BACHELOR'S THESIS

Fire Detection and Fire Alarm Systems in Trains and Aircrafts

A Pilot Study

Johan Stonegård
Martin Svensk

2013

Fire Protection Engineering
Fire Protection Engineer

Luleå University of Technology
Department of Civil, Environmental and Natural Resources Engineering

Johan Stonegård
Martin Svensk

Fire detection and fire alarm systems in trains and aircrafts

A pilot study

Luleå University of Technology
Division of Structural and Construction Engineering
Department of Civil, Environmental and Natural resources engineering

Preface

This report is the result of a bachelor thesis in Fire Protection Engineering at Luleå University of Technology. The work corresponds to 15 HE (higher education) credits for both participants, equal of 10 weeks of study. The report has been made in cooperation with SP Technical Research Institute of Sweden, Department of Fire Technology, as one of the projects under FFI (Strategic Vehicle Research and Innovation) within SP. 4 weeks has been spent at SP Fire Technology headquarter in Borås and the rest of the time has been spent at LTU (Luleå University of Technology).

We would like to thank VINNOVA (Swedish Governmental Agency for Innovation Systems) for letting us participate in the project ”*Fire detection & fire alarm systems in heavy vehicles – Research and development of international standards and guidelines*” lead by SP. We would like to give a special thank you to our mentor Jonas Brandt at SP for his tutoring through the process of this thesis and for all background material. We would also like to give special thanks to our examiner Björn Sundström (manager at SP Fire Technology and teacher at LTU) for his comprehensive view and tutoring. Thanks are also given to everyone within the FFI project at SP for their help and for letting us participate in the mini seminars held at SP and all other employees at SP for their encouraging attitude. At last we would like to thank the fire detection, aircraft and train industry for their sharing of useful knowledge, and special thanks to Consilium, SAS, SJ and all people there for sharing their expertise.

Luleå, November 2013

Johan Stonegård, Martin Svensk

Abstract

A proper fire detection and alarm system is an important part of the fire protection system to be able to discover the presence of a fire in an early stage. Passenger carrying vehicles are highly vulnerable, as passengers simply can't evacuate to a safe location immediately. The need of a detection and alarm system is to assure that the fire doesn't go unnoticed by monitoring different areas, both easy accessible but also out of sight areas, like engines and electrical cabinets.

Possible ways of detecting a fire is by knowing the signatures a fire emits. By knowing these signatures and their presence in a typical compartment a suitable detector can be fitted. Typical detectors that respond to these signatures are: smoke, heat, flame and gas detectors. By considering the compartments they are fitted in, different ways of operation can be used. The operational ways are: point, line, volume and aspirating detection.

In trains and aircrafts the fire protection system is derived from different safety cultures where standards, guidelines and regulations have set the demand. The aviation industry has for a long time focused on preventing onboard fires whereas trains have been less protected. By the introduction of the European Standard EN 45545*, Railway applications – Fire protection on railway vehicles*, new demands for fire protection, detection and alarm systems included, have been developed for trains.

Standards and similar often include test methods for e.g. fire detectors. These can in many cases be quite imprecise with the regards of where the detectors are placed. New test methods for specific branches or compartments should be developed to assure the best functional detection system.

Keywords: Fire detection, fire alarm, alarm management, extinguishing system, rolling stock, railway vehicle, train, aviation, aircraft, airplane, bus, heavy duty vehicle.

Sammanfattning

Ett fullgott detektions– och larmsystem är en viktig del av brandskyddet för att upptäcka en brand i ett tidigt skede. Passagerarfordon är särskilt utsatta vid en brand eftersom passagerarnas förmåga att snabbt utrymma är strikt begränsad. Behovet av ett detektions– och larmsystem är särskilt viktigt för att försäkra sig om att branden inte går obemärkt förbi. Detta görs genom att övervaka såväl lättillgängliga utrymmen och utrymmen utom synhåll, till exempel motorutrymmen och elskåp.

Möjligheten att upptäcka en brand underlättas genom att känna till de olika brandsignaturer som en brand avger. Genom att känna till dessa signaturer och deras uppkomst i olika utrymmen och miljöer kan en lämplig detektor installeras. Detektorer som reagerar på dessa brandsignaturer är: rök–, värme–, flam– och gas detektorer. Genom att ta hänsyn till de utrymmen en detektor ska installeras i finns det olika sätt en detektor kan upptäcka en brand. En detektor kan övervaka ett utrymme genom: Punkt–, linje–, volym– och aspirerande detektion.

Inom tåg– och flygplansindustrin har brandsäkerheten uppkommit från olika säkerhetskulturer där standarder, riktlinjer och regler har satt kraven. Flygindustrin har sedan länge fokuserat på att förebygga bränder ombord medan tågen har varit mindre skyddade. Genom introduktionen av Europa Standarden EN 45545, *Järnvägar – Järnvägsfordons brandsäkerhet*, har nya krav för ett förbättrat brandskydd inom tågindustrin tagits fram. Denna standard involverar även kraven för detektion– och larmsystem.

Standarder och regler inkluderar ofta testmetoder för exempelvis branddetektorer. Dessa testmetoder är dock relativt oprecisa med avseende på de sorts utrymmen detektorerna kan komma att installeras i. Nya testmetoder för specifika branscher och/eller utrymmen bör tas fram för att åstadkomma ett funktionellt detektionssystem.

Nyckelord: Branddetektion, brandlarm, larmhantering, släcksystem, rullande materiel, järnvägsfordon, tåg, luftfart, flygplan, buss, tunga fordon.

Table of contents

Abbreviations

ANSI – American National Standards Institute

APD – Advanced Pneumatic Detector

APU – Auxiliary Power Unit

ARGE – A Detection Technology Consortium

AS – Aerospace Standard

AUBE – Internationale Tagung über Automatische Brandentdeckung (International Conference on Automatic Fire Detection)

CFR – Code of Federal Regulations

EASA – European Aviation Safety Agency

EN – European Standard

EWIS – Electrical Wiring Interconnection Systems

FAA – Federal Aviation Administration

FAR – Federal Aviation Regulations

FFI – Fordonsstrategisk Forskning och Innovation

HVAC – Heating, ventilation and air conditioning

ICAO – The International Civil Aviation Organization

LHD – Line Heat Detector

NFPA – National Fire Protection Association

NIST – National Institute of Standards and Technology

RoR – Rate of Rise

RTI – Response Time Index

SAE – Society of Automotive Engineers

SARPs – Standards and Recommended Practices

TCMS – Train Control and Monitoring System

TSI SRT – Technical Specification of Interoperability relating to Safety in Railway Tunnels

UIC – International Union of Railways

1 Introduction

1.1 Background

It is often an occurred accident that shapes the safety measures of different branches. So were the cases of *Air Canada Flight 797* and *the Taunton sleeping car fire*. Flight 797 was a trans-border flight on route from Dallas/Fort Worth to Montreal on 2 June 1983. The aircraft developed a fire in the aircraft lavatory, spreading toxic fumes and flames in the aircraft. The fire burned through crucial electrical cables that disabled most of the instrumentation in the cockpit, forcing the plane to divert and land on an alternative landing field. When the passengers were to be evacuated, fresh air from the opened doors combined with the heat of the fire caused a flashover, killing 23 passengers. As a result of this accident, aviation regulations around the world were changed, with requirements to install e.g. smoke detectors in lavatories (National Transportation Safety Board, 1983) [1].

The Taunton sleeping car fire occurred in the early hours on 6 July 1978, England. The fire was caused by an electric heater that had been blocked by sacks of dirty bed linen that got overheated. The ventilation drew air from this compartment into the sleeping cars resulting in the deaths of 12 people. Most deaths were due to toxic smoke inhalation. As an aftermath of this accident newer train cars were fitted with better fire prevention measures including improved warning systems (Department of Transportation, 1980) [2].

A passenger-carrying vehicle is always vulnerable in the event of a fire due to problematic evacuation. It is therefore vital with a fast and reliable detection system to be able to discover and thus provide extinguishing opportunities in an early stage.

The aviation industry has for long been on the front edge regarding technology, fire detection included. This is largely due to its vulnerability whilst in the air, a small error or incident might have fatal consequences.

Nowadays even railway vehicle companies e.g. trains are focusing more on safety issues and the problems with fires onboard. Much of this is due to new regulations and standards. With the introduction of the new European standards EN 45545 – *Railway applications – Fire protection on railway vehicles* there is a big improvement regarding fire safety onboard trains.

In the last couple of decades, fire safety has been more and more important in transport industry. Fire detection systems are one part of fire safety, where also fire alarm, alarm management and extinguishing system are essential to prevent an emergency. Fire detectors are desired to discover the fire in an early stage, but still resistant enough to avoid false alarms due to small changes in the range of normal conditions. There are many fire conditions that require different types of detectors to sense the presence of a fire, and therefore it is important to match the hazardous conditions to optimize the detection system and secure its functionality.

1.2 Responsibility distribution

The distribution between the authors has been equally divided through the design of the report. Both participants have shared information with each other to achieve knowledge and understanding in all areas covered in the report. The participants have worked together daily, which have lead to a daily exchange of what the other participant has done. Both have contacted companies by email and telephone and both have been participating in study visits. To facilitate the writing of the report, each had their specific topic to begin with. Later the topics were switched in order to get a better understanding, fill out with more information and have the opportunity to ask questions in case of doubts.

1.3 Aim of this report

With railway and aviation industries focusing on fire safety it is almost impossible for other transportation industries to neglect the big impact of safety. What can they learn from train and aviation industry? And are the systems compatible in other heavy duty vehicles such as buses and trucks? These are interesting questions and a lot of investigation and testing is to be made to either apply existing systems or develop new.

The aim of this report is to investigate existing fire detection and fire alarm systems in trains and aircrafts. This is done in order to show useful and interesting solutions that could be applied and implemented in the heavy duty vehicle industry. The aim is also to gather and summarize the latest standards and guidelines within fire detection, train and aircraft industry to ensure an adequate fire detection system and compare what is applied to today's trains and aircrafts.

1.4 Questions to be answered

The finished report aims to answer following questions:

- What types of detectors are used in trains and aircrafts?
- How are the technical solutions for detection and alarm systems designed?
- In which areas are detectors and fire alarm systems placed?
- How does the alarm management work?
- What regulations, standards, guidelines and test methods exist for detection and alarm systems in trains and aircrafts?

1.5 Disposition

Chapter 1: Introduction. This chapter gives an introduction of the chosen subject, the background questions, responsibility distribution, the aim of the report and which limitations that are made.

Chapter 2: Method. This chapter describes how the work around the report has been made, the decision to do a literature study, to contact companies, perform site visits and participating in mini seminars.

Chapter 3: Fire signatures. To get a better understanding for fire detection, this chapter gives background information about fire signatures and other basic facts about different fires.

Chapter 4: Fire detection. This chapter investigates different fire detection methods, describes their function and also some advantages and disadvantages are presented for the most relevant detectors.

Chapter 5: Alarm system. Alarm system is the connection between fire detection and fire fighting action and here are some different alarm systems and their functionality described.

Chapter 6: Fire detection and fire alarm systems in trains. Here are existing fire detection and fire alarm systems described in some of the most common trains in Sweden. System overview, placement of the detectors and the alarm management are in focus.

Chapter 7: Fire detection and fire alarm systems in aircrafts. This chapter's focus lies on fire detection and fire alarm management in common passenger aircrafts. Here is a system overview, the placement of the detectors and the alarm management described.

Chapter 8: Standards and guidelines. Standards and guidelines are important to ensure the safety when a train or aircraft is constructed and operated. This chapter gives an overview of the standards and guidelines that exists today and some in a nearby future. Also interesting test methods are described.

Chapter 9: Analysis. Here the results are analyzed, also an analysis of the report making and all its chapters is made.

Chapter 10: Discussion. The result of the report is discussed and existing solutions, standards and test methods are questioned. Also examples of further work are proposed.

Chapter 11: Conclusions. This chapter takes up the conclusions made, with respect to the result presented in this report.

1.6 Delimitations

Due to the limitation of time, some things have not been investigated in this report. The standards and guidelines for trains and aircrafts are limited to the most relevant and those that have been accessible. Standards and guidelines in this report are from USA, Europe and Sweden. This report also delimits itself by looking into and describing the most common detection and alarm systems. Trains and aircrafts that have been investigated are the ones most accessible, where also a lot of information has been available. Companies that have been contacted are vendors of fire detection system, manufacturers of trains and aircrafts, and train and airline operative companies. Here is also a delimitation made and only the relevant and accessible companies within USA, Europe and Sweden are taken into consideration.

2 Method

This report has been made as a pilot study for the chosen subject. Below is a description how the work has been structured.

2.1 Literature study

To start the bachelor thesis a lot of background material was collected and sorted in order of relevance. Since this was part of a bigger project at SP a lot of background material was already available, but a lot was also gathered from other sources.

2.2 Company contact

Quite early it was taken into account that a numerous of companies were to be contacted. A standard email form both in English and Swedish was made and a list of interesting companies was prepared. Because of all people at different position in all companies the form was directed to match each recipient. In some cases there has also been telephone contact when it's been easier to find the right person that way. The companies that were contacted consisted of fire detector manufacturers, train– and aircraft manufacturers, train– and aircraft operators and pilots.

2.3 Site visits

To get a better understanding in fire detection and how it functions in general in trains and aircrafts, two site visits were made. The first company visited was Consilium, experts on solutions of fire detection for trains. with headquarter in Gothenburg, The other site visit was made at SAS Operational Centre at Arlanda where we were able to look at the fire protection system of a Boeing 737–800 aircraft. The site visits included interviews with knowledgeable people and were made in respect of the questions mentioned in subsection 1.4.

2.4 Mini seminars

Simultaneously as the bachelor thesis work started up at SP in Borås, the writers of this report were able to participate in mini seminars held by staff at SP. These mini seminars aim was to highlight a specific report, interesting lectures, or anything else connected to fire detection systems. The mini seminars were normally held twice a week and these helped achieve a more basic knowledge in the subject at the start up of the project.

2.5 Report making and presentation

To achieve the final exam in the fire protection engineer program at LTU this report was made and the work was presented at LTU and also by initiative at SP Fire Technology in Borås.

3 Fire signatures

Fire occurs when combining heat, fuel and oxygen. There are typically two types of fires, flaming fires and smoldering fires. The reaction products often contain CO_2, H_2O, CO, unburnt hydrocarbons and soot. Flaming fires occur when the combustion of fuels takes place in the gas phase, and therefore must all solid and liquid fuels first transform into the gas phase.

A smoldering fire on the other hand occurs when a porous fuel creates solid carbonaceous compounds when pyrolysed and doesn't shrink away when it heats up. A smoldering fire can translate into a flame fire if the ventilation is improved and opposite can a flame fire become a smoldering fire as ventilation decreases. The combustion occurs in a reaction of the surface in a solid phase, and this usually means that the fire doesn’t produce any flames. Typically materials that can create a smoldering fire are paper, sawdust, cloths, leather, shipboard and expanded plastics (Nilsson & Holmstedt, 2008) [3].

When talking about fires, different fire signatures are used to identify the fire depending on the criteria of the fire. Typically there are four ways to discover and identify a fire:

- Smoke
- Heat
- Flame
- Gas

The fire signatures can in turn be identified by different criteria. Smoke consists of soot particle and the cleaner the combustion is; the less smoke is produced. Smoke can be identified visually and is often the fastest way of identifying fire. Heat can both be noticeable by the much higher temperature but also the rapid temperature rise or *Rate−of−Rise* (ROR). Flames produce light, which emit radiation in a large wavelength area, and consists of ultraviolet (UV) light, visually light and infrared (IR) light. Depending on the light of the surrounding, these can be more or less easy to discover and the human eye has a limited wavelength that it can discover. When a fire occurs there will always be a production of gases. The most common are CO and CO_2 but there could also be NO_x and other gases and most of them are extremely toxic. These are normally invisible and therefore very hard to discover for a human, but sometimes the sense of smell can tell if there is gas in the air. Due to many different fire signatures, there are a lot of ways to discover a fire, and with technology all these can be measured and therefore detected when setting up boundary conditions based on what the normal conditions are.

4 Fire detection

As mentioned above a fire generates a lot of different signatures. Whether it is smoke, heat, flame or gas there must be a suitable detector for all these signatures. There are mainly four ways the detector can monitor possible fires:

- Point detection
- Line detection
- Volume detection
- Aspirating detection

Their operating procedure can be visualized in Figure 1.

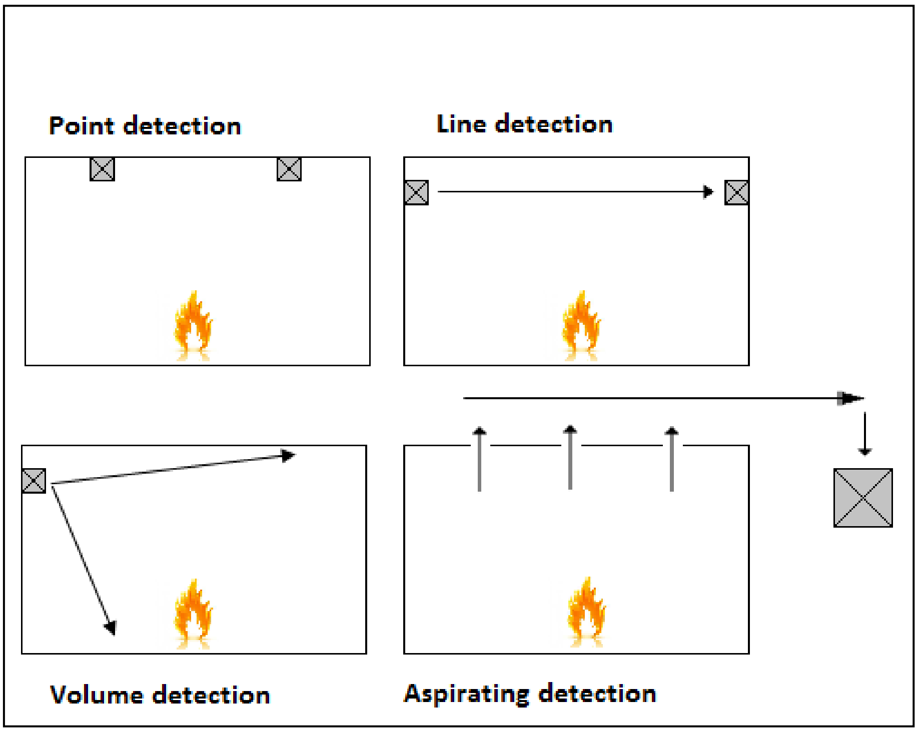

Figure 1. Different types of operating procedures of fire detection.

Each type of detection can be configured in different ways, which in their turn can react on typical fire signatures emitted by the fire.

- Smoke detection
- Heat detection
- Flame detection
- Gas detection

There are therefore a lot of ways a detector can indicate a fire, and next section focus on the different types. Also advantages and disadvantages are given for each detector type used in trains and aircrafts.

4.1 Smoke detectors

Smoke detector is the collective name and can in its turn be divided into subgroups in respect of function as seen below.

- Ionization smoke detectors
- Light scattering optical smoke detectors
- Light obscuration optical smoke detectors
- Aspirating smoke detectors

These are designed to detect the particles or aerosols created by an incomplete combustion. It is the far most used detector and has shown good performance in clean areas in the absence of dust. This is because smoke detectors react on the concentration of particles in the air (Nilsson & Holmstedt, 2008) [3].

4.1.1 Ionization smoke detectors

These function as a closed circuit where the detector transmits α−particles, which are ionized in the air into positive ions and negative electrons. These are in their turn attracted to charged metal plates inside the detector, and gives rise to a weak current in the circuit. When smoke passes through the detector, the positive ions and negative electrons get stuck on the smoke particles, and due to the mass of the particles they will simply pass by the metal plates without attaching to them. This will cause a decrease of voltage in the circuit and the detector will activate at a fixed value of decrease (see Figure 2).

