be realised in such way, that

[4] Op. cit., p. 77–97.

[5] Van Trigt P.: „Assessing aerosol fire protection for rolling stock", during *Fire Protection of Rolling Stock 2013,* Mar. 21-22, 2013, London, UK.

[6] Cit. Barbagli M.: *Rolling Stock and fire protection – An overview of aspects, solutions and requirements*, MBA Edizioni, Sesto Fiorentino, Italy, 2011, ISBN 978-88-906180-6-2, page 52.

the LHD cable will be able to react to temperature increase – and therefore allow the monitoring system to define an alarm – within a given time, depending on the specification or on the homologation procedure adopted.

A common and established procedure to define temperature and position of the LHD is to validate a design done by the specialist designer via a CFD (*Computational Fluid Dynamic*) simulation. Via simulations will be possible to calculate, according to a given fire scenario and a given LHD cable layout, the maximum detection time. Usually this time is set in 1' or 2', depending on the application and guideline or norm followed: the most diffused guidelines for fire protection in rolling stock – the ARGE Guidelines[7] – set 2' maximum detection time for technical areas with electrical equipment.

The second important part of the system subject to detail design is the CPU of the system: its functions, its features are defining the performances and abilities of the system. For this project we need a CPU capable of monitoring one LHD cable, command the activation of the aerosol generators in case of fire alarm, communicate with the train in a required standard, say Ethernet bus technology (Figure 4). Interface and communication requirements are some of the most varied affecting the CPU for fire protection systems in rolling stock: that's why for a supplier of such systems it is today of dramatic importance to have in portfolio modular solutions which can support several bus-based communication standards and the possibility of software development for such interfaces.

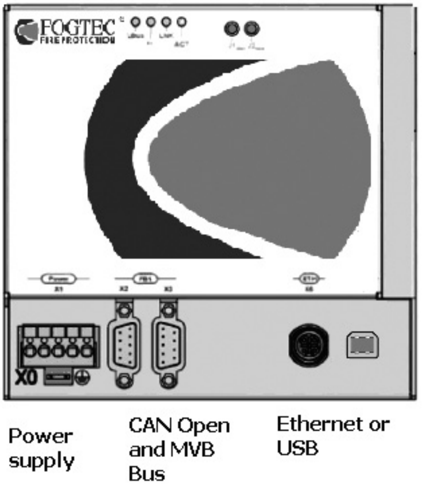

Fig. 4. from FOGTEC's product range, a CPU for a fire protection system for rolling stock application, with Ethernet interface

[7] ARGE Guidelines: „Fire Detection in Rolling Stock – Rev. 4.0", „Firefighting in rolling stock – – Rev. 2.0", and „System functionality, fire detection and firefighting systems in rolling stock– – Rev 2.0".

For calculating the amount of extinguishing agent to be used, the primary inputs data are the volumes of the area and the design *concentration* of the extinguishing agent used, a value expressing the quantity of agent necessary in a certain volume to lower the level of the oxygen low enough to avoid any combustion. The design concentration is expressed in % for gases and in g/mł for aerosols.

Let assume the aerosol we are using needs a design concentration of 90 g/m^3. The volume of the area to be protected can be calculated with easy geometrical calculations. Opening and occupied areas must be taken into account as well. Forced air movements (due to train's speed or air conditioning) can be of strong influence, so in that cases CFD simulations or real scale testing might necessary.

We will assume the volume of our main circuit breaker is 0.471 m^3. For ease of presentation, we will assume openings and air movements as negligible in our calculations. Being V the volume of the equipment and C the design concentration of the aerosol, we can calculate the mass m of aerosol we need with a simple formula:

$$m = C \cdot V = 90 \frac{\mathrm{g}}{\mathrm{m}^3} \cdot 0.471\ \mathrm{m}^3 \approx 42.4\,\mathrm{g}.$$

This calculated quantity must be now reported to the sizes of aerosol generators available: a big part of system design is in fact to put together existing products. If we assume the type of aerosol generators chosen is available with cartridge size of 30 and 60 g, we can choose to integrate one cartridge of 60 g or two cartridges of 30 g basing on the spaces available and on the distribution of the circuit breaker's internal volumes. The internal volume distribution is of extreme importance, while it can create hidden areas of separation between volumes, needing a larger number of aerosol generators then theoretically calculated (Figure 5).