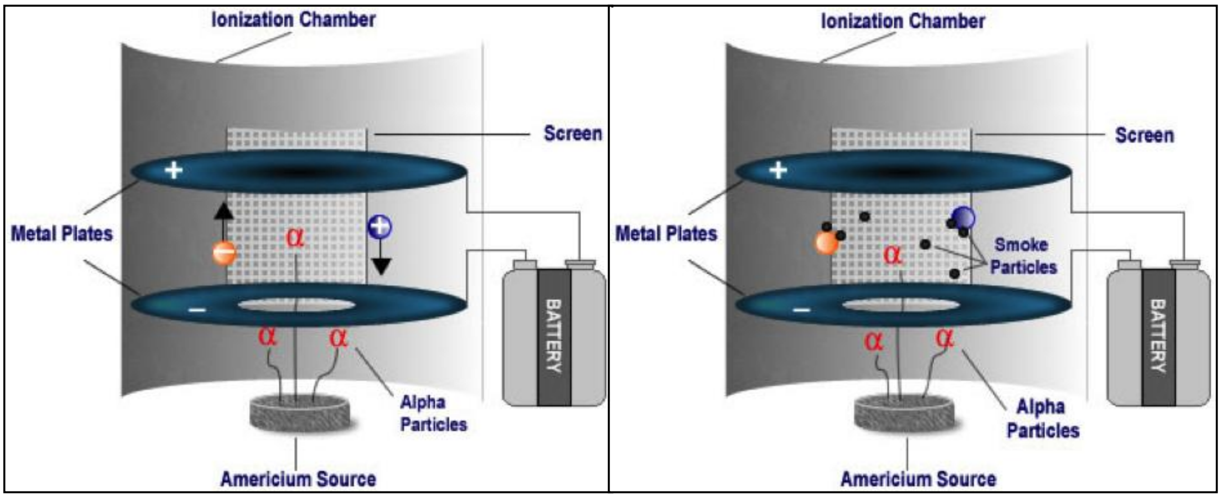

Figure 2. Example of how ionization smoke detector works (U.S. Environmental Protection Agency, 2012) [12].

Ionization smoke detectors are most sensitive for a high concentration of particles created by an open flame due to burning of e.g. wood, or paper. For more advantages/disadvantages see Table 1.

Table 1. Advantages and disadvantages of ionization smoke detectors.

Advantages	Disadvantages
Very sensitive to small smoke particles created from e.g. flaming fires	Radioactive waste material
Relatively cheap	Less sensitive to bigger particles created from a smoldering fire
	High false alarm rate due to cooking and/or hot steam.

4.1.2 Light scattering optical smoke detectors

This detector type consists of a light source and a photocell positioned at an angle to each other. In normal conditions the transmitted light passes into a "light maze" which prevents the reflection of light onto the receiver. In the event of fire, the passing of fumes through the detector scatters the light onto the photocell and at a specific threshold value of light intensity the detector activates (see Figure 3).

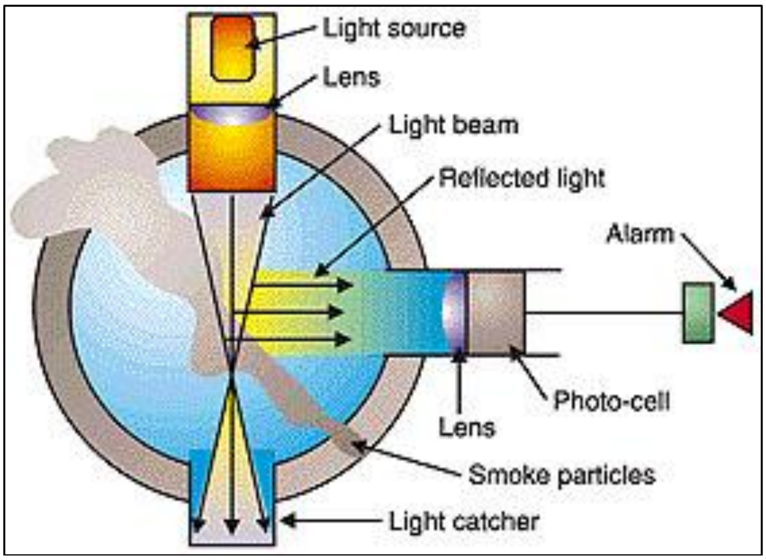

Figure 3. Example of how optical smoke detector works (New York City Fire Department, 2012) [13].

Scattering smoke detectors are more sensitive to large particles formed by a smoldering fire. They function best with brighter fumes since they reflect light better than darker fumes. Advantages and disadvantages for this detector type are summarized in Table 2.

Table 2. Advantages and disadvantages of light scattering optical smoke detectors.

Advantages	Disadvantages
Sensitive to larger smoke particles created by a smoldering fire	Less sensitive to smaller particles created from a flaming fire
Function best with brighter fumes	Less sensitive to darker fumes

4.1.3 Light obscuration optical smoke detector

An obscuration detector consists of a transmitter (light source) that sends out infrared light and a light sensitive receiver. The difference with the above mentioned optical smoke detector

(4.1.2) is that the incident light constantly affects the receiver. However when smoke enters in between the transmitter and receiver there will be a decrease in intensity and at a certain level of decrease the detector will activate (see Figure 4).

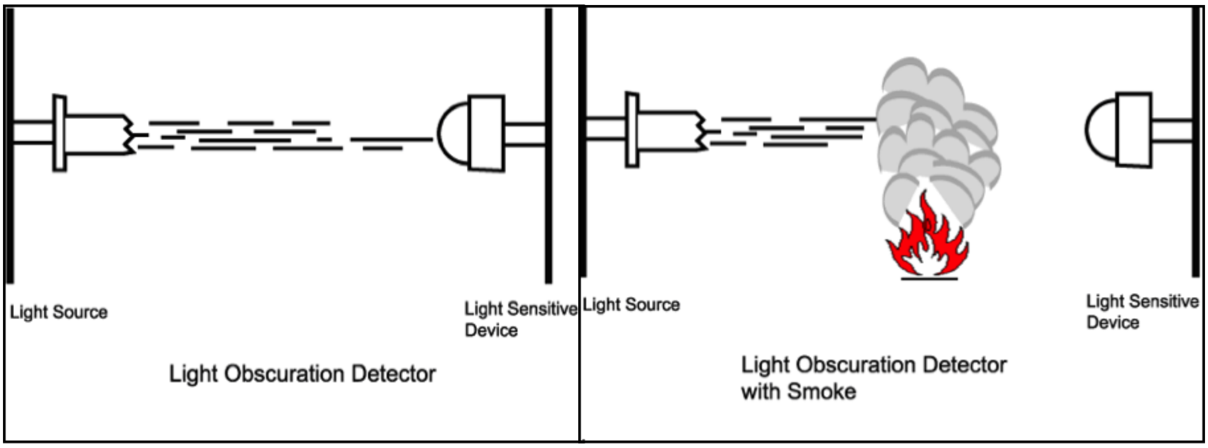

Figure 4. Example of how light obscuration detector works (New York City Fire Department, 2012) [13].

Light obscuration detectors activates on both bright and dark fumes since it doesn't consider the reflection of light. On the downside it requires a larger amount of particles in the fumes since it measures the difference in light intensity. It also needs to be protected from other light sources that might interfere with its functions. For more advantages/disadvantages see Table 3.

This detector type can be used both as a point or line detector, which can cover distances from 10 to 100 metres. The line type detector is ideal for long corridors and high atriums.

Table 3. Advantages and disadvantages of light obscuration optical smoke detectors.

Advantages	Disadvantages
Activates on both bright and dark fumes	Requires a larger amount of smoke particles
Possibility to cover long distances	Sensitive to other light sources

4.1.4 Aspirating smoke detection

This detector type often uses the same principles as a light scattering optical smoke detector. The difference is that it is constantly drawing in air (hence aspirating) into the holes of a pipe network as seen in Figure 5. This is done by the pressurization of a fan that is constantly creating a negative pressure and transports the air to a filter where dust and other contaminants are removed. The air then enters the detection chamber and uses light scattering technology, often by a laser beam to detect the presence of very small amounts of smoke particles. Because the laser light has a significantly higher intensity than other light sources, the reflection of light from particles will also be much higher. Due to this lower concentrations of particles can be detected. Detectors of this type are often fitted with a flow meter to ensure a constant suction from the fan.

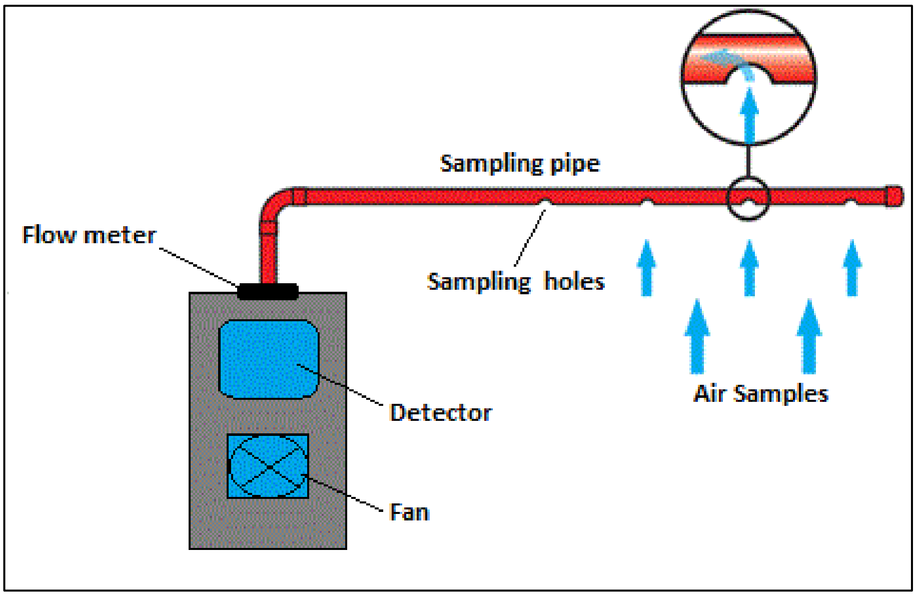

Figure 5. Example of how an aspirating system works.

The system as other smoke detection systems can be calibrated to detect smoke particles of various sizes. This means that the system can be set to activate on the typical particle sizes created by a fire. This makes the detector one of the fastest and it can activate on smoke particles before they are visible to the human eye (Fire Safety Search) [14]. Advantages and disadvantages for this detector can be seen in Table 4.

Table 4. Advantages and disadvantages of aspirating smoke detectors.

Advantages	Disadvantages
Can cover a large area	Hard to determine the location of the fire
Clean installation	Hard to tell if a hole is clogged
Low false alarm rate, when using a filter	Transportation time for smoke

There are also variants where no pipe is connected to the chamber. This type only uses a fan to draw in air to the detector chamber where often a normal smoke detector analyzes the presence of smoke (see Figure 6). This type can be compared to an ordinary light scattering detector but more protected from dust and other contaminants due to the protecting chamber.

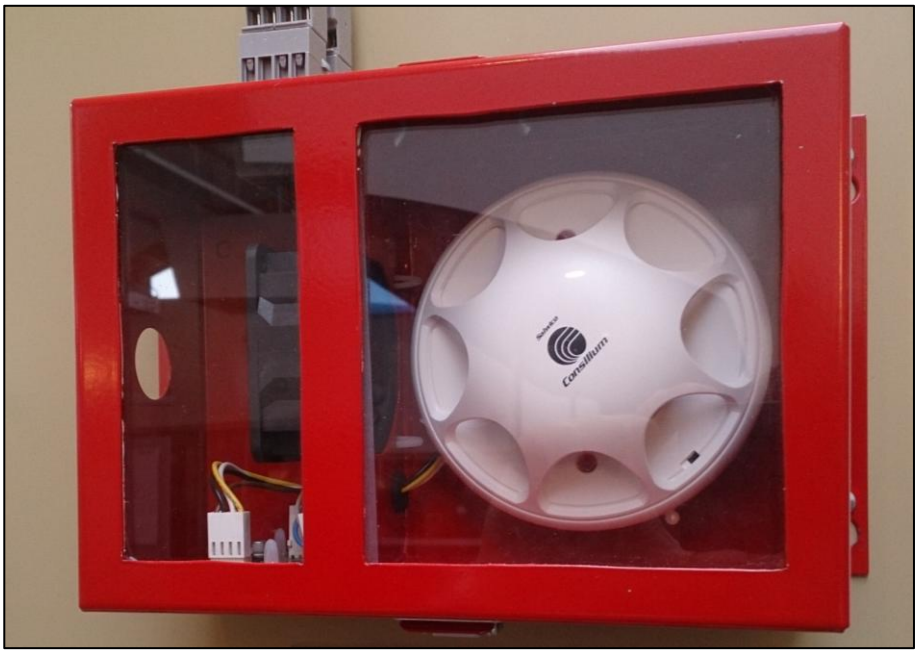

Figure 6. Example of an aspiration box. Note: Cover is removed to make the function visible.

4.2 Heat detectors

4.2.1 Point heat detectors

This system uses classical heat transfer analogy; heat is transported to colder areas and spreads throughout different materials. In point heat detectors there are one or more thermal elements, which are heated when hot fumes are passing the detector. These elements have a mass and a specific heat capacity, which results in a thermal inertia when heated. Thermal inertia controls how fast a surface reaches a specific temperature and depending on the material used it take different time. It is this technology that is used in heat detectors and the inertia can be expressed with a RTI−value (Response Time Index) that is set experimentally (Nilsson & Holmstedt, 2008) [3].

Heat detectors are normally divided into two main classifications of operation:

Fixed temperature, which will activate once the thermal element has reached a specific temperature. This procedure is often slower due to heat exchange and heat conduction.

Temperature Rate of Rise (RoR), which will activate at a certain temperature increase rate. This procedure will detect a fire faster than fixed temperature since temperature rise per unit time is faster than achieving a fixed temperature.

There are also detectors that operate using a combination of fixed temperature and temperature rise. This combination has the advantages of both detectors and has proven to be a more reliable detector (Nilsson & Holmstedt, 2008) [3]. For more advantages/disadvantages see Table 5.

Table 5. Advantages and disadvantages of heat detectors.

Advantages	Disadvantages
Insensitive to disturbances from e.g. dust	Long activation time in large areas
Good to detect high flames and intense heat	Almost impossible to detect smoldering fires due to the low temperature
Low false alarm rate	

4.2.2 Line heat detector (LHD)

This detector uses a cable to detect heat anywhere along its length. There are many types of cables to be used; one example is a gas filled pipe that reacts to the heat during a fire. The built up pressure due to the fire makes the gas expand and activates the detector. This solution is widely used in the aviation industry and goes under the name Advanced Pneumatic Detector (APD). Widely used are also Line heat detectors using low resistance twisted wires, insulated from each other by thermal polymers that are set to break down at a fixed temperature (see Figure 7). The breaking of the polymers causes the wires to connect and activate the detector. To determine where the fire is located a distance−locating module can be attached (Bukowski, 1987) [4].

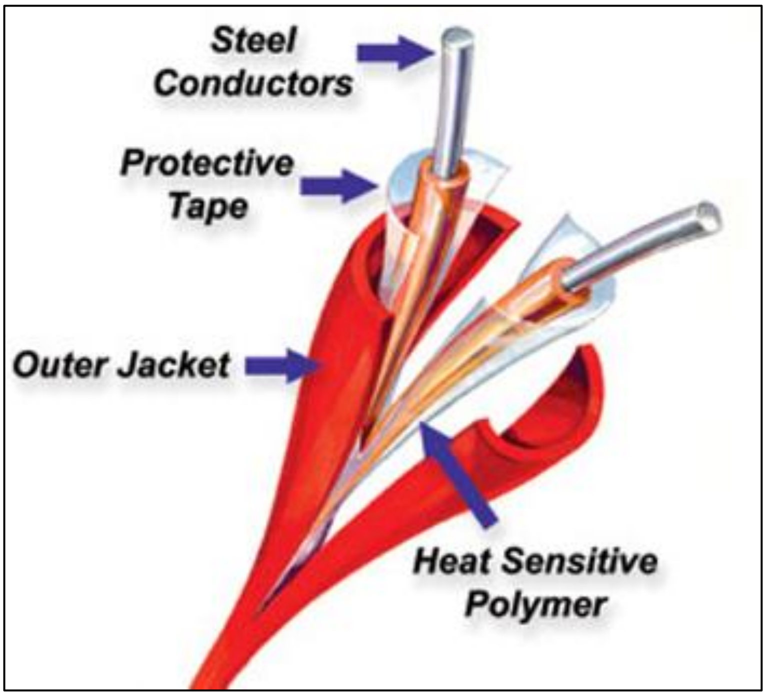

Figure 7. Example of how an LHD cable is constructed (Consilium Marine & Safety AB, 2012) [5].

Newer technologies have also emerged on the market. One type uses fiber optics and consists of glass fiber yarns and a laser that sends light through the fiber yarn. In the event of fire and/or temperature rise small changes in the fibers causes a change in its refractive properties. This change is noticed by a light receiver that activates the detector.

Fiber optics can be used to detect temperature changes along a loop up to several kilometers long. The exact location of the temperature increase can also be located with good accuracy (Nilsson & Holmstedt, 2008) [3].

Advantages and disadvantages for LHD's are shown in Table 6.

Table 6. Advantages and disadvantages of line heat detectors.

Advantages	Disadvantages
Suitable for enclosed and/or narrow compartments.	Hard to detect low temperature smoldering fires
Resistant to dust	

4.3 Flame detectors

Characteristic for detectors of this type are that they oversee a specific volume, e.g. a room. The fire signatures they react to are the radiation that is emitted from a visible flame. Either infrared (IR), ultraviolet (UV) or a combination of both radiation types.

Typical for flame detectors according to Bukowski (1987) [4] are that they have the highest false alarm rate and are the fastest ones to detect a fire. Due to the fast response time of a flame detector they are widely used in high risk organizations, where very rapid fires and/or explosions may occur. For a flame detector to function at its best they should be fitted in a large open area. This is because the detector must "see" the location and the fire. Corners and objects blocking the detector may therefore interfere and stop the signatures needed for detection.

4.3.1 IR detectors

These detectors basically consist of a lens and a filter to screen out unwanted wavelengths. Depending on the type of lens and filter used they can be either single frequency detectors or multi spectrum detectors.

The single frequency detectors are designed to detect an increase of light intensity at specific wavelengths. Typical in a fire situation is the combustion product, carbon dioxide that emits radiation in the specific wavelengths where a detector would activate. Also the produced carbon dioxide will absorb sunlight, which could interfere with the detector and cause false alarms.

The single frequency detector is also set to only detect radiation that fluctuates between certain intervals typical for an open flame. This will exclude the activation of radiation from e.g. radiators that doesn't tend to fluctuate as much as an open flame. However it might still according to Nilsson and Holmstedt (2008) [3] consider the fluctuation from the sun reflecting in water as an open flame and cause false alarms.

The multi spectrum detectors operate in different wavelength intervals other than the single frequency detector. Typical for this detector type is to compare different wavelengths, both from an open flame and from a radiating item. As the intensities in each wavelength intervals are compared the detector can distinguish a fire from a radiating item. In Figure 8 there is an example of a triple frequency IR flame detector.

Figure 8. Triple frequency IR flame detector.

4.3.2 UV detectors

UV−detectors use the same principles as an IR detector by detecting radiation at specific wavelengths. These wavelengths will be detected from the radiation emitted by free radicals that are produced in all open source fires. The detector won't activate due to sunlight since the atmosphere absorbs much of the UV radiation in the specific wavelength intervals.

Some substances as toluene, acetone or ethanol, absorbs UV−radiation and might screen the incident radiation. Even fumes produces by fires might screen the detector from UV−radiation. This is crucial in the placement of the detector (Nilsson & Holmstedt, 2008) [3].

4.3.3 UV/IR-detectors

These use both principles of the above explained detectors. To activate both mechanisms must detect, therefore this detector reduces the amount of false alarms due to the redundancy.

4.4 Gas detectors

Gas detectors are mainly used to sense the presence of high concentrations of combustible gases before a fire or explosion occurs. However they can be used to detect typical substances produced from a fire such as carbon monoxides and hydrocarbons, but this requires that they can detect very low concentrations.

Gas detectors can be divided in three main classifications of operation: Catalytic−, Electrochemical− and IR− gas detectors. These detectors are mainly fitted in industries and are not that common in aviation and in trains and won't be considered in this report.

4.5 Other detectors

4.5.1 Combined-/Multi detectors

More common today are the so called combined detectors that are a combination of two or more detection types. One popular solution is to combine an optical smoke detector with a heat detector as seen in Figure 9. This gives the advantages of both systems and a more reliant detector. Often are the signals that activate each detector analyzed by so called algorithms and a certain combination of the signals activates the detector. Algorithms also make the detector more redundant by discriminating interferences that may cause a false alarm (Nilsson & Holmstedt, 2008) [3].

Figure 9. Example of a combined smoke and heat detector (Consilium Marine & Safety AB, 2012) [5].

5 Alarm system

As mentioned in the previous section a detector simply detects the presence of a fire condition. This would be useless unless anyone or anything notice it and take action. Alarm systems can be designed in many ways; it can either give a signal by sound (acoustical), by a flashing light (optical) or an indication on a monitored control panel.

Alarm systems of today are often more flexible and customized. One example is a module based system where it is possible for the customer to design and optimize the system depending on the requirements. Modules can easily be changed and together make up the entire fire protection system.

The core of an alarm system is the control unit containing all central functions for detection, alarm, suppression and other vital functions. With a module based system this can be done totally automatic; a detector activates, a signal is given to the alarm system and suppression system, fire barriers automatically shut, the ventilation system shuts down and fire ventilation kicks in (C. Nylander, personal communication, September 18th, 2013) [32].

5.1 Conventional or addressable

In a conventional system all signals from detectors in a certain area represents the alarm address. This means that the fire cannot be specifically located to a single detector but simply an area of detectors. This may also mean that a suppression or extinguisher system activates over the whole area instead of just above the fire source.

In an addressable system each detector has its own alarm address. This means that the exact position of the activated detector can be determined. When connected to a suppression or extinguishing system only the fire in the affected zone will be extinguished instead of the whole section (The Fire Safety Advice Center) [15].

5.2 Analog and digital systems

Analog and digital systems are always addressable. This is because either the detector or control unit must interpret the incoming signals as a fire or not and take the right actions. Analog systems are primarily used to prevent the rate of false alarms.

There are mainly two types of analog systems; the bulk of analog systems only use output signals from the detector, representing the value of what is detected. These signals are then interpreted by the control unit that decides whether there is a fire, fault or other. In a more complex analog system each detector has its own computer that evaluates its surrounding environment and decides whether there is a fire, fault or other. It may even signal when the detector head is soiled and adjust its threshold activation level so a constant sensitivity is maintained (The Fire Safety Advice Center) [15].

The analog system incorporates a digital system. With a digital system it is possible to receive output and input data of the systems functionality by downloading it from the control unit. It is also easy to change the function of each detector; activation level or disconnect one function in e.g. combined detectors. If the control unit is programmed with this information it is according to C. Nylander (personal communication, September 18th, 2013) [32] possible to replace a detector that malfunctions and the new one will automatically adjust to the latest settings made in the control unit.

5.3 Redundant systems

Systems of today are more reliable than before due to redundancy. Systems are often connected in *closed loops* or *return loops* as seen in Figure 10, which ensure that all detectors can be functional and accessed even with a breakage somewhere. Redundancy can also be obtained by using two or more control units (Figure 11), in case one breaks down. They all share the same information, but with one lost the other will take over the system and no information will get lost.

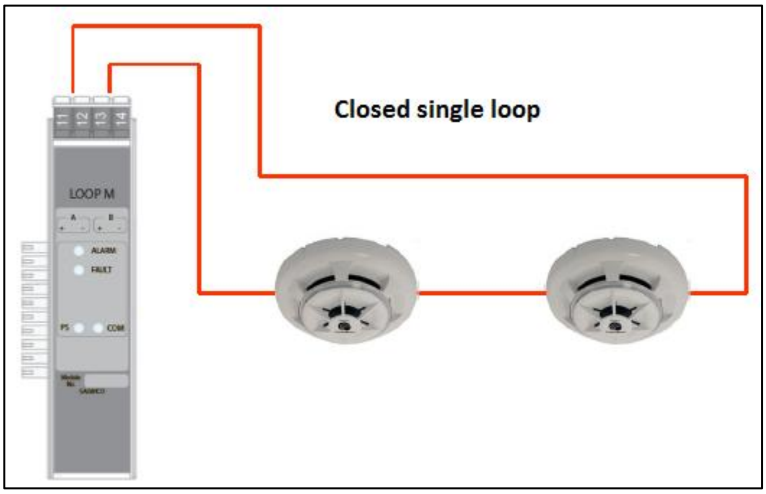

Figure 10. Example of a closed single loop (Consilium Marine & Safety AB, 2012) [5].

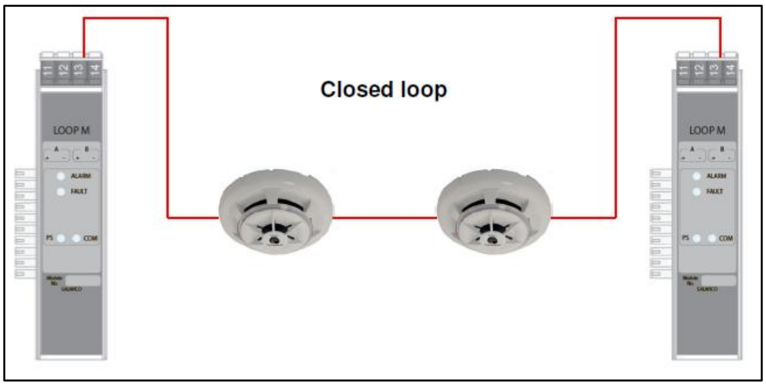

Figure 11. Example of closed loop with two control units (Consilium Marine & Safety AB, 2012) [5].

Other examples of redundancy are short circuit isolators, which are placed in segments in the loop. In the event of a short circuit only the affected segment will be disabled, keeping the rest of the detectors operational (Consilium Marine & Safety AB, 2012) [5].

6 Fire detection and fire alarm systems in trains

Detection systems used in trains are mainly fitted in passenger and staff compartments where they can be assumed to function under many different circumstances and fire signatures. These types of transportations are also often exposed to very harsh conditions like heat, cold, humidity, shock and vibrations. Vandalization is another thing to take into account when fitting the detection systems, e.g. by fitting the system out of reach for the passengers. The fire detection system must therefore be reliable, durable and minimize the amount of false alarms.

6.1 Existing solutions in trains

The fire detection systems in trains often consist of two types of detectors: S*moke detectors* and *heat detectors.* According to J. Vedholm (personal communication, September 10th, 2013) [33] Smoke detectors are often fitted in staff and passenger areas of the train whereas heat detectors are most used for electrical cabinets. The following subsection will give examples of some solutions used in Swedish trains.

6.1.1 Train X2

Train X2 also known as SJ2000 (former X2000) is one of the most common fast trains used in Sweden today. It has been in traffic since 1989 and the fire protection system is nowadays often built up as retrofits.

6.1.1.1 System

Detector types: Combined smoke and heat detector

Alarm goes to: The driver

In train X2 each car has its own independent fire detection system, built up as a module based system that communicates directly with the Train Control and Monitoring System (TCMS) through central units (see Figure 12). The TCMS in turn oversee all functions. If a control unit in one car malfunctions other central units will take over the loop communication with the TCMS (C. Nylander, personal communication, September 18th, 2013) [32].

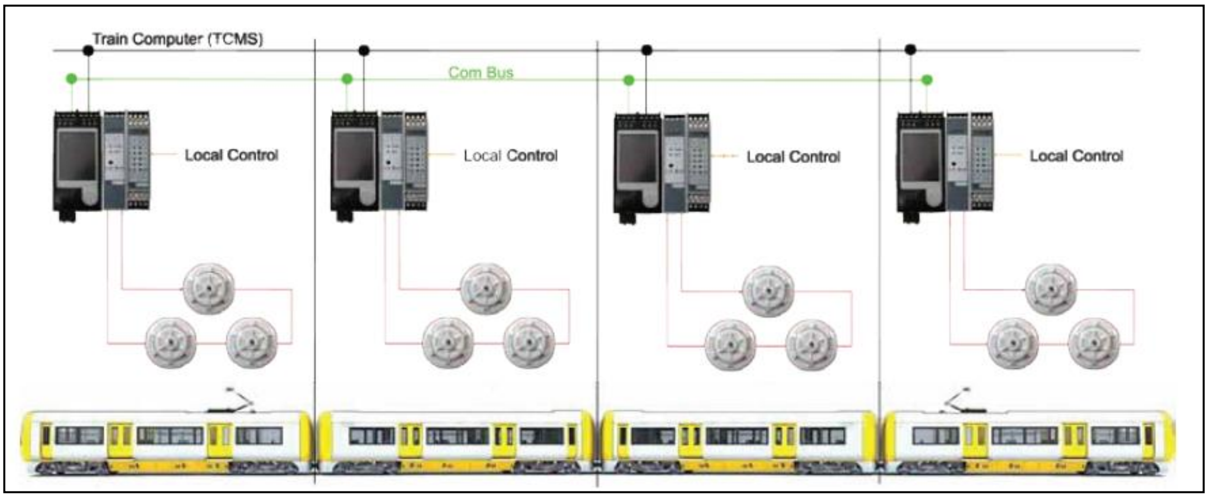

Figure 12. Example of fire detection system in train X2 (Consilium Marine & Safety AB, 2012) [5].

The local controls seen in Figure 13 are used to supervise and control all functions of the fire alarm system. This is done by a menu based system that gives instructions in a text window.

Figure 13. Example of drivers cab with control unit and text window to the right, similar system used in SJ2000.

6.1.1.2 Detectors

Passenger areas

The detection system is built up using so called return loops connected to analog addressable combined detectors with two separate activation mechanisms. One optical smoke detector using light scattering technologies (4.1.2) and one temperature heat detector with a fixed value of 54° C (4.2). Each function of the combined detectors can be deactivated in the control panel in case of disturbances causing false alarms. When replacing a detector the control unit will remember its latest settings and won't affect its function (M. Presthus, personal communication, September 19th, 2013) [34].

When the detector is activated a red LED light appears on the detector until the detector has been receipted.

All detectors in passenger areas are placed in the ceiling. Where risk of damaging the detector e.g. above luggage compartments, the detector is protected by a protecting cage (see Figure 14).

Figure 14. Example of a protection cage on top of a smoke detector to prevent damage.

Figure 15 along with Table 7 shows an approximate placement and numbers of detectors used in train X2.

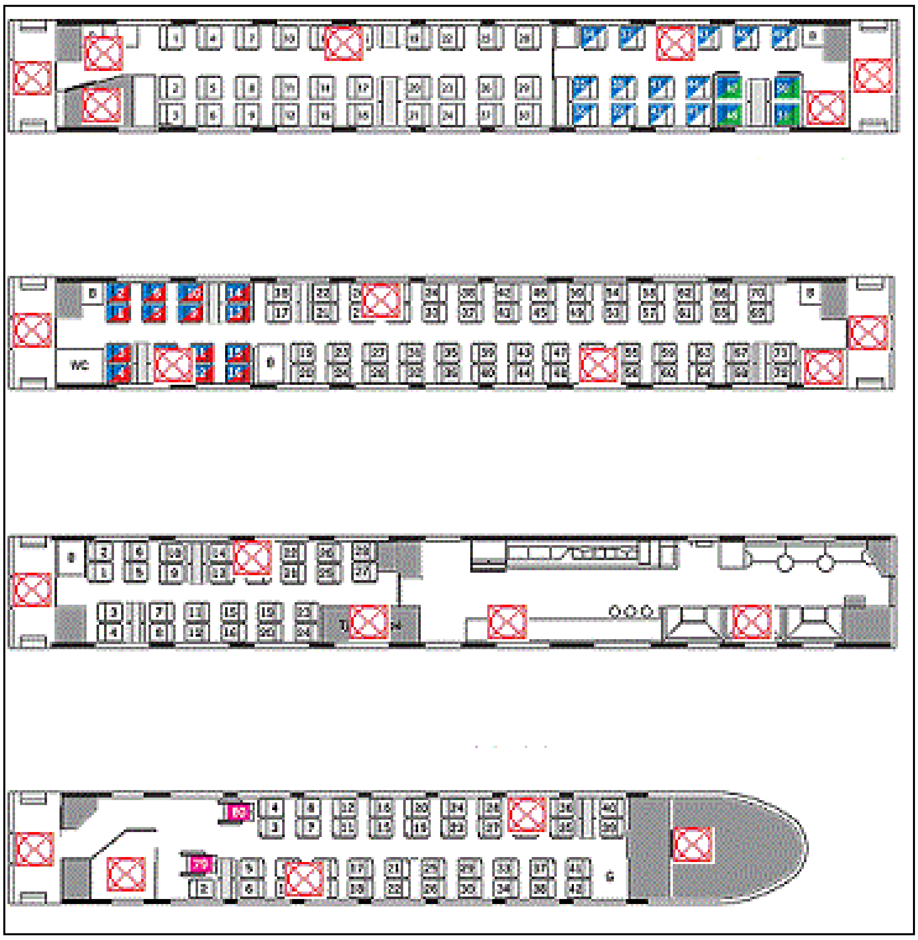

Figure 15. Approximate placement of smoke/heat detectors in SJ2000 seen from above (M. Presthus, personal communication, September 19th, 2013) [34].

Table 7. Placement and number of different detectors.

Area	Number of detectors	Detector type	Placement
Toilets	1	Combined smoke/heat	Ceiling
Vestibules	1 or 2	Combined smoke/heat	Ceiling
Restaurant	2	Combined smoke/heat	Ceiling
Service compartment	1	Combined smoke/heat	Ceiling
Undercarriage	1	Smoke with fan	–
Electrical cabinets	1	LHD	Aloft

Electrical cabinets

In the X2's engine car, heat sensitive cables, so called LHD's (4.2.2), are used for fire detection in electrical cabinets. These are according to O. Hammar (personal communication, October 21st, 2013) [35] placed aloft in the cabinet. It consists of low resistance twisted wires, insulated from each other by thermal polymers that are set to break down at a fixed temperature. In this case the heat sensitive cables break down, causing the wires to connect and activate the detector when the temperature has exceeded 85°C.

Undercarriage

The undercarriage detects fire using an optical smoke detector with a fan (4.1.4). The detector is also fitted with a dust filter because of the dusty environment.

6.1.1.3 Alarm management

When a detector has indicated a fire a signal is given to the driver through the control unit (see Figure 16). First step is to begin deceleration and plan for a suitable place of evacuation but also to make sure the train doesn't come to a halt in a tunnel where the situation might get even worse. The driver then contacts the onboard staff using the train's speaker system. The staff controls the indicated area and takes necessary actions.

Figure 16. Example of an indication panel. Note, not used in train X2.

When the driver is given an indication signal of fire, a flashing red light will appear and a buzzer will make a sound. The system is menu based and instructions are given in the text window of where the fire is located. When all alarms are receipted the indication lights will stop flashing and switch to a steady light. This type of system is of the addressable kind (5.2) where the location of the activated detector can be seen on e.g. a control unit (M. Presthus, personal communication, September 19th, 2013) [34].

For detected fires in electrical cabinets located in the engine car the LHD will trigger an extinguishing system consisting of Argonite; 50% Argon and 50% nitrogen. The extinguishing agent will release automatically when a fire is detected and spread through nine nozzles placed in the electrical cabinets. After the first extinguish dose is released, a secondary spread of Argonite will occur from the cabinets into the engine room (M. Presthus, personal communication, September 19th, 2013) [34].

It is also possible for the driver to manually activate the Argonite in case of a malfunction.

Engine car fires will also automatically shut down the HVAC (Heating, ventilation and air conditioning) system and the main switch is turned off.

6.1.2 Train X55

Train X55 also known as SJ3000 is made to replace X2 on some routes and has been in traffic since 2012.

6.1.2.1 System

Detector types: Smoke detectors

Alarm goes to: The driver

Within train X55 the fire alarm system is similar to the X2 train, every detector is connected to control units in a return loop as seen before in Figure 12.

6.1.2.2 Detectors

This train type uses ionization smoke detectors (4.1.1) with a minimum active material. Some detectors also use a built−in fan fitted with a flow controller to ensure constant airflow. The flow controller consists of a red signal flag (plastic strip) attached on the incoming air supply. In normal operation the flag is slightly turned due to the airflow through the detector (M. Presthus, personal communication, September 19th, 2013) [34].

Train X55 is fitted with detectors in passenger compartments and drivers cab (see Figure 17). More specifically smoke detectors are placed in:

- Drivers cab
- Seating compartments
- Toilets
- Staff compartments
- Restaurant
- Kitchenette

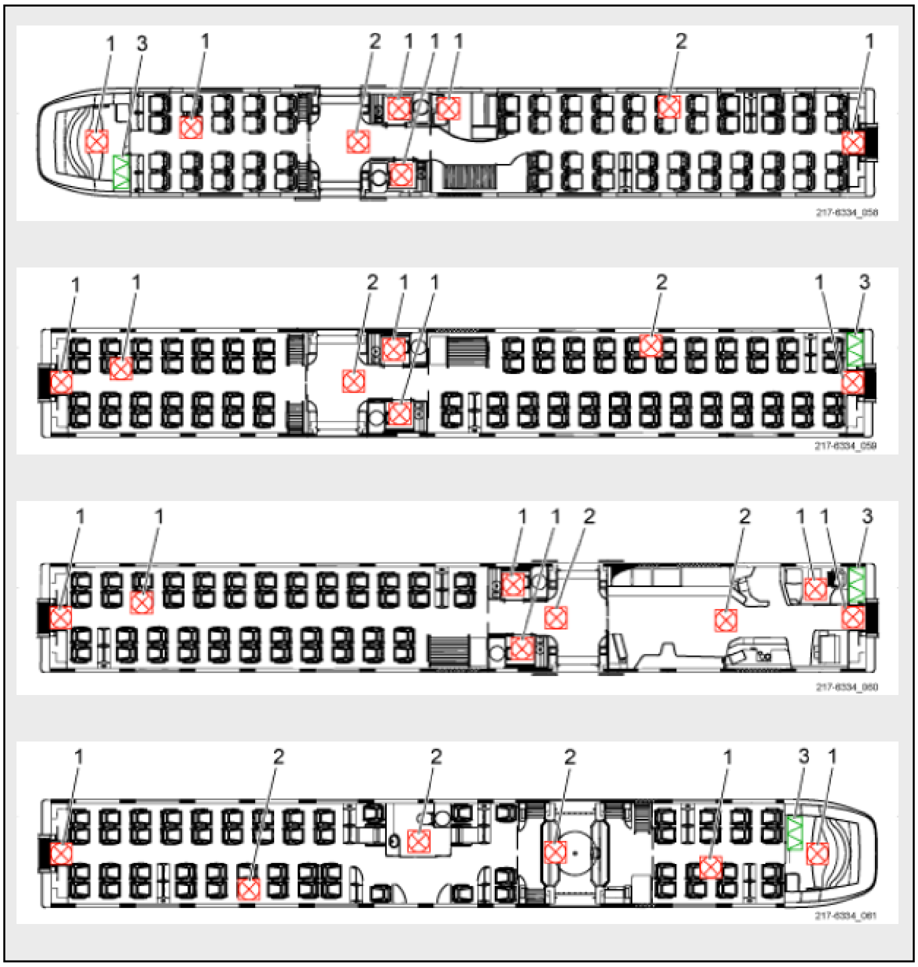

Figure 17. Placement of different detectors and control units in SJ3000 seen from above (M. Presthus, personal communication, September 19th, 2013) [34].

Table 8. Description of the different positions in Figure 17.

Position	Description
1.	Smoke detector
2.	Smoke detector with fan
3.	Control unit

Noticeable is that the control units are placed so that either staff or the driver easily can access them.

6.1.2.3 Alarm management

If smoke is detected onboard, the fire alarm system will signal both with an acoustic and an optical signal. This is done by igniting a yellow indication lamp and a buzzer will sound on the drivers control unit. The control unit will show information that smoke has been detected, but not where. This is typical for a conventional system (5.1). The alarm will also trigger the TCMS that immediately shuts down the HVAC−system, setting the exhaust air unit on maximum speed in order to remove the smoke. The TCMS will also deactivate all interior doors to keep the smoke from spreading between compartments. Interior doors can only be opened manually in case of an evacuation.

In case of an alarm the driver immediately contacts the onboard staff using the train's speaker system. The staff controls the indicated area and takes necessary actions. If needed the driver begins deceleration and plan for a suitable place of evacuation but also to make sure the train doesn't come to a halt in a tunnel where the situation might get even worse (M. Presthus, personal communication, September 19th, 2013) [34].