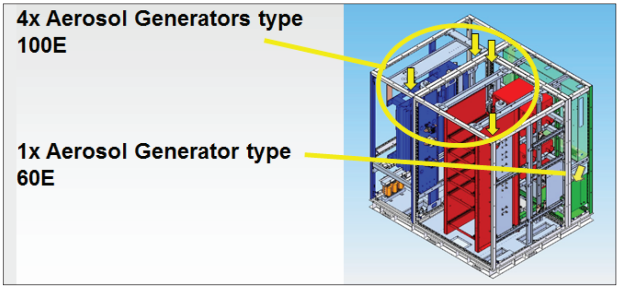

Fig. 5. Example of the position of aerosol generators

The final step of detail design is of course a bill of materials. Here some factors must be taken into account to choose the right components:

- Rail-worthiness: only components with proved rail-worthiness must be used. Resistance to shock, to vibrations, to electromagnetic interferences, must be tested and proved and certified according to EN railway specific norms;
- Often commercial of the shelf (COTF) can be a good solution, but the performances must be carefully verified and certified;
- Purpose-developed new components reduce strongly the risk of non withstanding with railway norms, but of course introduce high costs and a higher risk of non-suitability (non „service proven" solution).

From author's experience, the safest solution is to go for components which are specifically design and developed for railway application, and with a proven service and operational history of demonstrated rail-worthiness.

From the theory to the practise, each conceived system requires a validation; the process of such a validation follows strict steps and gates due to the importance of the safety and criticality of such a system for the passengers.

4. System Validation and Homologation According to Railway Standards

Now is time of making sure, that our system will be accepted by the customer and end user. But it would be unfair to reduce the validation and verification process only to the target of acceptance. It would be even not professional, too.

The acceptance and homologation is just the summit of a process which must ensure:

- That the technical requirements set are fulfilled;
- The design performances are met too;
- COTS used have gone through proper testing and certification to verify their rail-worthiness;
- The development of new parts is fault-free and the parts fully reflect their specifications;
- The system and software engineering have been done properly to ensure that functionality of the whole system is according to requirements.

Eventually, all these steps must be documented and yes, the final target will be the acceptance. To present more in detail this process, we will take another example from the „everyday life": a fully integrated fire detection and firefighting system for a 2-car DMU, protecting passenger areas and the two power-packs. The system is based on a smoke detection system for passenger saloons, LHD detection system for the power-packs, and high pressure water mist system for firefighting in both passenger areas and power-packs, via the use of section valves. Cylinder tank modules are used for storing the water. According to the quality processes adopted by international standards like ISO and IRIS, we can set following milestones of the process:

1. Type test **A**, for the components;
2. Type test **B**, for the system design;
3. Verification of the first installed system and hand out to customer (commissioning).

Applied to our example of system, we will have several verification and validation cases. Starting our analysis from the type test **A**, so at component level, we will see:

1. Smoke and temperature detectors are usually COTS. Here the type test **A** consists of a verification of the railway certifications. In that case, due to their nature of rail-borne electronic equipment, smoke detectors must be verified according to EN 50155 in all its parts concerning shock and vibrations, electro-magnetic compatibility, environmental conditions.
2. The CPU, the section valves and the monitoring units of the LHDs are manufacturer's specific components. Here the type test **A** consists of a verification of the development process according to IRIS, ISO (e.g. v-process) and final railway certification, done independently for the project and therefore already accomplished at project design phase.
3. The cylinder tank modules are manufacturer's project specific assembly components. Here the type test **A** consists of a verification of railway certification of the components used, and a verification of the general design and assembly like FEM calculations (Figure 6).

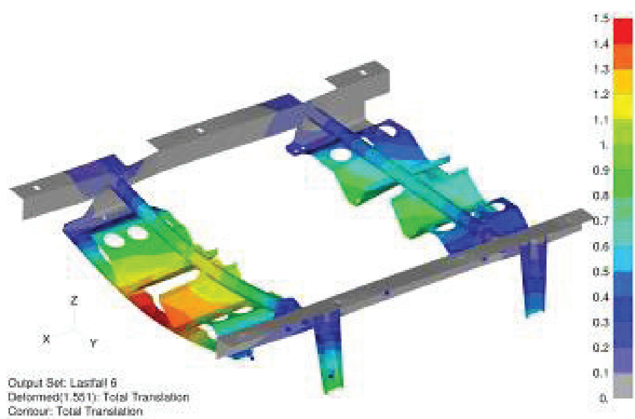

Fig. 6. FEM calculation of frame for high pressure water mist cylinders

The type test **B** is for system design, as mentioned. Here it is validated and verified not the function or design of the single component or device, but the function or design of the system or of subsystem as a whole. In details, for this project the type test **B** is applicable to:

- Design of the smoke detection system for passenger areas: quantity and position of the smoke detectors;
- Design of the LHD detection system for power-packs, based on the CFD simulation done during the detail design (example of previous chapter);
- Design of the water mist system for passenger areas and power-packs.