6.2 Other train types

6.2.1 Sleeping and couchette vehicles

Detector types: Heat and smoke detectors

Alarm goes to: Staff pagers

Design and regulations of the fire protection system tend to differ somewhat in sleeping and couchette vehicles. Due to sleeping passengers the system must be reliable and unavoidable.

6.2.2 Alarm management

When a detector has activated a buzzer will sound in all passenger compartments, lavatories, showers and an alarm bell will sound in all corridors. Meanwhile the onboard staff will receive a signal to their pagers, telling them in which car the fire is located. To locate the exact detector an annunciator placed in a cabinet in each car will tell the location. There could also be a light diode outside each coupe indicating an alarm.

When the onboard staff has received and acknowledged the alarm at the control unit the alarm will be silenced. They will now investigate the activated zone and take action, with the possibility to reactivate the sound or reset the alarm.

If there is a malfunction in the fire protection system in a car, all passengers should be moved to another car. If this is not possible onboard staff must stay in that car regularly, at least once every 15 minutes during sleep time (M. Presthus, personal communication, September 19th, 2013) [34].

6.2.3 Older trains

In some older vehicle types there is no fire protection system. This is mainly due to old regulations and standards.

6.3 Applicable fire detection systems in trains

By the introduction of module based fire detection systems (5) only the imagination can stop the design of the systems. Many types of detectors, fire alarms, suppression– and extinguishing systems can be connected and operated within the same system.

Below some examples of multi integrated solutions are shown. These systems are available but not used in Swedish rail vehicles of today.

6.3.1 Example 1

This is an example of an analog redundancy system (5.3) with two central units in the first and last car sharing the same loop. Both central units are sharing information and if one is lost the other one will take over. The system is also fitted with short circuit isolator. In addition to the addressable combined smoke and heat detectors each car also has an extinguishing system using a pump unit, which creates a high pressure water mist that is released from the spray heads. This extinguishing system is controlled by the central units communicating with the module as seen in Figure 18 and can activate separate spray heads or all in each car depending on where the fire is located (C. Nylander, personal communication, September 18th, 2013) [32].

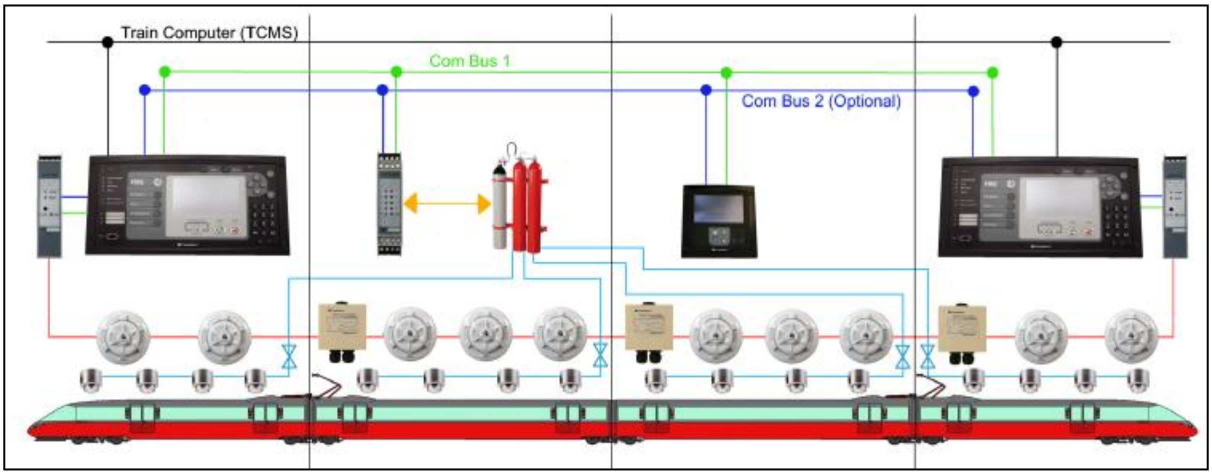

Figure 18. Example of a redundant system with integrated extinguishing system (Consilium Marine & Safety AB, 2012) [5].

6.3.2 Example 2

Similar to the X2 train solution (6.1.1) each car has its own independent fire detection system where each central unit communicates with the TCMS directly. If one control unit is lost the other will take over the loop communication. The detectors are combined smoke and heat detectors and aspirating smoke detectors in passenger areas. In Figure 19, the second car from the left is fitted with LHD's and these are mainly used in electrical cabinets and traction units.

The second car from the left is also fitted with an address unit. This device is designed to connect different types of devices to the fire alarm system, e.g. a LHD, as shown in Figure 19.

As *Example 1* (6.3.1) this solution also uses a high pressure water mist as extinguishing system. The difference is that each car has its own pump unit communicating with a control unit. The extinguishing system can be activated in separate zones or in the whole car, depending on where the fire is located.

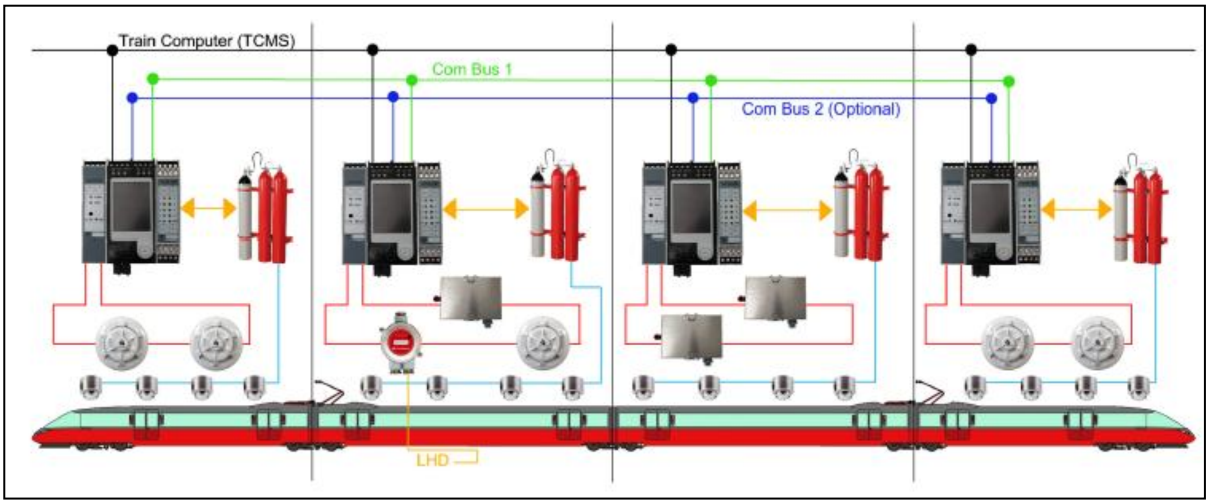

Figure 19. Example of a redundant and independent system with integrated extinguishing system (Consilium Marine & Safety AB, 2012) [5].

6.3.3 Example 3

This is a rather easy configuration using one control unit in the driving car where the TCMS is located (see Figure 20). A return loop enables the system to communicate with each detector even if a connection has been damaged.

The detection system consists of one Laser Aspiration Detector (4.1.4) in each car. The use of laser provides fast detection and a system immune to ambient air temperature and pressure changes.

Each car is also fitted with an addressable indication control unit connected in the loop. This allows the control and monitor of external devices such as fire doors, spray heads and fire dampers.

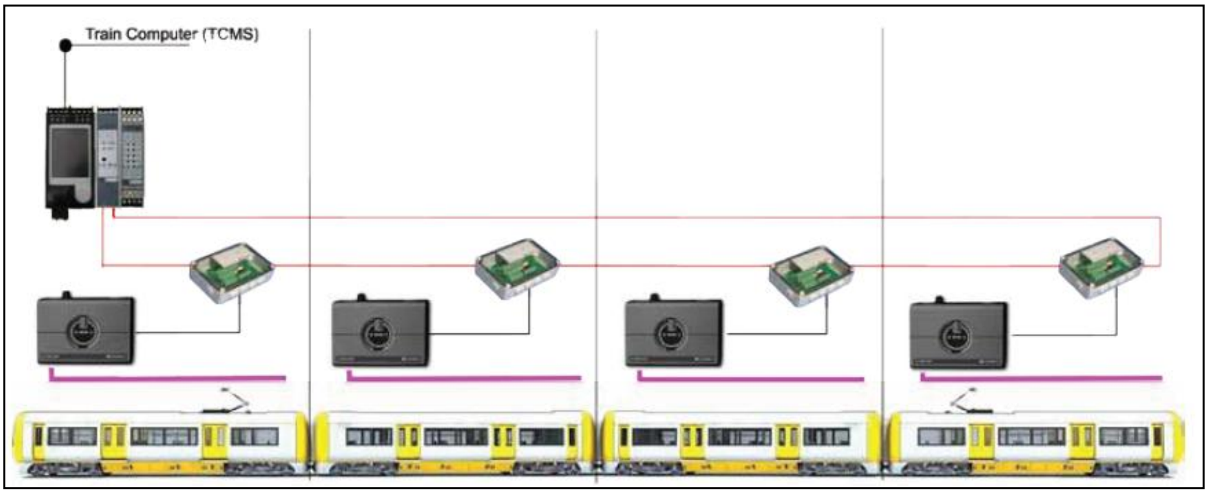

Figure 20. Example of a closed loop laser aspiration system (Consilium Marine & Safety AB, 2012) [5].

7 Fire detection and fire alarm systems in aircrafts

An airplane is very exposed in the event of fire while in the air. It can't simply stop, start evacuating its passengers and wait for the fire brigade to extinguish the fire. This demands a highly reliable and redundant fire detection and extinguishing system. The system must also be very sensitive, stable (free of false alarms) and able to withstand extreme environment e.g. temperature, vibrations and high airflows (Cote et al., 2008) [6].

7.1 Existing solutions in aircrafts

The main purposes of a fire protection system in aircrafts are to monitor following conditions:

- Fire
- Smoke
- Overheat

Following section gives an example of a fire protection system in aircrafts. Information concerning design and performance of these systems are mainly gathered from big manufacturers of aircrafts such as Boeing and Airbus.

7.1.1 System

The aircraft fire detection system is designed to detect the above mentioned conditions. When any of these conditions are sensed fire detection modules will provide an acoustic or visual signal to flight deck and the fire protection panel.

The detection system is addressable and will indicate where a potential fire/overheat has occurred. The system must also automatically reset to notify the flight crew when the fire has been extinguished (Cote et al., 2008) [6].

The "critical" zones in the fire protection system e.g. engines and cargo compartment use detectors in a dual loop. In an event of fire both loops must indicate a fire and supply a signal to flight deck. The purpose of having both loops indicate a fire is the possibility of false alarms. According to P. Ekenbratt Ågren (personal communication, September 9th, 2013) [36] it is not desirable to shut down an engine unnecessarily. In the event of a failing loop, the system has a fault monitoring circuit which automatically deselects that loop and the remaining loop functions as a single loop detector. There is no signal to flight deck indicating a single loop fault but if both loops fail a fault light illuminates and the system is inoperable (Smart cockpit) [16].

Other units such as the Auxiliary Power Unit (APU) use a single loop also connected to a fault monitoring circuit, if malfunctioning it signals inoperability. The extinguishing system is placed in the critical zones and uses Halon gas as extinguishing agent.

7.1.2 Detectors

The fire detection system consists of:

- Engine fire/overheat detection
- APU fire detection
- Wheel fire detection
- Cargo compartment smoke detection
- Lavatory smoke detection

An overview of the detector placement can be seen in Figure 21.

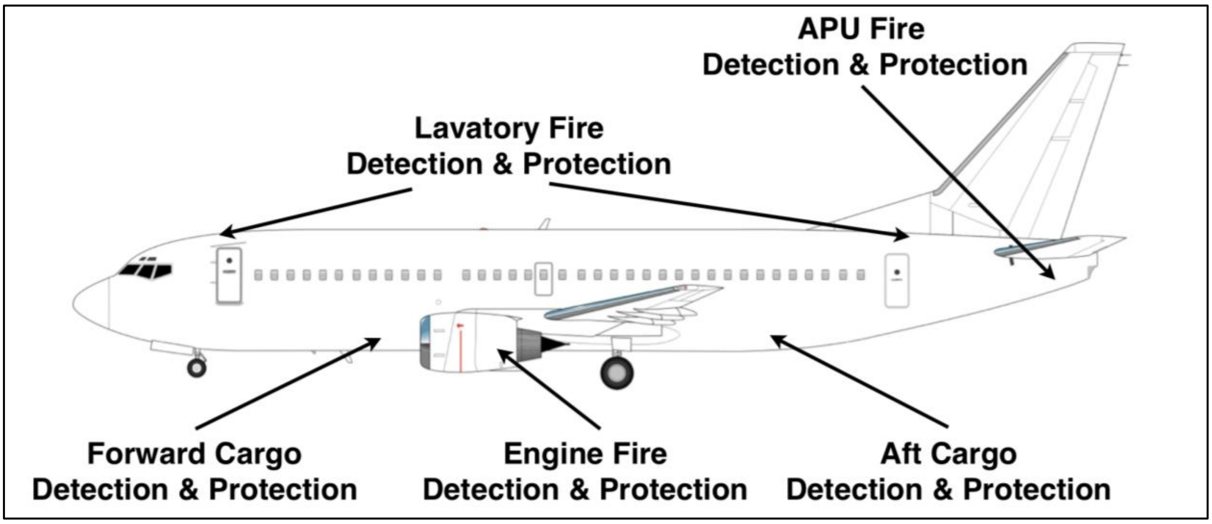

Figure 21. Overview of fire detection & protection placement in an aircraft (Aircraft Photos & News) [17].

7.1.2.1 Cabin and flight deck

There are no detectors in these areas. The reason is, according to P. Ekenbratt Ågren (personal communication, September 9th, 2013) [36], that these areas always are monitored by either passengers or crew. If the airplane is flying without any passengers the cabin door is left open so the pilots have a clear view of the cabin.

7.1.2.2 Engine

Each engine contains four fire/overheat detector loops mounted in parallel and connected to Advanced Pneumatic Detectors (APD) (4.2.2) in each end (see Figure 22). These pressurized tubes sense an increased pressure due to temperature rise and give a signal to the fire detection module in three cases:

- Overheat – at a predetermined pressure increase
- Fire – at higher pressure than overheat
- Fault – loss in or no pressure

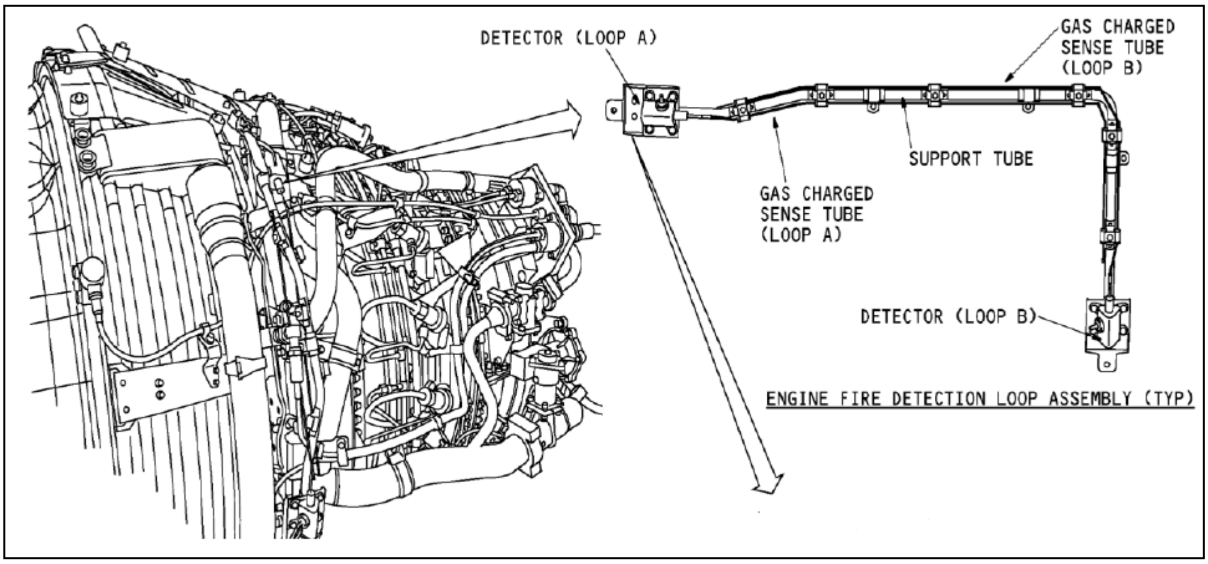

Figure 22. Example of an engines dual loop APD's (O. Andersson, personal communication, October 3rd, 2013) [37].

APD's have two sensing functions. They can react to an overall *average* temperature threshold or localized *discrete* temperature increase due to flames or hot gases.

Averaging function – The detector functions as a fixed volume device filled with helium. The helium gas pressure increases in proportion to the absolute temperature and operates a pressure membrane that closes an electrical contact, activating the alarm. The alarm threshold is preset at an average temperature and normally operates in the range of 200 °C to 454 °C.

Discrete function – The detector sensor tube also contains hydrogen filled core material. When a section of the tube is heated to a preset temperature or higher hydrogen gas is released, which increases the pressure inside the detector and actuates the alarm.

Both these functions are reversible and when the tube is cooled the average gas pressure is lowered and the discrete hydrogen gas returns to the core material (Federal Aviation Administration) [18].

As mentioned above both loops must sense a fire or overheat condition to signal flight deck. The detection loops consists of detectors in the engines:

- Pylon nacelle
- Core engine
- Compressor
- Fan section

7.1.2.3 Auxiliary Power Unit (APU)

The APU uses a single fire detection loop based on Advanced Pneumatic Detectors (APD's) and activates at a predetermined pressure for fire situations or loss in pressure for fault. The loop is placed onto the APU's hatch and connected to a support tube to minimize damages due to vibrations (see Figure 23). This single loop does not have the same redundancy as the engine detectors. If it fails the fire detection module will simply report a fault to the fire protection panel (Smart cockpit) [16].

Figure 23. Placement of the APU's single loop APD.

7.1.2.4 Cargo compartment

The forward and aft cargo compartments use dual loop optical smoke detectors (4.1.2). They work in the same manner as the engine dual loop i.e. both detectors must activate to signal an alarm. The detectors are placed in the ceiling of the cargo compartment (see Figure 24) and are covered, providing protection from external damage e.g. when loading the compartment.

Aspirating systems (4.1.4) can also be used. These work by having a fan that is constantly drawing air from the sampling ports located in the cargo compartment ceiling to the smoke detectors located outside the cargo compartment. The air is later exhausted outside the compartment (Hipsher & Ferguson) [7].

Figure 24. Placement of smoke detectors in cargo compartment. Note that cover has been removed.

7.1.2.5 Wheel well

In the main wheel well a single fire detection loop using APD´s could be used. There are also examples of LHD's (4.2.2) or sensing elements consisting of a single strand of nickel wire embedded in insulation. A current flows in the centre wire, and the insulation that is impregnated with a salt compound in a tube is electrically grounded. The LHD functions by having a resistance inversely proportional to temperatures. This means when the temperature in the wire increases its resistance decreases. The insulation decomposes due to the temperature increase and a current flow between the outer sheath and the centre conductor. The current flow is sensed by the control unit, which activates the alarm in flight deck (O. Andersson, personal communication, October 3rd, 2013) [37].

The front wheel well has no fire detection due to the absence of brakes and lack of power transmission, causing less heat than the main wheels.

7.1.2.6 Lavatory

This compartment uses a smoke detector placed in the ceiling. The lavatory waste bin is also protected by a heat activated extinguishing system with no electrical interface as seen in Figure 25. When heated to a certain point the fusible seals on the end caps of the extinguish bottle melts and releases the end caps. This releases the extinguishing agent that discharges into the waste bin (Smart cockpit) [16]. No indication is provided when the waste bin extinguisher has discharged. The only way to make sure it's operable is by weighing it or according to P. Ekenbratt Ågren (personal communication, September 9th, 2013) [36] checking a temperature indicator above the waste bin. This indicator has four dots representing different temperatures and turn from white to black when exposed to high temperatures, which could indicate a discharge.

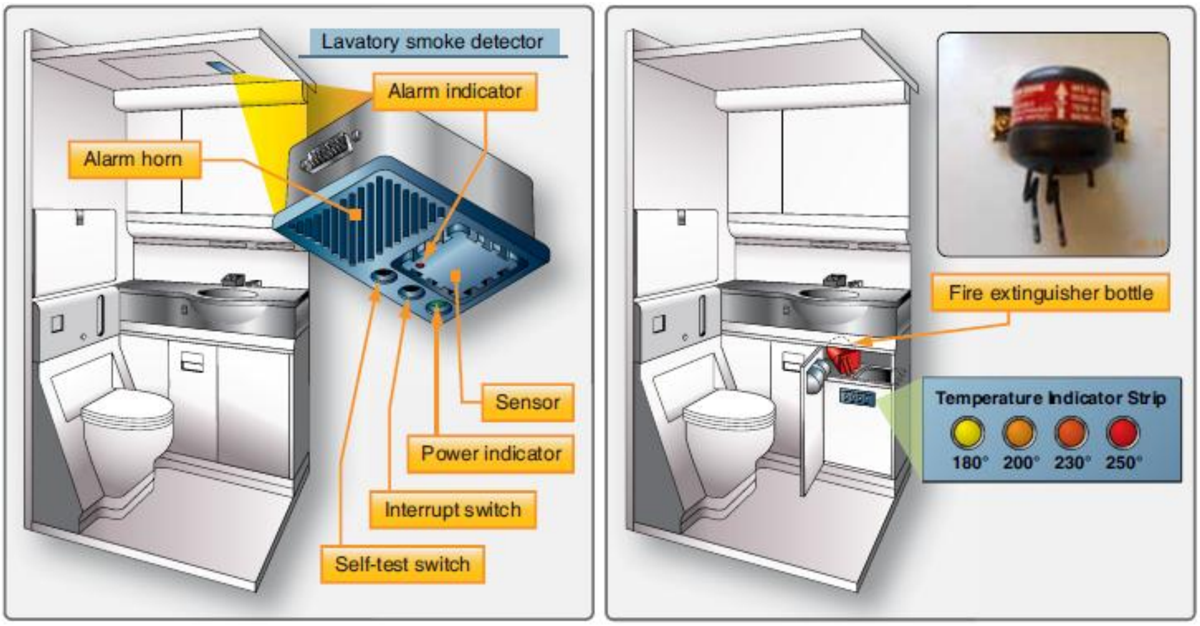

Figure 25. Lavatory smoke detector and extinguishing bottle placement. Temperature indicator to the right (Federal Aviation Administration) [18].

7.2 Alarm management

All activated detectors give a signal, acoustic and optical, to flight deck and onto the fire protection panel. An activated detector will first indicate on the Master Fire Warning Light The pilots are now aware of a fire or fault and it is now possible for the pilots to monitor where the fire/overheat condition is located and activate the extinguishers.

Extinguisher's may be armed and discharged in all compartments from the fire protection panel except the lavatory waste bin which discharges automatically due to high temperatures (Smart Cockpit) [16].

Figure 26. Master Fire Warning Light (red) to the left and Overheat/Fire Protection Panel to the right.

If e.g. a fire occurs in one of the engines the detector send a signal to the fire protection module, which in turn provides a signal to the fire protection panel and the *Master Fire Warning Light* is illuminated (see Figure 26). This unlocks the affected engine's *Fire Switch* seen in Figure 26 and the pilots may now activate it by pulling the handle up. When activated following happens: the engine stops because the fuel feed is shut off, hydraulic fluids are shut off and the fire extinguishing system is armed. It is now possible to manually discharge the extinguisher bottles into the engine by rotating the *Fire Switch* left or right (Smart Cockpit) [16].

Similar actions happen in the APU and the cargo compartment with an occasional exception in the cargo compartment. Sometimes aircrafts are fitted with two types of fire extinguisher bottles in the cargo compartment. There is one primary and one secondary discharge of the extinguisher agent. The first is manually controlled from the *Cargo Fire Panel* in flight deck (see Figure 27). When a fire condition is detected the *Master Fire Warning Light* is illuminated followed by the *Cargo Fire Warning Lights* on the *Cargo Fire Panel*. It is now possible to manually arm and discharge forward and/or aft cargo compartment extinguishing bottles. The secondary discharge is released slowly after a time delay. This is done to keep the correct concentration of extinguishing agent for up to 180 minutes (Federal Aviation Administration) [18]. In addition to the cargo compartments extinguishing system, techniques like air starvation are often used (Cote et al., 2008) [6]. When the detection systems activates, all ventilation to the compartment is sealed off. The fire will then hopefully self−extinguish due to the lack of oxygen.

Figure 27. Example of Cargo Fire Panel showing forward and aft Cargo Fire Warning Lights and Bottle Discharge Light (The Boeing 737 Technical Site) [19].

The main wheel well is often exposed to high temperatures due to hot brakes, hydraulic pumps, engines for maneuver the landing gear and hot wheels at landing and takeoff. Here there is no extinguishing system. In case of a fire the landing gears are according to P. Ekenbratt Ågren (personal communication, September 9th, 2013) [36] simply lowered to prevent an explosion of the wheels and also to blow out the fire with the high wind speed. Also the entire well is covered in non−combustible grease that prevents vital parts to ignite.

During maintenance or on the ground it is according to O. Andersson (personal communication, October 3rd, 2013) [37] common to keep the APU running to provide power to vital functions. In the event of a fire the main wheel well has an APU ground control that give external indications of an APU fire. A horn and a red light will operate alternately at a one per second rate. It is possible for ground personnel to discharge the halon bottles from here and into the APU (see Figure 28). In some aircrafts it is possible for automatic discharge if there is an APU fire when on the ground (Smart Cockpit) [20].

Figure 28. Main wheel well fitted with APU Fire Control.

In the event of fire in the cabin or flight deck, necessary actions will be taken e.g. portable Halon fire extinguishers.

8 Standards and guidelines

The use of standards and guidelines are to ensure the protection of vehicles and most importantly safety of passengers. Today there are several standards and guidelines regarding fire protection. Presented below are short summaries about the standards and guidelines that exist today or in a nearby future and are the most relevant for this study.

8.1 General

8.1.1 EN 54

This European Standard specifies requirements, test methods and performance criteria for fire detection and fire alarm systems installed in buildings. The lack of other applicable standards and guidelines in this area has made it useful for all types of detection and alarm systems. This standard consists of 25 parts and the ones of most interest for trains and aircrafts are listed below. For a complete list see Appendix A.

- ❑ EN 54−4, Power supply equipment
- ❑ EN 54−5, Heat detectors − Point detectors
- ❑ EN 54−7, Smoke detector − Point detectors using scattered light, transmitted light or ionization
- ❑ EN 54−10, Flame detector − Point detectors
- ❑ EN 54−11, Manual call point
- ❑ EN 54−12, Smoke detectors. Line detectors using an optical light beam
- ❑ EN 54−16, Voice alarm control and indicating equipment
- ❑ EN 54−20, Aspirating smoke detector
- ❑ EN 54−22, Line type heat detectors
- ❑ EN 54−23, Fire alarm devices − Visual alarms
- ❑ EN 54−24, Components of voice alarms – Loudspeakers

8.1.2 NFPA

The National Fire Protection Association (NFPA) was founded in 1896. Their mission is to prevent and reduce fire and other hazards, focusing on saving human lives. To do this, they provide and advocate consensus codes and standards, research, training and education. NFPA is a member of the American National Standards Institute (ANSI), which is equivalent to the European Standards (EN). NFPA has over 70,000 members throughout the world and they develop, publish and disseminate more than 300 consensus codes and standards that has the intention to minimize the possibility and effects of fire and other risks (NFPA, 2013) [21]. The US National Fire Alarm Code, NFPA 72, is the counterpart to EN 54 and involves fire alarm and fire detection regulations, focusing on installation, performance, testing and maintenance procedures.

8.2 Trains

8.2.1 EN 45545

This European Standard for fire protection on railway vehicles has been given the status of national standard, either by publication of an identical text or by endorsement since September 2013. The main objectives of this standard are to minimize the probability of a fire starting, to control the rate and extent of fire development and to allow passengers and staff to evacuate the railway vehicle and reach a place of safety.

Freight transportation vehicles are not covered by EN 45545.

This European Standard for fire protection on railway vehicles has its background in the International Union of Railways (UIC) existing fire safety regulations for railway vehicles and was taken into effect in 2013. This standard supersedes CEN/TS 45545:2009 that was the first preview of this standard and was only published as a technical specification. Part 1 specifies the general criteria for trains such as operation and design categories. Part 2 has a transitional phase and conflicting standards shall be withdrawn at the latest by March 2016. Before that it is optional to follow the country's own or this standard. Part 6 of this standard is the most interesting for this report since it deals with fire detection, fire alarm and alarm management systems. Listed below are first all 7 parts followed by a short summary of the parts of relevance in regards of fire protection systems.

- ❑ Part 1: General.
- ❑ Part 2: Requirements for fire behavior of materials and components.
- ❑ Part 3: Fire resistance requirements for fire barriers.
- ❑ Part 4: Fire safety requirements for railway rolling stock design.
- ❑ Part 5: Fire safety requirements for electrical equipment including that of trolley buses, track guided buses and magnetic levitation vehicles.
- ❑ Part 6: Fire control and management systems.
- ❑ Part 7: Fire safety requirements for flammable liquid and flammable gas installations.

8.2.1.1 Part 1 – General

All trains are built different and therefore must also the fire protection be suitable for each train and where it operates. Part 1 divides the trains into four operational categories, which then decides the vehicle specification due to running capability. These categories are listed below.

Operation Category 1: Vehicles for operation on infrastructure where railway vehicles may be stopped with minimum delay, and where a safe area can always be reached immediately.

Operation Category 2: Vehicles for operation on underground sections, tunnels and/or elevated structures, with side evacuation available and where there are stations or rescue stations that offer a place of safety to passengers, reachable within a short running time.

Operation Category 3: Vehicles for operation on underground sections, tunnels and/or elevated structures, with side evacuation available and where there are stations or rescue stations that offer a place of safety to passengers, reachable within a long running time.

Operation Category 4: Vehicles for operation on underground sections, tunnels and/or elevated structures, without side evacuation available and where there are stations or rescue stations that offer a place of safety to passengers, reachable within a short running time.

These operation categories then have several demands on running capability and minimum average speed depending on tunnel length, how evacuation is available and open sections between tunnels. For a more detailed list of guidance on the designation of Operation Categories (OC) see Appendix B.

There are also design categories depending on how the train is designed, and these together make a classification for each vehicle and shall be specified in the procurement documents. The design categories are divided into four letters as shown below.

A: vehicles forming part of an automatic train having no emergency trained staff on board.

D: double decked vehicles.

S: sleeping and couchette vehicles.

N: all other vehicles (standard vehicles).

Part 1 also describes 5 different ignition models that are used during all performance tests within railway vehicles, e.g. material and components. These are developed to be as similar as possible to real fires. Examples of fires that the ignition models are based on are newspaper or rubbish (ignition model 1), horizontal surface of seats and floors (ignition model 2), above or alongside the fire such as wall and ceiling surface (ignition model 3), arcing in power equipment (ignition model 4) and severe fire such as luggage fire (ignition model 5) (Swedish Standard Institute, 2013) [29].

8.2.1.2 Part 6 - Fire control and management systems

This part specifies technical requirements to cover the objectives in part 1 e.g. requirements for fire detection, alarm systems, equipment shutdown, information and communication systems and fire fighting systems. When applicable this part focuses on the process steps that are: automatic detection, leading to alarm and leading to action.

This part also tells that a few points shall be taken into consideration for the verification of functionality, these are: (1) The origin of the fire; (2) the size of the fire; (3) the materials involved in the fire; (4) the nature of any detectors; (5) the air flow. It also says it should be functionally suitable for the expected fire products, for example heat, smoke, gas and flames.

Depending on the train’s variety, there are different requirements on where fire detection must be assigned. The most common are:

- In combustion engines
- Technical cabinets containing traction equipment
- Luggage compartments

Other places where it's often a requirement, but sometimes just a recommendation:

- Passenger areas
- Corridors
- Toilets
- Staff areas
- Cooking or catering area
- Other technical cabinets

To see the full table with all the requirements, see table 1 in SS−EN 45545−6:2013 [30].

Response to automatic detection

Section 5.3 in SS−EN 45545−6:2013 is about response to automatic detection and a few requirements are listed below:

- There shall be an automatic alarm status and automatic alarm on activation of a detector; it could be local and/or remote.
- For sleeping and couchette vehicles, there shall be a local alarm given in the nearby of the activated detector in passenger areas and sleeper compartments.
- All local alarms shall also give a remote alarm either to the driver or to the control centre if non−emergency trained staff is onboard.
- The alarm shall be audible and/or visible depending on its type and location, and it should be able to wake a sleeping occupant.

Specified actions required for response to automatic alarm

Section 5.4 in SS−EN 45545−6:2013 specifies the required actions for a fire affected vehicle with an automatic alarm system. These actions mainly consider the requirements of selective shut down of energy in order to avoid additional energy to the fire and to maintain function of vital systems during a fire. The requirements are divided into two levels, *the primary* and *the secondary.*

Primary level requirements

The primary level focuses on equipment in the area where a detector has activated and to avoid an additional supply of energy to the fire. This can be done by selective shut down of systems and equipment. For example: If a fire is detected in electrical equipment, this equipment needs to be shut down to avoid additional damage and energy supply to the fire. However, if the equipment is of great importance for safety of the passengers, train or running capability it should not be shut down.

Depending on the train's *Operation Category*, there are different requirements on which equipment or systems that need to be shut down and which are required to function in the event of a fire. Generally, the following equipment and systems are considered:

- Heating, ventilation and air conditioning units in passenger and staff area
- Combustion engines
- Technical cabinets containing traction equipment

For the full table of which equipment that needs to be shut down or not, see table 2 in SS−EN 45545−6:2013 [30].

Secondary level requirements

This level focuses on equipment that is not burning but is or may make the situation worse in case of a fire. For example: if a vital system that is essential for the fire protection system fails. Its requirements are aimed to prevent fire spread and reduce the impact of the fire. The requirements are:

- Control the ventilation to limit the fire spread.
- Power shall be removed from photoelectric activated fire barrier doors.
- Automatic public address system is required in some specific trains.
- Held−open fire barrier doors shall either close automatically or be closed by manually initiated remote control.
- Fixed fire fighting equipment in some combustion engines and technical cabinets containing traction equipment depending on train category.

Requirement for system used in manually initiated processes

In case of an alarm, the system must still work at some point and not totally be disabled. Passenger alarm systems have to meet the requirement of another standard, prEN 16334, which is mentioned in subsection 8.2.2. Below are some examples of requirements from section 6.2 in SS−EN 45545−6:2013 [30]:

- Passengers shall not be able to stop the train by using the emergency brake without the possibility of staff intervention to keep the train running to an appropriate stopping point where it's safe to evacuate.
- The staff alarm shall inform the driver or the control centre if the train is by design category A and have no emergence staff on board.
- All voice contact system shall inform the driver or the control centre if the train is by design category A and have no emergence staff on board. The voice contact system shall allow bi−directional communication and identification of the contact location.

Fire fighting - mobile or portable equipment

There are many requirements for the fire extinguishers in a train. It is said that extinguishers shall be suitable for their intended use and at appropriate locations and shall meet the requirement of the European standards EN 3−7, EN3−8, EN3−9 and EN3−10.

More requirements that are specific to the train industry can be found in section 6.3 in SS−EN 45545−6:2013 and some are listed below:

- The total weight of an extinguisher shall not exceed 15 kg.
- Extinguishers shall be usable when the train is operating.
- Where there are requirements for extinguishers of different classes, these may be combined in one extinguisher.
- An extinguisher shall be positioned within 15 m of any place in a passenger or staff area.
- If a passenger or staff compartment is longer than 6 m, it shall be equipped with an additional extinguisher.
- Each driver's cab shall be equipped with an extinguisher.
- In railway vehicles with sleeping compartments there shall be a fire extinguisher at each end of the vehicle in the passenger area outside the sleeping compartments.
- In cooking areas, an additional adequate fire extinguisher shall be provided. If fat or oil based frying is carried out, a fire blanket shall also be provided.
- Where combustion equipment is positioned above floor within the railway vehicle an additional extinguisher shall be provided in the vicinity of the equipment.
- If fixed fire fighting equipment is present, no additional extinguisher needs to be supplied.

Source: Swedish Standard Institute, 2013 [30].

8.2.2 prEN 16334:2011 Railway applications – Passenger Alarm System – System requirements

This standard has not yet come to publish but a draft has been made. In general it specifies requirements and essentials of the Passenger Alarm System (PAS) fitted to passenger carrying rolling stock. It will include 7 parts listed below:

- The system itself
- The functional requirements for an alarm triggered in the driving cab
- The communication channel between the driver and passengers or on−board staff
- The dynamic analysis of the Passenger Alarm System
- The requirements for the degraded modes management
- The safety related requirements
- Requirements for the handle and handle area

The range of applicability for this standard delimits itself to passenger trains, including Tram−Trains, High Speed Trains, metros with drivers and excluding Trams, metros without driver and historical vehicles (Austrian Standards Institute) [22].

8.2.3 EN 50553:2012 Railway applications. Requirements for running capability in case of fire on board of rolling stock

This standard is to define requirements of running capability under fire conditions so that a train will be able to reach a “safe area” as defined in the Safety in Rail Tunnels TSI (TSI SRT). This standard is intended to clarify and rationalize the requirements for rolling stock running capability in EN 45545 and to define specific technical measures.

For example, the requirement of the system is derived from one or more of the following:

- Absence of a relevant fire
- Assuring system function under the fire
- Assuring system function for a redundant array under the fire
- Extinguishing the fire
- Assuring sufficient remaining tractive effort under the fire

Source: Swedish Standard Institute, 2012 [31].

8.2.4 ARGE Guideline

ARGE Guideline is the result of a cooperation of the Detection Technology Consortium (ARGE) with TÜV SÜD Rail GmbH as responsibility editor in association with many other companies. The guideline can also be applied to comparable technical systems e.g. buses. The guideline is divided into three parts as listed below.

- ARGE Guideline – Part 1 "Fire detection in rolling stock"
- ARGE Guideline – Part 2 "Fire fighting in Rolling Stock"
- ARGE Guideline – Part 3 "System functionality fire detection and fire fighting systems in rolling stock"

ARGE Guideline focuses on safety of persons. Many other standards include requirement for the installation of fire detection systems and running capability in case of fire but ARGE seems to be more conservative compared to the standard requirements. This guideline's focus lies on protection of passengers and staff member in rolling stock. The Guideline is accepted by the regulatory authorities of Germany (Federal Railway Authority – EBA), Austria (Federal Ministry for Transport, Innovation and Technology – BMVIT) and Switzerland (Federal Office of Transport – BAV). In addition, through the cross acceptance process for vehicle registration, the Guideline is being applied Europe wide. The Guideline is already accepted in many countries as acknowledged code of practice. Part 1 and 3 involves fire detection and its functions and are summarized below.

8.2.4.1 Part 1

Part 1 focuses on functional proof procedure for the positioning of fire detectors in passenger areas, in electrical cabinets and in areas of combustion engines. It gives examples of response times, detector mounting positions and takes up some threshold values to be met to ensure safety considering carbon monoxide, carbon dioxide, oxygen and smoke gas temperature.

Part 1 also includes test methods for smoke detectors, mentioned below. In combustion engines areas, smoke should generally not be used as a parameter for fire detection due to the large amount of dirt there. The same is for temperature as a parameter in passenger areas where the area is too big to react on temperature before it is probably is too late.

Test methods in passenger and staff areas

ARGE's recommendation is that the detection system in passenger and staff area must respond within 1 minute after the beginning of smoke release under all possible operational conditions. Noticeable is that EN 50553 prescribes a maximum detection time of 2 minutes, but in relation to the reaction and evacuation time of passengers, ARGE experts evaluate this as too long.

To perform the assessment for detector position and selection this part verifies that the installed fire detection equipment responds within the specified time. In testing the passenger and staff areas, the fire risks are defined by possible arson or vandalism, and therefore ignition model 1 in EN 45545–1 is used and specified below.