For all the mentioned steps, the specification for validation and testing can vary: the most commonly used is, as already mentioned, the package of the three ARGE guidelines. The smoke detection system for passenger areas will be tested and verified via smoke tests according to ARGE guideline „Fire detection in rolling stock", the water mist system according to the related „Fire fighting in rolling stock". The smoke tests are done to verify that, given a certain smoke source, the system can detect it within a given time – 1' for passenger saloons according to ARGE guidelines (Figure 7).

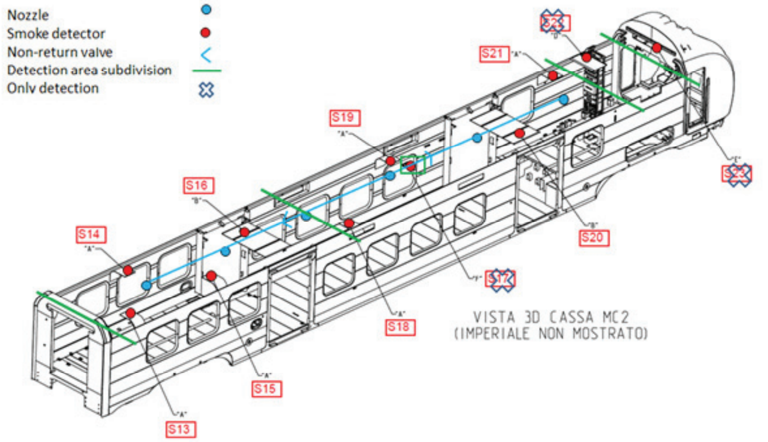

Fig. 7. Layout of a fire detection and firefighting system for passenger areas for the vehicle object of our example. This layout is subject to design validation via smoke tests and full scale fire tests

The verification of the water mist system consists of following steps:

- Verification of the nozzles' position;
- Verification of the correct amount of water stored (Fig. 8);
- Verification of the piping, with distributed and localized pressure losses (Fig. 9);
- Verification of the results of the full-scale fire tests conducted for the project specific application or for the general application, with verification of similarity and applicability.