Ignition model 1: ”This represents a typical ignition source due to arson or vandalism, for example newspapers or rubbish. The ignition model is a flaming source of 3 min duration and average power output of 7 kW generating a flux of 25 kW/m^2 to 30 kW/m^2.”

When performing a test, the position of the test equipment and the insight of the test smoke's thermal lift should be focused in areas which:

- Are most unfavorable for quick detection of the fire.
- Permit hidden ignition.
- Can be used for storage of larger items e.g. travel baggage.

Appendix 5 in ARGE Guideline part 1 describes specification of test equipment for function tests of fire detection. In Figure 29 the test setup for areas accessible to people is shown.

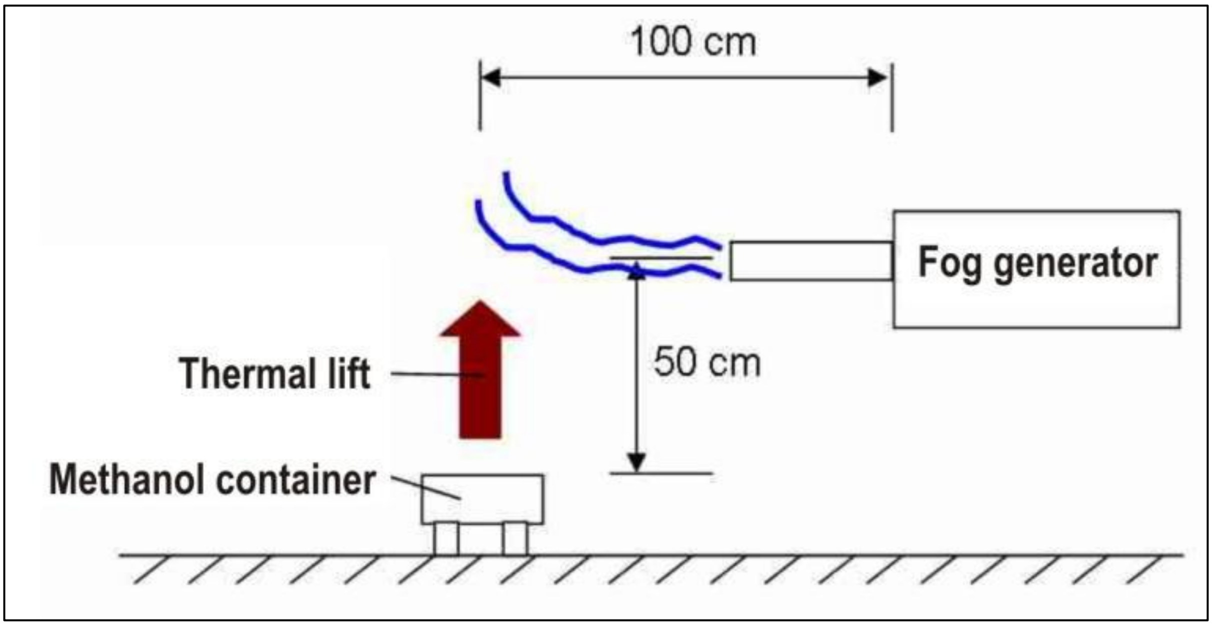

Figure 29. Test setup with methanol container (Tüv Süd Rail GmbH, 2013) [25].

Here are some more technical specifications of the test for the passenger area:

- Square shaped metal container of maximum 500 cm^2 base area.
- Container height should be up to 10 cm to ensure that the flames do not extend beyond the edge.
- 2 to 5 cm high legs (to reduce heat transfer to the floor), but also other measures possible (e.g. heat–insulated support); observing the vertical stability particularly at tests while train is moving.
- The container should be filled between 0.5 and 1 cm (this corresponds to a minimum fire duration of 1 minute).

The fog must also meet some recommendations, and this is described in appendix 6 in ARGE Guideline Part 1. Fog volume and fog duration must meet the following requirements for passenger and staff areas:

- Release time max 1 minute.
- Total fog duration 60 seconds with totally 10 ml +/− 1 ml.
- Of this, 30 seconds with totally 4 ml +/− 0.5 ml and 30 seconds with totally 6 ml +/− 0.5 ml.

Test method in technical areas

In electrical/technical areas the detection time must be under 2 minutes and for technical areas with combustion engines maximum time until response is set to 1 minute due to the risk of huge damage.

Technical vehicle areas such as control cabinets try to replicate an enclosed compartment and must focus on other factors. The point where the test smoke comes out should be located where:

- The risk−bearing component's location is most unfavorable for quick detection of the fire.
- The air volume flow for heat removal at the risk−bearing component is the lowest.
- In cases of failure in other surrounding components (e.g. by liquid fire loads), permanently hot surfaces can occur on the technical cabinet (e.g. diesel engine rooms).

In Figure 30 there is a test layout for technical compartments. Since these compartments are more complex, a thermal lift of the fog is needed. This can be done with a fog heater as seen in Figure 30. The heater could consist of a twisted copper sheet as seen in Figure 31. The sheet is about 10 x 10 cm, and glued on this a heating foil (also 10 x 10 cm) with the power of 12 W and 10 V. This could be powered by an AC adapter, and generate temperatures of 80 to 90 °C. This will make the fog streaming through to be heated and therefore rise as it leaves the tube.

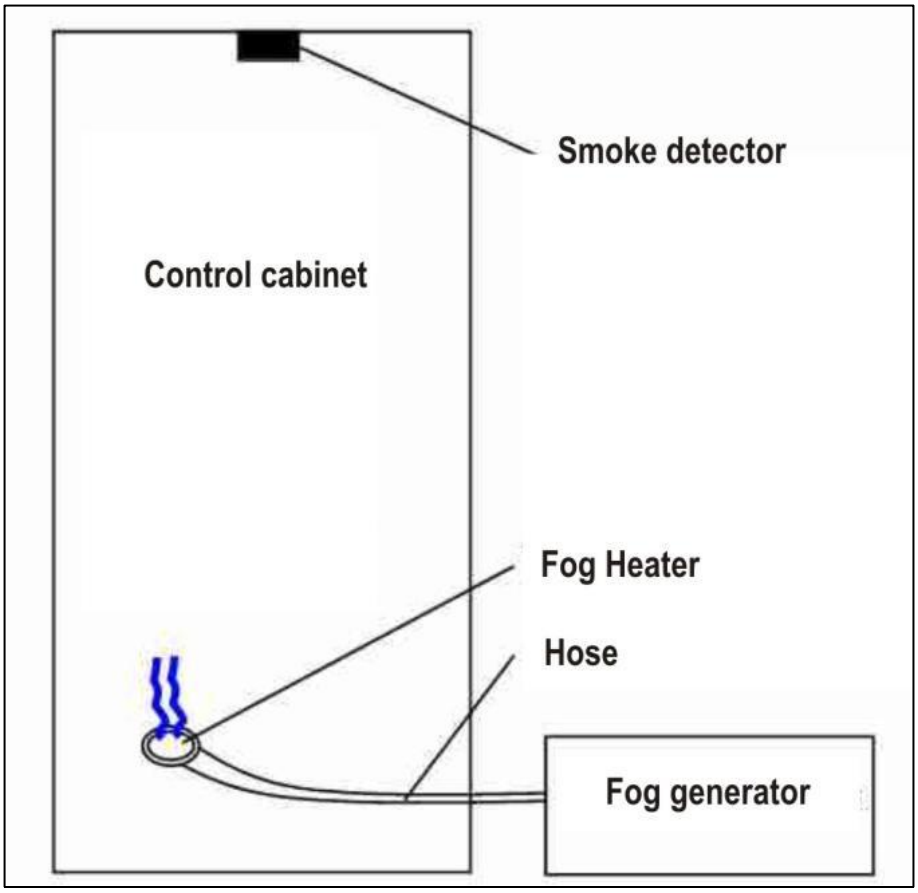

Figure 30. Test layout for technical compartment test (Tüv Süd Rail GmbH, 2013) [25].

Figure 31. Example of fog heater for hose (Tüv Süd Rail GmbH, 2013) [25].

The fog recommendations described for equipment areas (e.g. control cabinets or machine rooms):

- Release time max 2 minutes.
- Total fog duration 120 seconds with totally 15 ml +/− 1 ml.

Detector positioning in installation spaces

Appendix 7 in ARGE Guideline Part 1 describes the specification of the detector positioning in small installation spaces. These requirements are:

- Where combustion will be limited in enclosed and non−ventilated installation spaces. Installation requirement above potential sources of ignition up to approximately 0.5 m.
- Where combustion with normal thermal lift occurs in installation spaces with static ventilation. Installation requirement above potential sources of ignition up to approximately 2 m and in the ceiling area of the room.
- Where combustion with deflected thermal lift occurs in strongly ventilated installation spaces. Installation requirement at the bottom flow−off edge of the air−outlet of the installation area.
- If the installation spaces include extensive obstructions or separating elements, the detectors for fire risk areas have to be positioned below these obstructions. In case of forced ventilation a separate positioning can possibly be omitted.

Appendix 8 in ARGE Guideline Part 1 describes the specification of the detector positioning in large installation compartments (e.g. engine rooms) and at equipment installed outside (e.g. under−floor areas) by numerical fire simulation. The requirements for the areas should involve numerical fire simulations with a field model, such as FDS or Kobra 3D (Tüv Süd Rail GmbH, 2013) [25].

8.2.4.2 Part 3

Part 3 focuses on functional proof for detection, control of system functions and the interaction in between, including alarms and fault messages. The guideline sets a number of minimum requirements for the system technology up to the system interface to the rail vehicle.

The following requirements for the alarm are defined as below:

- The fire alarm must be transmitted to the driver and/or train staff visually and acoustically, according to the operating concept.
- A local alarm has to be signalized in the passenger area when a limited noticeability of a fire by the passengers can be assumed. This means in sleeping or couchette cars, in double−deck coaches and in lavatory areas, an acoustic signal has to be provided. Also in sleeping and couchette cars additionally a visual signal has to be provided.
- The driver has to be informed about the triggering of a fire fighting or fire extinguishing system (e.g. in connection with the shutdown of devices affected by the fire).

Source: Tüv Süd Rail GmbH, 2013 [26].

8.3 Aircrafts

8.3.1 ICAO

The International Civil Aviation Organization (ICAO) was founded in 1944 to promote the safe and orderly development of international civil aviation. It's a specialized agency of the United Nations, and consists of 191 member countries. They create universally accepted standards known as Standards and Recommended Practices (SARPs). These cover all technical and operational aspects of international civil aviation and consist of annexes. There are 18 different annex (19 in November 2013), and Annex 8 is about "Airworthiness of Aircrafts" that handles fire detection.

8.3.2 FAA - Federal Aviation Administration

Federal Aviation Administration (FAA) is part of U.S. Department of Transportation. FAA creates Federal Aviation Regulations (FARs), which coordinates with the ICAO, and these regulations are often used in many countries when building an aircraft since many countries don't have their own standards.

8.3.2.1 FAR 25 — Airworthiness standards: Transport category airplanes

FARs are part of the Code of Federal Regulations (CFR) that consists of 50 titles. Title 14 is about *Aeronautics and Space,* and part 25 in title 14 handles airworthiness standards of transport category airplanes. 14 CFR consists of subparts (A−I), which are divided into sections. These subparts are:

- Subpart A − General
- Subpart B − Flight
- Subpart C − Structure
- Subpart D − Design and Construction
- Subpart E − Powerplant
- Subpart F − Equipment
- Subpart G − Operating Limitations and Information
- Subpart H − Electrical Wiring Interconnection Systems (EWIS)
- Subpart I − Special Federal Aviation Regulations

(Source bulleted list: Federal Aviation Administration) [28])

Section *Fire Protection* under subpart D (Design and Construction) consists of §§ 25.851 − 25.869 and section *Powerplant Fire Protection* under subpart E (Powerplant) consists of §§ 25.1181 − 25.1207 are all about fire protection and the most interesting sections are summarized below. Parts of or whole sections below are quoted from U.S. Government Printing Office (2013) [27] *Code of Federal Regulations,* title 14, sec. 25.851−25.1207. A complete list of subparts and sections can be seen in Appendix C.

§ 25.851 Fire extinguishers

Hand fire extinguishers are required inside an airplane, and depending on the number of passengers the minimum number of extinguishers varies. Number of extinguishers needed can be visualized in Table 9, and the recommendation is to locate these easily accessible and evenly distributed throughout the aircraft.

Table 9. Number of extinguishers depending on the passenger capacity.

Passenger capacity	Number of extinguishers
7 through 30	1
31 through 60	2
61 through 200	3
201 through 300	4
301 through 400	5
401 through 500	6
501 through 600	7
601 through 700	8

There are also some additional requirements that need to be considered. For example, a minimum of one hand fire extinguishers must be located in the cockpit area accessible to the pilot. Also if a passenger aircraft's cargo or baggage compartment are accessible to crewmembers during flight, one hand fire extinguisher must be available here. If there is a galley onboard, there must be an easily accessible hand fire extinguisher here that could be located above or below the passenger compartment.

Eeach hand fire extinguisher must also be approved according to current standards. If the passenger capacity is between 31 and 60, at least one hand fire extinguisher must contain Halon 1211 (bromochlorodifluoromethane CBrC1 F2) or equivalent. If the passenger capacity is more than 61, at least two is needed and must be located in the passenger compartment. Regarding the remaining hand fire extinguishers these must be suitable for the typically fires that can occur where they are located, and if they are intended for use in personnel compartments the spread of toxic gas concentration must be minimized.

If a built–in fire extinguisher is provided, they must be installed so that there will be no hazard to the passengers or crewmembers if discharged and no discharge should cause structural damage. Still the capacity of the built–in fire extinguishing system must be suitable for the compartment where it is used both considering ventilation and volume of the compartment.

§ 25.854 Lavatory fire protection

Small airplanes don't need fire protection in the lavatory. For airplanes with a minimum capacity of 20 passenger there must be a smoke detector or equivalent installed in each lavatory that provides a warning light in the cockpit, but in some cases there should also be a warning light or audible warning in the passenger cabin if a flight attendant readily detects it.

Also each waste bin for e.g. towels, paper or waste located within the lavatory must be equipped with a built–in fire extinguisher. If a fire occurs here, the extinguisher must be designed to automatically discharge into the affected waste bin.

§ 25.855 Cargo or baggage compartments

Cargo and baggage compartments are complex areas because of the huge fire load and the fact that most compartments are out of site for the staff when flying. There is also a problem that the staff doesn't know what all baggage contains.

Each cargo or baggage compartment must meet one of the A–E class requirements that are specified below in § 25.857. And if there is some kind of heat source within the compartment, this must be protected and insulated to prevent the cargo from ignite.

Additionally, there must be a flight test conducted to show that classifications in § 25.857 are held regarding the accessibility of the compartment. Also that the entry quantities of hazardous smoke or extinguishing agents must show compliance in compartments occupied by crewmembers, passengers and in class C compartments concerning dissipation of the extinguishing agent.

The flight tests above must show that no accidental operation of smoke or fire detectors would occur in any compartment if a fire was to start in another compartment. This must be held both during and after extinguishing, unless if the extinguishing system simultaneously floods both the fire and the non–fire compartment.

§ 25.857 Cargo compartment classification

CFR 25.857 currently describes four classifications of cargo compartments. With the exception of class A compartments, they all require a fire detection system that will give a warning to the pilot or flight engineer station. Class A compartments are small compartments adjacent to occupied areas where a fire would be immediately discovered by a crewmember. Definitions for class A–E cargo or baggage compartment are listed below.

Class A

This is a compartment where:

- A possible fire can easily be discovered by a crewmember.
- The entire compartment is easily accessible during flight.

Class B

This is a compartment where:

- The crewmembers easily can reach the entire compartment with a hand held fire extinguisher during flight.
- No hazardous amount of smoke, flames, or extinguishing agent can enter any compartment occupied by the crew or the passengers when the access provisions are being used.
- A separate approved fire detection system is located to give an early warning at the pilot or flight engineer station.

Class C

This compartment does not meet the requirements for either Class A or B but where:

- A separate approved fire detection system is located to give an early warning at the pilot or flight engineer station.
- An approved built–in fire extinguishing or suppression system controllable from the cockpit is installed.
- It is possible to exclude hazardous quantities of smoke, flames, or extinguishing agent, from passenger and crew compartments.
- It is possible to control the ventilation and drafts within the compartment in order to confine the fire and to allow the extinguishing agent to control a possible fire within the compartment.

Class D cargo compartments were removed from the CFR after an occurred accident. This class formerly relied on passive oxygen starvation and that the compartment was small and sealed enough not to threaten the airplane in the event of a fire. No fire detection or suppression systems were required (Federal Aviation Administration) [28].

Class E

This compartment is applied for aircrafts only used for cargo carriage and where:

- A separate approved fire detection system is located to give an early warning at the pilot or flight engineer station.
- It is possible for the flight crew to easily shut off the ventilating airflow to, or within the crew compartment.
- It is possible to exclude hazardous quantities of smoke, flames, or extinguishing agent, from the flight crew compartment.
- The required crew emergency exits always are accessible during cargo loading.

§ 25.858 Cargo or baggage compartment smoke or fire detection systems

If a fire detection system is needed in the cargo compartment, it must provide a visual indication to flight deck within one minute after the start of the fire. A fire must be detected significantly below the temperature when the structural integrity of the airplane is substantially decreased. It is essential to know if the detectors are working properly during a flight, and therefore the crewmembers must be allowed to check each fire detector circuit during flight. The standard also describes that the fire detection system must be shown efficient enough for all approved conditions and operating configurations.

In addition, flight tests are required to demonstrate that the detection system will respond to smoke or a smoke simulant in less than 1 minute (Blake, 2006) [8].

§ 25.1181 Designated fire zones; regions included

A fire zone in an aircraft is typically an area or a region designed to require fire detection and/or fire extinguishing equipment and a high level of fire resistance.

Typical fire zones in an aircraft include the powerplant's designated fire zones that are:

- The engine power section.
- The engine accessory section.
- The auxiliary power unit compartments.
- Fuel−burning heaters and other combustion equipment installation.
- The compressor and accessory sections of turbine engines.
- Combustor, turbine, and tailpipe sections of turbine engine installations that contain lines or components carrying flammable fluids or gases.

(Source bulleted list: Federal Aviation Administration) [28])

§ 25.1191 Firewalls

Firewalls are needed to prevent the spread of fire and other toxic fumes into the aircraft. The description in CFR 25.1191 says that: "each engine, auxiliary power unit, fuel−burning heater and other combustion equipment intended for operation in flight, must be isolated from the rest of the airplane by firewalls, shrouds, or equivalent means. Each firewall and shroud must be:"

- Fireproof.
- Constructed so that no hazardous quantity of air, fluid, or flame can pass from the compartment to other parts of the airplane.
- Constructed so that each opening is sealed with fireproof material.
- Protected against corrosion.

(Source bulleted list: Federal Aviation Administration) [28])

§ 25.1195 Fire extinguishing systems

CFR 25.1195 requires that every designated fire zone must have a fire extinguisher system. One exception is where a fire originating in equipment containing lines or components of flammable fluids or gases easily can be controlled.

This part also specifies that the performance of the extinguishing system is sufficient enough to extinguish a fire in flight conditions. This is done in regards to the quantity of the extinguishing agent, the rate of discharge, the discharge distribution, the concentration of extinguishing agent and the probability of reignition. These factors must be shown to work properly by either actual or simulated flight tests where e.g. high airflows might interfere with the functionality of the extinguishing systems.

The requirements of extinguishing a fire in designated fire zones are listed below.

- One individual discharge ("one−shot") system may be used for auxiliary power units, fuel burning heaters, and other combustion equipment.
- For each other designated fire zone, there must be two discharges which produce an adequate concentration.
- The nacelle's fire extinguishing system must be able to protect each zone of the nacelle simultaneously, where protection is provided.

(Source bulleted list: Federal Aviation Administration) [28])

§ 25.1197 Fire extinguishing agents

This part specifies the requirements of the extinguishing agent in terms of effectiveness and performance when released. CFR 25.1197 requires that fire extinguishing agents must:

- Be able to extinguish flames from burning fluids or other combustible materials in its operating area.
- Be thermally stable within the temperature ranges likely to be experienced in the compartment where they are stored.