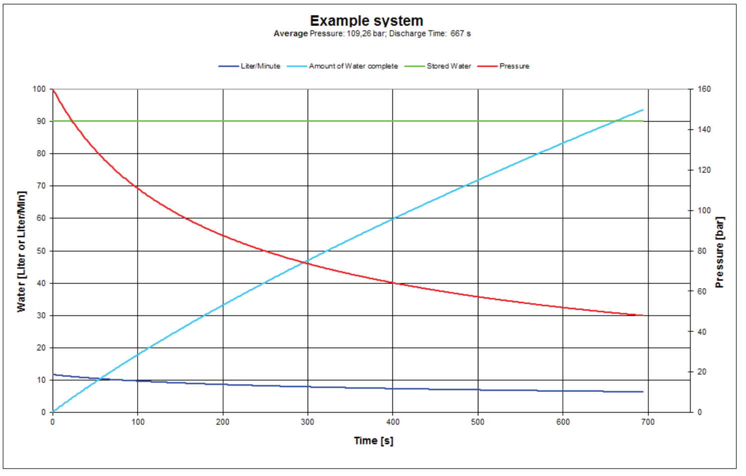

Fig. 8. Calculation of stored water quantity for the passenger areas

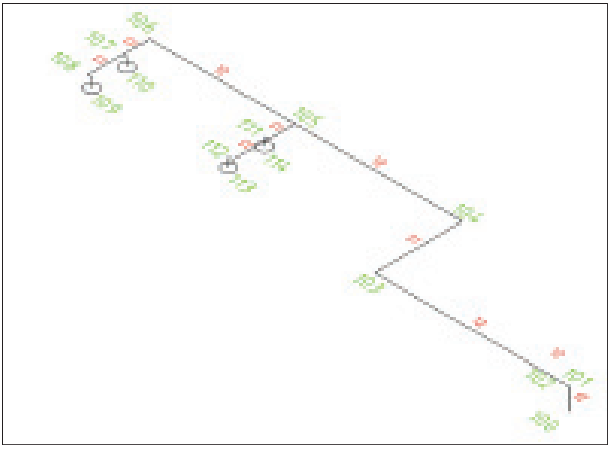

Fig. 9. Power-pack piping verification via HFC software

Nozzles' position must be verified according to design specifications set by the designer, which are based on the nozzles' technical data. The quantity of nozzles activated simultaneously defines the amount of water to be stored. The piping must be verified so that there will be no excessive pressure loss during the discharge to affect the water mist qualities. Eventually, the firefighting system must be assed based on project-specific fire tests or, if available, result of tests previously done. This procedure is the one adopted by ARGE guidelines.

Full-scale fire tests must demonstrate that, given the activation of the water mist within a certain time based on the performance of the fire detection system (according to ARGE, max 1' for passenger areas and technical areas with combustion engines), the water mist intervention is effective in fighting the fire. This is verified by:

- For passenger areas: check of survivability indicators are CO, CO_2 and O_2 concentration, and temperatures;
- For technical areas: complete extinguishment of the fire source within a certain time.

When finally all this results are available and documented, the system can go through acceptance and homologation: if the job have been done properly, no fear should come now.

5. Conclusions

Referring to the introduction of this article, the first steps of the V-model in project management are the realization of the product, which are:
- How to draft a concept based on requirements;
- And how to integrate such concept on the application with a detail design.

These steps should be validated through a verification phase, which is how to validate, verify the design and how to document it. For each of those parts some bullet points can be listed down:
- While drafting a concept, a major knowledge and experience of the designer will help understand the requirements, especially those that are not explicit;
- The designer must also have a holistic approach to the concept, watching beyond the crude requirements to understand the needs, and being able to pick the right solution out of several;
- While making detail design, the choice of the components based not just on their function, but also on their rail-worthiness is of dramatic importance;
- Fitting the system within the given spaces, architectural constraints of the vehicle, installation areas, is a very challenging task that needs expertise and accuracy;
- A proper system validation and verification according to railway standards ensures, beside the an effective and fault-free operation, the successful homologation process;
- For the homologation process, the importance of proper documentation is vital.

In this article, the purpose was not to treat the operation and maintenance which is the last step of a product / project implementation. This part is indeed really important and could be the subject of many further writings and articles. Thus, the purpose is to propose a draft „guide” on how to bring a fire protection system from concept to homologation.

Literature and Property Rights

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2. Design documentation of projects PESA 111D, Alstom Coradia, Bombardier DoSto.

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1. Figure 1: from http://en.wikipedia.org/wiki/V-Model; accessed on 18.06.2014.
2. Fugure 2: from http://www.bahnbilder.de/name/einzelbild/number/152930/kategorie/Deutschland~Wagen~Doppelstock-Zwischenwagen.html, accessed on 10.05.2011.

Od projektu studyjnego do walidacji i weryfikacji: analiza przypadku dla nowoczesnego i zintegrowanego układu ochrony przeciwpożarowej do zastosowań w taborze kolejowym

Streszczenie
W artykule przeanalizowano projekt i realizację nowoczesnego układu ochrony przeciwpożarowej dla taboru kolejowego. Wykorzystano analizy przypadków zaczerpnięte z praktyki zawodowej autora w zarządzaniu projektami wielu układów ochrony przeciwpożarowej na całym świecie.

Słowa kluczowe: ochrona przeciwpożarowa, wykrywanie pożaru, zwalczanie pożaru, bezpieczeństwo pożarowe, tabor kolejowy, projekt, mgła wodna, aerosol, gaz, azot

От студийного проекта до легализации и проверки: практический анализ для современной интегрированной системы противопожарной защиты для применения в железнодорожном парке

Резюме
В статье проанализированы проект и создание современной системы противопожарной защиты для железнодорожного парка. Здесь использовались анализы примеров из профессиональной практики автора в области управления проектами ряда систем противопожарной защиты во всем мире.

Ключевые слова: противопожарная защита, выявление пожара, пожаротушение, пожарная безопасность, железнодорожный парк, проект, водяной туман, аэрозоль, газ, азот