Some extinguishing agents used are more or less toxic. After a discharge of the extinguishing system there might be leakage of toxic fluids or vapors entering personnel compartments. To prevent this from happening this part also specifies requirements to prevent harmful concentrations to spread. To avoid harmful spread tests must be performed, except for built in carbon dioxide fire extinguishing systems where: five pound or less will be discharged or if there is protective breathing equipment for each crewmember available on flight deck.

§ 25.1199 Extinguishing agent containers

To ensure a reliable extinguishing system CFR 25.1199 has some requirements of how the extinguishing agent is contained.

The containers of the extinguishing agent must meet the following requirements:

- Each container must be fitted with a pressure relief to prevent it from bursting by excessive internal pressures.
- Each container must be located so it won't cause damage to the airplane when discharged. The container must also be located or protected to prevent clogging caused by ice or other.
- Each container must be able to indicate a discharge or if the pressure is below the minimum necessary for a functional discharge.

(Source bulleted list: Federal Aviation Administration) [28])

An additional requirement is that the temperature in each container must be maintained, under intended operating conditions. This is done in order to prevent the pressure from falling below the necessary needed for a discharge or to rise high enough to cause an unnecessary discharge.

If the container uses a pyrotechnic capsule to release the extinguishing agent, each container must be installed so that temperature conditions won't affect its function.

§ 25.1203 Fire detector system

Each designated fire zone must have its own quick acting fire or overheat detection system. Regarding the combustion, turbine and tailpipe section of turbine engine installations, they must be installed in locations and numbers ensuring the fire detection to be quick in those zones.

There are some criteria that need to be fulfilled regarding installation and construction of each fire detector system:

- It must resist the vibration, inertia, and other loads that can occur during operation.
- While being served, each sensor or associated wiring, within a designated fire zone must have a way to warn the crew unless the detection system continues to function satisfactorily after the serving is made.
- In the event of a short circuit within a designated fire zone, there must be a way to warn the crew unless the detection system continues to function satisfactorily after the short circuit.

Additionally, if there might be any oil, water, other fluids or fumes present, the fire or overheat detector may not be affected of this. The crewmembers must be allowed to check the functioning of each fire or overheat detector electric circuit in flight, and the fire or overheat detector components must be fire resistant.

The fire or overheat detector system components belonging to a fire zone cannot pass through another fire zone, unless one of these conditions apply:

- In cases of possible false alarms, the component must be protected from fires in zones through which it passes.
- If the same detector and extinguishing system is used to simultaneously protect each zone involved.

§ 25.1207 Compliance

The compliance with the above mentioned parts §§ 25.1181 – §§ 25.1203 must be demonstrated by a full scale fire test unless otherwise specified, or it could be done by one or more of the following methods:

- Similar powerplant configuration tests.
- Tests of components.
- By using powerplant configurations where service experience of a similar aircraft exists.

- Analysis.

Source: U.S. Government Printing Office, 2013 [27].

8.4 Other standards and guidelines within train and aircraft

There are many other standards and guidelines today that are regulating fire detection, but due to the delimitations and the accessibility of these, they are not mentioned in this report but some are summarized below.

8.4.1 Joint Aviation Authorities (JAA)

The Joint Aviation Authorities started in 1970 and was an associated body of the European Civil Aviation Conference representing the civil aviation regulatory authorities. They were developing and implementing common regulatory standards and procedures but have now given the responsibility to EASA (8.4.2).

8.4.1.1 Joint Aviation Requirements (JAR)

The Joint Aviation Authorities (JAA) was responsible for publishing regulations governing the operations, maintenance, licensing and certification/design standards for all classes of aircraft. These regulations were introduced to achieve common ground between the states involved. These regulations are known as Joint Aviation Requirements (JARs) (Skybrary, 2006) [23].

8.4.2 European Aviation Safety Agency (EASA)

The European Aviation Safety Agency (EASA) is the centerpiece of the European Union's strategy for aviation safety. Their mission is to promote the highest common standards of safety and environmental protection in civil aviation. They started in 2003 and have now taken over the responsibility from JAA (European Aviation Safety Agency) [24].

8.4.3 AUBE – International Conference on Automatic Fire Detection

AUBE (internationale tagung über AUtomatische BrandEntdeckung) is an international conference on automatic fire detection. It's held every 5th year and the latest AUBE conference, the 14th, was held 2009 at the University of Duisburg−Essen in Duisburg, Germany. The conference length is three days, and authors from all over the world participate and present their reports, which then will be included in the AUBE Papers that are printed. AUBE is organized by the Department of Communication Systems (NTS) at the University of Duisburg−Essen. Cooperation partners are societies, institutes, research foundations and companies within fire detection industry. Down below are two interesting presentations summarized from AUBE '09 session 11 that is about fire detection in aircrafts.

8.4.3.1 AUBE '09 – Session 11 – Fire detection in aircraft, special applications

Presentation 1 – Behle

This presentation is made by Kai Behle and the subject is "Standardization of False Alarm Rejection Capability Assessment". The presentation covers the harsh demands of early fire detection in cargo compartments in aircrafts there have been problems with false alarms. The maximum allowed time to detect a fire is 60 seconds, but the amount of smoke used when testing is not specified. The FAA has distributed a video in a policy letter in 1997 due to a cargo compartment fire in an aircraft. Their intention was to provide a visual guidance for smoke detection requirements but no physical data was distributed and therefore the test is hard to reflect. Figure 32 shows a comparison of the test at two different time intervals.

Figure 32. Snapshots from "Burning Suitcase Video" from FAA (Behle) [9].

Since there is a very small amount of smoke produced in one minute, the high sensitivity settings on the detectors have caused a high false alarm rate. To minimize this, test scenarios have been built both at University of Duisburg and at Siemens Aerospace in France, the latter also was the inventor of the test chamber for multi–criteria smoke detector used in Airbus A380. Figure 33 gives an overview of the set up test chamber.

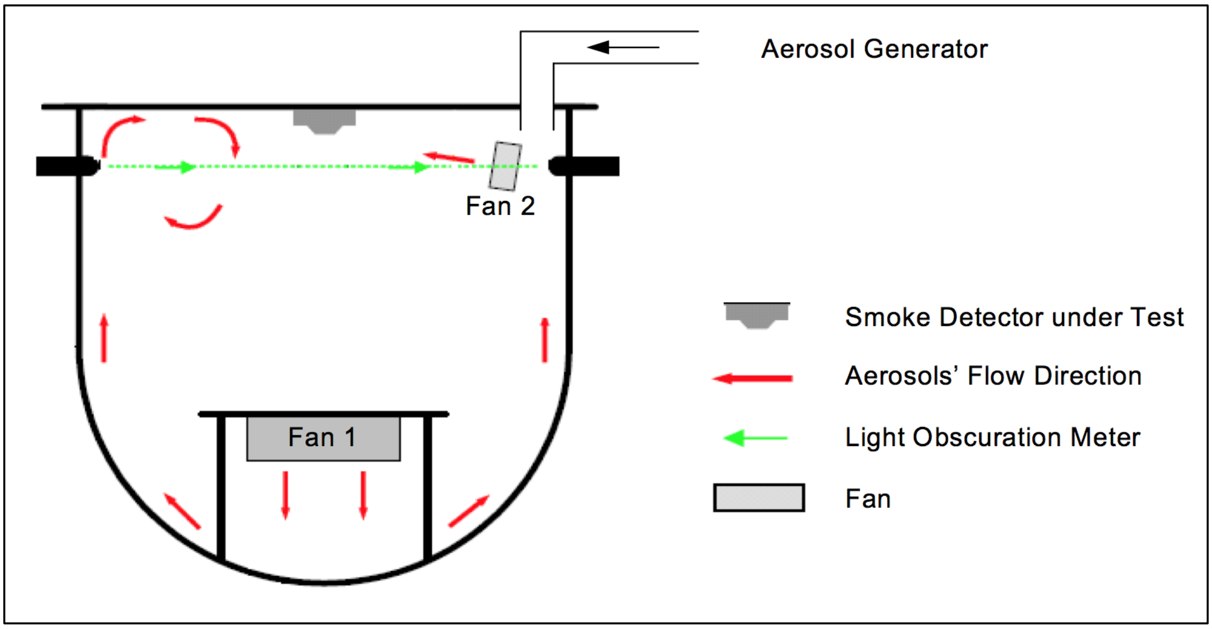

Figure 33. Smoke and false alarm test chamber (Behle) [9].

The aerosol generator could be either a smoke–, dust–, haze– or other false alarm stimulus generators. The test has been made by comparing optical– and multi–criteria smoke detectors but no standard has been assessed. The proposed standardization method in this article is to introduce a false alarm rejection ratio (R), which is based on a comparison between a false alarm stimulus and a real smoke scenario (Behle) [9].

Presentation 2 – Freiling, Willenbrock

Performance tests for point smoke detectors in aircraft cargo compartments have been made by Airbus. The test was done to optimize the detectors installation locations in regard to functionality and detection time. The test chamber was built as a transport cargo compartment with a 1:1 scale diameter and half size in length. To replicate the ventilation conditions of a cargo compartment, different switchable air inlets and outlets were installed (see Figure 34). There are a total of 28 air inlets positioned on each side of the compartment, 14 at floor level and 14 located 2.3m above floor level. The total airflow through these amounts to 1650 l/s. The extraction of the total volume of air is provided by 3 outlets located in the ceiling.

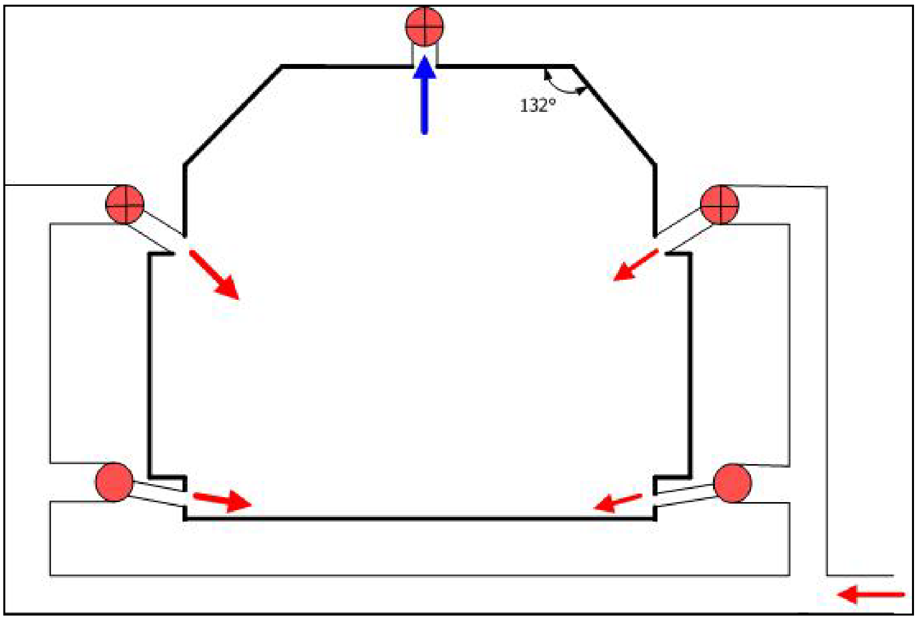

Figure 34. Air ventilation in a transport aircraft showing inlets and outlets (Freiling & Willenbrock) [10].

Smoke detectors were installed under the ceiling at 6 different locations. These were mounted pair wise in so called smoke detector cavities in the ceiling. The reason for these cavities are to keep the detectors from external damage e.g. luggage and to guide the smoke adequately to the detectors. To activate the detectors a smoke generator used for certification tests for smoke detection systems was used (Freiling & Willenbrock) [10]. This was placed in different positions in the compartment. For example directly underneath an air outlet and the considered worst case positions.

One condition of this test was that at least two detectors would activate to raise an alarm. Also every test was conducted at least 3 times for reproducibility reasons.

8.4.4 Society of Automotive Engineers (SAE), Aerospace Standard (AS)

SAE International is a global association of engineers and related technical experts in the aerospace, automotive and commercial vehicle industries. They have some Aerospace Standards that discuss fire detection and test methods that are of worthiness.

8.4.4.1 Test methods

SAE have also published a report concerning different fire detection methodologies in engine compartments. In these various tests SAE have focused on two types of typical engine compartment fires. The first is fast flaming fires due to ignition of e.g. fuel leakage onto hot surfaces. The second is slow growth fires resulting from overheating of electrical cables.

The detectors types used in the test where: Heat detectors, both spot and linear heat detectors and optical flame detectors. These were used because of their common usage and good performance in transit vehicle engine compartments.

The tests concentrated on the detectors performance with respect to the detection time. Factors that also had an impact were installation costs and maintenance (won't be focused on here).

The comparison of detectors was done in an enclosed test chamber with a free volume of 3600 litres, corresponding to a transit vehicle engine compartment. The test chamber also had variable airflow across the chamber varying from 0 – 1950 litres per second which was believed to be equivalent to an engine speed of 2200 RPM.

The fuel leakage test

Three different fire pans of various sizes where used during the tests. These were square fire pans with the dimensions 200 mm x 200 mm, 300 mm x 300 mm and 400 mm x 400 mm, each with an estimated height of 100 mm. The fire pans were filled with water up to 25 mm from the top of the pan. The fuel that was used consisted of 0.5, 1.0 and 2.0 litres of diesel corresponding to the dimensions of the fire pans and was added into the pans.

Inside the test chamber fifteen 0.5 mm diameter metal sheeted type K thermocouples where installed. There are certain sensitivities and combinations of alloys used in thermocouples, and type K corresponding to the most common general purpose thermocouple. The spot thermal detectors were installed 300 mm below the ceiling of the test chamber and directly above the fire pan. The linear heat detector used in the test was installed at the same height as the spot heat detector and placed along the wall as seen in Figure 35. An optical flame detector was placed 300 mm above the top and directly above the fire pan and fire source.

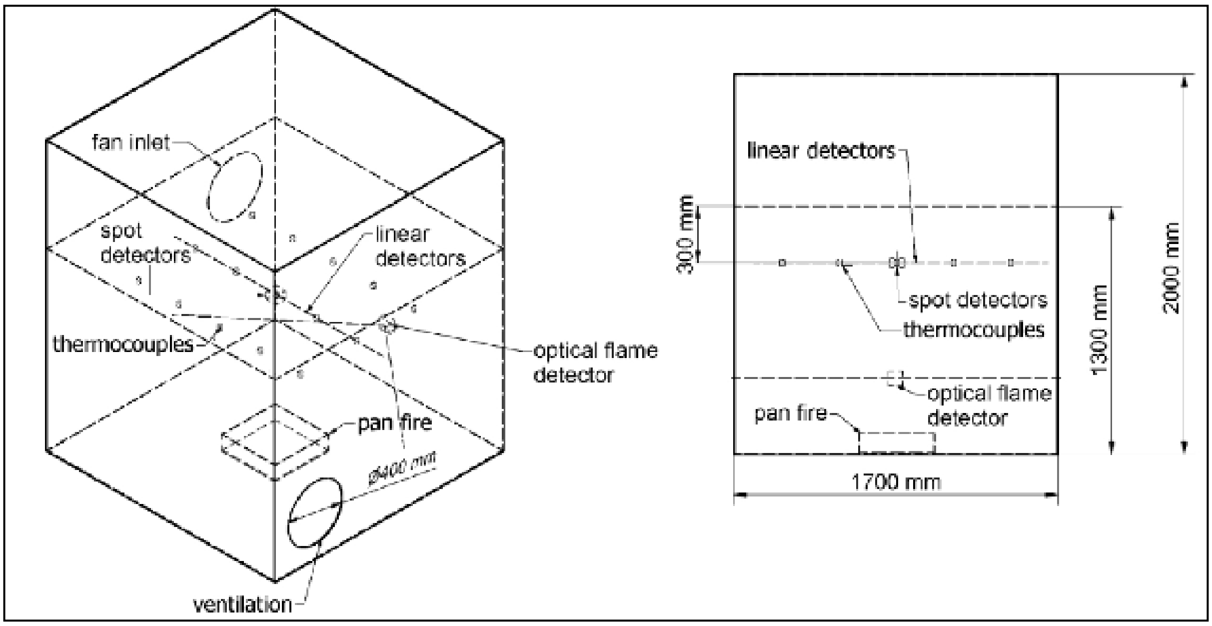

Figure 35. Test setup during fuel leakage test (Smith & Chattaway, 2012) [11].

A number of tests were then made with the fire pan placed 500 mm and 1000 mm below the detectors. Data from the alarm output and temperature measured from the thermocouples were recorded at 0.5 s intervals. During tests with forced airflow a fan created an airflow that represents a running engine. In tests without any airflow the inlet and outlet were partially blocked.

Electrical cable overheat test

This test simulated a short circuit in a cable leading to an overheat/fire condition. At the beginning of the test a switch is closed causing a current to flow along the cable and through a 0.2 Ω resistive load. After a short period of time a second switch is closed leading to a short circuit in the resistive load and generates the effect of a short to ground.

The cable used during the tests was installed 200 mm above the floor in the test chamber (see Figure 36.) The LHD's used were installed along the cable with a distance of 10 mm between the cables. Spot heat detectors were installed 900 mm from the end and 10 mm below the cables. Also used were three flame detectors placed along the sides of the test chamber to provide full coverage. Temperature was measured by six thermocouples, same kind used in the fuel leakage test, attached onto the cable. These measured the temperature in 0.5 s intervals along with the alarm output.

Materials and data used in the test:

- 2 x 12 V 110 AH automotive lead acid batteries
- 1800 mm AWG6 electrical cable
- Resistive load, 5 x 1 Ω 200 W

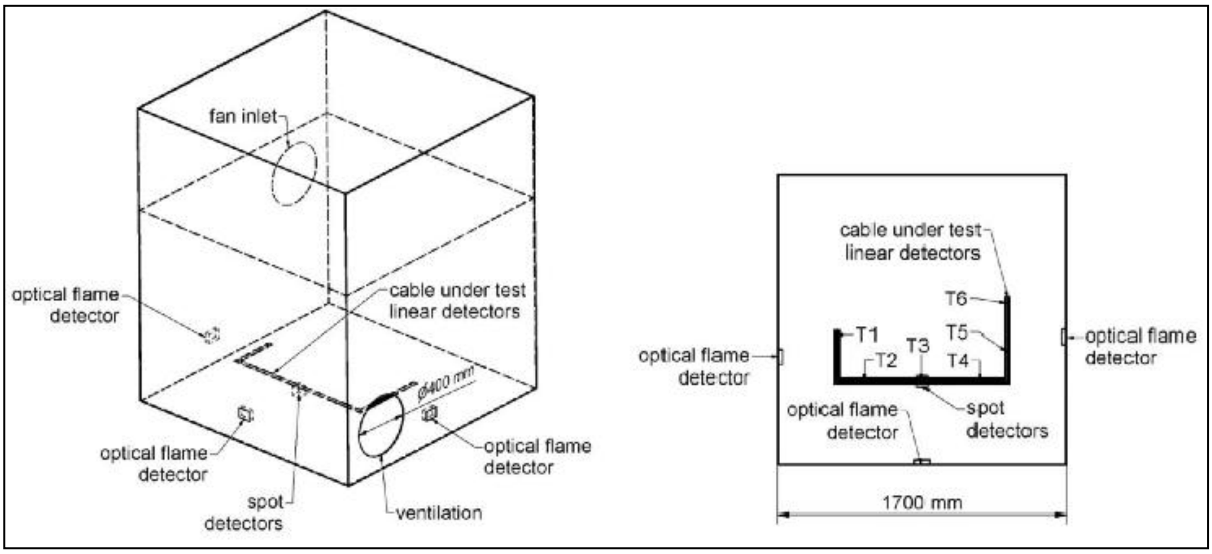

Figure 36. Test setup during electrical cable overheat test (Smith & Chattaway, 2012) [11].

Source: Smith & Chattaway, 2012 [11].

9 Analysis

This section aims to summarize and analyze the obtained results. This is done by following the questions stated in section 1.4. This section also gives our reflections of the making of this thesis.

Detectors used in trains and aircrafts

The different types of detection systems covered in this report are the most common for passenger trains and aircrafts of today. There were no revolutionary or high tech systems used. However technology is advancing rapidly and there are some newcomers that would be interesting when fitted in trains or aircrafts.

Technical solutions for detection and alarm systems

Technical solutions for detectors have emerged by extensive research and knowledge about fires and their typical signatures. Boundary conditions and threshold levels have thereby been assigned to fire detectors that they activate on. Some fire signatures might have a harmless “lookalikes” e.g. dust or different wavelengths of light. By knowing these, the amount of false alarms can be minimized by protecting the detectors from these. Having knowledge of the specific places the detectors are placed in is also valuable for example to prevent sources of interference like high airflows.

Fire alarm system might be considered as the secondary level of the fire protection system, yet still as important. Without an aural or visible signal of a fire it might be unrecognized. These technical solutions are not as complex as for the detectors. It is just a matter of having a signal from the detector converted to an alarm panel, indication light or sound.

Areas where detectors and fire alarm systems are placed

As for all detectors they are placed in areas where a fire might have fatal consequences as in passenger areas, engines or out of sight compartments as electrical cabinets and hidden luggage compartments.

Fire alarm systems are placed so that they are highly noticeable, from a control panel operated by the pilot/driver or the responsible staff to an audible or visible signal in passenger compartments

Alarm management

This is connected to a good and fully functional detection and alarm system. With a highly operational system there is an opportunity to determine procedures and integrate fire suppression systems. On the other hand, with a less effective system, different solutions like relying on human supervision must be made.

Regulations, standards and test methods

To perform all above mentioned parts in the fire protection system it is vital to have regulations, standards and test methods. This can off course differ in certain countries, but this report addresses the biggest and most important mainly set by EU and USA.

9.1 Reflections of the making of this thesis

In the making of this thesis a lot of background material was handed out from SP that already had been collected within the FFI project. At the beginning a lot of skimming through information was done in order to build up a basic knowledge in the chosen subject. Due to the large amount of information available, this was also confusing and everything almost merged. After a while, the decision of digging deeper into a specific subject was made to avoid this and after that making the report step by step instead of first read all, and then write the report.

A good decision that was made was to contact relevant companies at a very early stage, guessing that it would be difficult to find the "right" people within the corporations with the knowledge that was desired. This lead to a very early personal communication with people within the fire detection industry, but also within train and aircraft operation business, as well as pilots and technicians with valuable knowledge. After gaining contact with these people, all experts in their area of operation, a couple of study visits were planned with the restriction of what was capable due to economy and time limit of this research. To achieve more detailed information about the difference of and the products of fire detection used in this report, more study visits were desirable. The time spent at SP in Borås was highly appreciated and educative, and gave the opportunity to achieve valuable contacts. It has been good to have a company name and project behind when contacting other companies for them to understand the importance of this work.

The existing solutions written about in this report come from reliable sources within the train and aircraft industry, many times from a technical specification made from the manufacturers and implemented in the operative companies.

A hard work in the making of the report has been to sort out the relevance of the gathered information since it today overflows with material due to e.g. Internet publications. One more difficulty in gathering information is that most of the standards are not freely accessed, which is also why only aviation regulations from the US are taken into consideration in this report instead of the European regulations. This should not be a concern though since they are basically identical.

The achievement was to have as much specific information about the given subject as possible and due to time limit and accessibility, this report should be considered as a pilot study within the subject.

10 Discussion

Fire protection systems for trains and aircrafts tend to differ quite a lot. They have both emerged from quite different safety cultures, where more work seems to have been focused on the aviation industry than on trains. This could be due to the high vulnerability for aircrafts, they don't have the same possibility to stop and evacuate safely for example. The trend is however that more work is put into the safety systems, fire protection included, for trains. With a progressing and more vulnerable infrastructure such as long tunnels and dense traffic, the trains must keep up with this progress.

Previous work seems to have focused a lot on detecting and suppressing fire exposed trains in tunnels, which is one of the most critical places when affected by fire. Also large scale tests have been performed and analyzed. However not as much work has involved fire exposed trains while running or standing still in the middle of nowhere. With the introduction of EN 45545 this part has been considered and requirements have been developed, but still there is numerous testing to be done e.g. realistic full scale testing.

A good example is ARGE Guideline, which has developed certain test methods for smoke detection in specific areas as passenger areas and technical compartments. It is however strange that these tests only include smoke detection in technical compartments. These compartments have exclusively used heat detectors in the train types investigated in this report.

ARGE Guideline is however just a guideline compared to the European Standard EN 45545. For requirements and test methods companies in train industry turn to EN 54, which focus on fire alarm and fire detection systems installed in buildings. This is of course a good standard to verify the function of detectors but is not applicable in trains with complex compartments, airflows different than buildings and the fact that a train is moving.

Harmonized standards for the aviation industry have been around for a long time. These include strict testing of the fire protection systems and compliance to these is done by full scale testing or by comparing similar tested systems. These tests rely on that technical components work as they were designed, but are they as fast and reliable as in a test environment? There are many factors to take into consideration: placement of detectors, fire source and air flows for example. Previous work has been made considering these factors. For example AUBE and SAE that presents test methods for both aircrafts and engine compartments (8.4.3 and 8.4.4). Methods like these should be implemented in existing standards, both for aircrafts and trains.

To validate a good fire protection by using suitable and reliable fire detectors, standards and test methods are crucial for every branch where they are implemented. This is an expensive procedure and could take a long time to finish. Instead it could be favorable to develop test methods for specific compartments and their typical exposure of heat, dust, airflows and vibrations. This way one standard could be applicable for many branches. This is mainly what the EN 54 has done for buildings. Not every building looks the same, yet test methods have been produced. This would very well be used in vehicle industry as well.

This report is meant to focus on existing detectors in trains and aircrafts. But with newer technologies emerging on the market recent reports and testing have been made. It would be of great interest to see how these new technologies are suitable in trains, aircrafts or other heavy duty vehicles. SP, Technical Research Institute of Sweden is part of a project for fire detection and fire alarm systems in heavy duty vehicles. Facts about fire detection and fire alarm system in aircrafts and trains may well be useful in these types of vehicles. They may not look that similar by first appearance but certain areas and compartments are quite alike: e.g. lavatories in aircrafts and buses and electrical cabinets in trains and trucks/lorries. It would also be interesting to investigate if the *Operation Categories* for trains mentioned in subsection 8.2.1.1 are applicable to buses and coaches.

Aviation industry has introduced different classifications for cargo compartments. These include specific requirements regarding fire protection in each class and they also include additional tests to verify the detection system. This is also something that could be implemented in heavy duty vehicles.

The existing solutions for fire alarm systems seem to be very up to date and reliable. These are easier to test and testing can be done on scene or at the manufacturer. Systems might even be applicable in all types of vehicles and it's just a matter of opinion and cost how you want the system designed. Some vehicle operators might have different opinions concerning alarm management; a text display with lots of information might be confusing while operating the vehicle whereas some might find it necessary to make justified decisions.

10.1 Further work

Down below are a few areas of interest that could be suitable for further work in this subject.

Interesting for future work is to make a comparison between different train and aircraft manufacturers, how they choose to install and test fire detection and fire suppression systems and which manufacturers of these system they choose.

It would also be interesting to compare the different manufacturers of fire detection and fire alarm systems and compare how their test methods are designed and performed. By the use of different standards (EU and USA) a comparison might show some differences. Problems with the above mentioned could be due to patent and copyright protected material.

Do a comparison between similar compartments of trains and aircrafts and how they differ compared to each other. These could in turn be compared to other vehicles such as buses and heavy duty vehicles and similarities in areas, like cockpit, drivers cab, passenger area, engine compartment, toilets and electrical cabinets could be evaluated.

Construct similar *Operation Categories* used on trains for buses and coaches. For example: public transportation buses, long distance buses and double decked buses.

Investigate if there could be any deviations from the standards and guidelines, without decreasing the safety, by the help of verification with substitutes such as computer simulations.

Do a research of the upcoming fire detection products and compare the functionality of the products that are used in trains and aircrafts today.

11 Conclusions

Some conclusions that can be made are that standards and guidelines for the aviation industry have been acknowledged for a long time and the safety requirements are high in comparison with other automotive business.

The Standards for the railway industry is on the other hand very new and untested. This means that the train safety will be increased with the new standards, especially regarding that detection systems are relatively new in the railway industry. A trial period will certainly be needed to see if the new standards meet the desired level of sufficiency. A recommendation here is that the new standards are to be evaluated within three years to see if the new standards meat up with the desired level of sufficiency.

As for all standards and regulations they need to be maintained and updated at the same rate as society and technology is advancing. Otherwise there is a risk of a stagnant market where branches settle with the minimum demands. This could lead to few innovative solutions.

This report results in which fire protection systems that are accepted within the regulations and guidelines in the most common trains and aircrafts that exist today. With new solutions already on the market it is often just a matter of cost how advanced the system can be.

One part of the transportation industry that has the need but still lacks standards and guidelines for fire detection are heavy duty vehicles. These are often more vulnerable due to e.g. harsh road conditions, traffic conditions or recklessness driving and therefore involved in more accidents than trains and aircrafts. While vehicles are becoming more complex the lack of fire protection system is more and more questionable. Without standards and regulations the safety cannot keep up with the complexity of vehicles and the demands from e.g. insurance companies. As of today the systems that have been taken up in this report could be implemented in the heavy duty vehicle business e.g. buses. Some reasons these systems as far as we know doesn't exist in these branches are the lack of standards and due to harsh price margins in these industries compared to the aviation and train industries. There should definitely be a minimum demand laid out as a draft of a standard within the next three years. This draft should involve classification for the selected vehicle in the same manners as in EN 45545 for railway vehicles. It should also consist of test methods that ensure a fast fire detection system in the affected compartments.

To summarize what's been acknowledged by working on this thesis is that most of the wanted parts for a satisfaction fire protection system exists on the market. Detection types, alarm systems, regulations and test methods are already available at a certain point. It's just a matter of learning from different branches and integrate them.

12 References

Literature

1. National Transportation Safety Board. (1983). *Aircraft Accident Report.* Washington D.C., USA. United States Government.
2. Department of Transportation. (1980). *Railway Accident – Report on the Fire that occurred in a Sleeping-Car Train on 6th July 1978 at Taunton.* London: Her Majesty's Stationary Office, United Kingdom, ISBN O 11 550513 X.
3. Nilsson, D. & Holmstedt, G. (2007). *Kompendium i Aktiva system – Detektion.* Report 7030, Lund, Department of Fire Safety Engineering. Lund University, Sweden.
4. Bukowski, R.W. (1987). *Techniques for fire detection.* Center for Fire Research National Bureau of Standards.
5. Consilium Marine & Safety AB (2012). *TS1000 Fire Protection Systems for Rolling Stock Applications*. Transport Safety Division.
6. Cote, A., Grant, C., Hall, J., Solomon, R. (2008). *Fire Protection Handbook*, 20th edition. Quincy, Massachusetts, USA: National Fire protection Association, Volume II, ISBN-10:0-87765-758-0.
7. Hipsher, C. & Ferguson, D. *Fire protection: Cargo Compartments*. Boeing.
8. Blake, D. (2006). *Development of a standardized fire source for aircraft cargo compartment fire detection systems*. U.S. Department of Transportation.
9. Behle, K., *Standardization of False Alarm Rejection Capability Assessment.* AUBE´09 Session 11, Presentation 01.
10. Freiling, A. & Willenbrock, K. *Studies on the Performance of Smoke Detectors and their housing in an Aircraft Cargo Compartment Environment.* AUBE´09 Session 11, Presentation 02.
11. Smith P. & Chattaway A. (2012). *A Comparison of Various Fire Detection Methodologies in Transit Vehicle Engine Compartment Fire Protection Systems*. SAE International.

Webpages

12. U.S. Environmental Protection Agency (2012). *Ionization Technology.* Taken from http://www.epa.gov/rpdweb00/sources/smoke_ion.html 15 October 2013.
13. New York City Fire Department (2012). Study material for the certificate of fitness for: Inspection, cleaning & testing of smoke detectors S-78 (citywide) / F-78 (premises related). Taken from http://www.nyc.gov/html/fdny/pdf/cof_study_material/s78_f78_st_mat.pdf 15 October 2013.
14. Fire Safety Search. *Aspirating Smoke Detectors*. Taken from http://www.firesafetysearch.com/products/fire-detectors/aspirating-smoke-detectors/ 20 September 2013

15. The Fire Safety Advice Center. *Fire Alarm Systems.* Taken from http://www.firesafe.org.uk/fire-alarms/ 16 September 2013.
16. Smart Cockpit. *Boeing737cl Fire Protection.* Taken from http://www.smartcockpit.com/plane/BOEING/B737NG.html 9 September 2013.
17. Aircraft Photos & News. Taken from http://www.airliners.net/aviation-forums/aviation_hobby/read.main/95489/ 31 October 2013
18. Federal Aviation Administration. *Aviation Maintenance Technician Handbook – Airframe*, *Chapter 17. Fire Protection Systems*. Taken from http://www.faa.gov/regulations_policies/handbooks_manuals/aircraft/amt_airframe_handbook/media/ama_Ch17.pdf 19 September 2013.
19. The Boeing 737 Technical Site. http://www.b737.org.uk/fireprotection.htm#Cargo_Compartment_(Optional)
20. Smart Cockpit. *Airbus A320 Fire Protection*. Taken from http://www.smartcockpit.com/aircraft-ressources/A320-Fire_Protection.html 12 September 2013.
21. National Fire Protection Association. *About NFPA.* Taken from http://www.nfpa.org/about-nfpa 24 October 2013.
22. Austrian Standards Institute. *prEN 16334:2011 – Railway applications – Passenger Alarm System – System requirements.* Taken from https://shop.austrian-standards.at/Preview.action;jsessionid=978F517B829E486051DA73504586C65B?preview=&dokkey=411914&selectedLocale=en 1 October 2013.
23. Skybrary (2006). *Joint Aviation Requirements.* Taken from http://www.skybrary.aero/index.php/JARs 14 September 2013.
24. European Aviation Safety Agency. *More about EASA.* Taken from http://easa.europa.eu/more-about-EASA.php 14 September 2013.
25. Tüv Süd Rail GmbH. *ARGE Guideline – Part 1 "Fire detection in rolling stock".* Taken from http://www.tuev-sued.de/uploads/images/1348570015346044510781/arge-guideline-part-1-fire-detection-rollig-stock-v-4.pdf 9 September 2013.
26. Tüv Süd Rail GmbH. *ARGE Guideline – Part 3 "System functionality fire detection and fire fighting systems in rolling stock".* Taken from http://www.tuev-sued.de/uploads/images/1348570105016039960398/arge-guideline-part-3-system-functionality-rollg-stock-v-2.pdf 9 September 2013.
27. U.S. Government Printing Office. *Code of Federal Regulations*. Title 14. Chapter 1. Airworthiness standards: Transport category airplanes. Taken from http://www.ecfr.gov/cgi-bin/retrieveECFR?gp=&SID=0303b82afa1d51b2b913cb53ea84ef50&r=PART&n=14y1.0.1.3.11 13 September 2013.
28. Federal Aviation Administration. *Lessons Learned.* Taken from http://lessonslearned.faa.gov/ValuJetDC9/ClassC-Dregulations.pdf 5 November 2013.

Standards

29. Swedish Standard Institute (2013). SS−EN 45545−1:2013. Railway applications – Fire protection on railway vehicles – Part 1:General.
30. Swedish Standard Institute (2013). SS−EN 45545−6:2013. Railway applications − Fire protection on railway vehicles − Part 6: Fire control and management systems.
31. Swedish Standard Institute (2012). SS−EN 50553−1. Railway applications. Requirements for running capability in case of fire on board of rolling stock.

Personal communications

32. Nylander, C. (September 18th, 2013), Project Technical Engineer, Consilium Marine & Safety AB.
33. Vedholm, J. (September 10th, 2013), Fire Safety Lead Expert, Bombardier Transportation.
34. Presthus, M. (September 19th, 2013), Safety officer SJ, Department of Vehicle Safety.
35. Hammar, O. (October 21st, 2013), Vehicle Engineer SJ, Vehicle Division Team X2.
36. Ekenbratt Ågren, P. (September 9th, 2013), Pilot, Ryan Air.
37. Andersson, O. (October 3rd, 2013), Senior Power Plant Engineer, Scandinavian Airlines (SAS).

Appendix A

All chapters in EN 54:

EN 54−1, Introduction

EN 54−2, Control and indicating equipment

EN 54−3, Fire alarm devices – Sounders

EN 54−4, Power supply equipment

EN 54−5, Heat detectors – Point detectors

EN 54−7, Smoke detector – Point detectors using scattered light, transmitted light or ionization

EN 54−10, Flame detector – Point detectors

EN 54−11, Manual call point

EN 54−12, Smoke detectors. Line detectors using an optical light beam

EN 54−13, Compatibility assessment of system components

EN 54−14, Guidelines for planning, design, installation, commissioning, use and maintenance

EN 54−16, Voice alarm control and indicating equipment

EN 54−17, Short circuit isolators

EN 54−18, Input/output devices

EN 54−20, Aspirating smoke detector

EN 54−21, Alarm transmission and fault warning routing equipment

EN 54−22, Line type heat detectors

EN 54−23, Fire alarm devices – Visual alarms

EN 54−24, Components of voice alarms – Loudspeakers

EN 54−25, Components using radio links and system requirements

Appendix B

Guidance on the designation of Operation Categories (OC).

Operation Category 1 (OC1)

OC1 is applicable to vehicles which operate on infrastructure where:

- They form part of a train that is within the range of permitted train lengths for that infrastructure;
- Side evacuation is normally available and there are no tunnels or elevated structures longer than the minimum permitted train length where side evacuation is not possible;
- In the event of activation of a fire alarm, braking can be initiated immediately and evacuation to a safe area can take place as soon as the train has stopped;
- There are only tunnels or elevated sections of no greater than 1 km in length;
- Open sections between tunnels and/or elevated structures are longer than the maximum permitted train length.

Operation Category 2 (OC2)

OC2 is applicable to vehicles which operate on infrastructure where:

- Side evacuation is available;
- There are only tunnels and/or elevated sections of no greater than 5 km in length.

Operation Category 3 (OC3)

OC3 is applicable to vehicles which operate on infrastructure where:

- Side evacuation is available;
- There are tunnels and/or elevated sections greater than 5 km in length.

Operation Category 4 (OC4)

OC4 is applicable to vehicles which operate on infrastructure where:

- Evacuation from either end or both ends of the train is available but side evacuation is not available;
- There are only tunnels and/or elevated sections of no greater than 5 km in length.

Appendix C

Interesting chapters in CFR Title 14: Aeronautics and Space, Part 25 – AIRWORTHINESS STANDARDS: TRANSPORT CATEGORY AIRPLANES

Contents

Subpart D—Design and Construction

Fire Protection

§ 25.851 Fire extinguishers

§ 25.853 Compartment interiors

§ 25.854 Lavatory fire protection

§ 25.855 Cargo or baggage compartments

§ 25.856 Thermal/Acoustic insulation materials

§ 25.857 Cargo compartment classification

§ 25.858 Cargo or baggage compartment smoke or fire detection systems

§ 25.859 Combustion heater fire protection

§ 25.863 Flammable fluid fire protection

§ 25.865 Fire protection of flight controls, engine mounts, and other flight structure

§ 25.867 Fire protection: other components

§ 25.869 Fire protection: systems

Subpart E—Powerplant

Powerplant Fire Protection

§ 25.1181 Designated fire zones; regions included

§ 25.1182 Nacelle areas behind firewalls, and engine pod attaching structures containing flammable fluid lines

§ 25.1183 Flammable fluid–carrying components

§ 25.1185 Flammable fluids

§ 25.1187 Drainage and ventilation of fire zones

§ 25.1189 Shutoff means

§ 25.1191 Firewalls

§ 25.1192 Engine accessory section diaphragm

§ 25.1193 Cowling and nacelle skin

§ 25.1195 Fire extinguishing systems

§ 25.1197 Fire extinguishing agents

§ 25.1199 Extinguishing agent containers

§ 25.1201 Fire extinguishing system materials

§ 25.1203 Fire detector system

§ 25.1207 Compliance

Subpart H—Electrical Wiring Interconnection Systems (EWIS)

§ 25.1713 Fire protection: EWIS

§ 25.1723 Flammable fluid fire protection: EWIS

§ 25.1731 Powerplant and APU fire detector system: EWIS

§ 25.1733 Fire detector systems, general: EWIS