Learning from Real Fire Incidents : a Methodology for Case Studies

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Published in:
Fire and Materials Conferance

2011

LEARNING FROM REAL FIRE INCIDENTS A METHODOLOGY FOR CASE STUDIES

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ABSTRACT

Much information has been gathered through the years from fires in fire investigation reports or as statistics. The information might have been collected centrally by an agency, an insurance company or locally by the local fire service. The information can be used to learn from these events and to improve the fire safety in buildings. In this paper a methodology to find technical deficiencies in fire safety in buildings are presented. The methodology offers a systematic way of presenting several events to be able to draw cross-event conclusions that can represent a systematic problem in the studied system. The methodology is demonstrated in the article with a study of severe school fires in Sweden, with the purpose to find underlying factors that causes some fires to grow large. The methodology is believed to be a useful tool to find underlying factors or causes to fires.

KEYWORDS

Fire investigation, case study, fault tree, methodology

INTRODUCTION

In Sweden about one percent of fires contribute to 50% of the total costs of fires according to statistics from insurance companies[1]. It is possible that there are both technical and organizational factors that cause some fires to grow large and become more costly because major accidents almost never result from one single cause, but form multiple interrelated casual factors[2]. To be able to reduce the number these fires or the consequences of them it is necessary to study these factors. If more knowledge can be gathered about these factors more cost efficient actions can be taken.

Statistics can be a useful tool to retrieve information about these factors. In London, the London Fire Brigade investigators collect data from large fires and the information from these fires is entered into the Real Fire Library[3]. The Real Fire Library contains very detailed information on fire development, fire scene details, detection, cause of the fire, and source of ignition etcetera. The Real Fire Library has been used in several studies[4, 5, 6]. Holborn et al[4] used the database to identify several factors that are common to fires with high growth rates. Holborn et al concluded among other things that flammables, thermoplastics, insulations materials in concealed spaces, paint de-lamination and other extensive distributed fuel sources contributed to high fire growth rates. However the conclusions are only divided between two building types, “dwellings” and “other buildings” furthermore the used data is limited to buildings in London and the conditions might not be the same in other countries because of differences in for example constructions, regulations and culture.

In Sweden the Swedish Civil Contingencies Agency (MSB) (former Swedish Rescue Service Agency) has gathered statistics from all rescue service operations since 1996[7]. A total of 155.000 incidents where the fire service has responded to fire in a building are included in the database. The statistics can e.g. be used to study room of fire origin, cause of the fire and building type. However it is difficult to draw any solid conclusion on the mentioned factors only on the basis of the statistics since it does not include much information on the building, construction or fire development. Some information is available on passive and active fire protection systems, this information is however too limited to draw any conclusion from it. It is therefore necessary to study fire investigation reports as a complement to obtain a deeper understanding of e.g. what on factors that causes some fires to grow large and how they can be influenced to reduce the consequences of fire.

In Sweden fire investigation reports are produced by the different rescue services. MSB has contracts with around 40 fire investigators, which are working in the rescue service, to deliver a specific number of fire investigation reports per year. The fire investigation reports are made de-identified and public in a database that is managed by MSB[8]. All rescue services in Sweden are however obliged by law to conduct accident investigations, which means that more than the investigations provided to MSB are conducted. There is no national standard on how fire investigation reports should be written and the focus and content can be different between different fires and different fire services. The original purpose of fire investigation reports has been to determine the cause of fire, however there are reports that dig much deeper in describing and analyzing e.g. fire spread, fire development, building design, building properties and fire service operations.

Through the years much effort has been devoted to analyze fires and write fire investigation reports. The reports are however based on specific events and it is hard to generalize conclusions form one event. This can be done in a case study where several fires (incidences of analysis) are studied[7] that probably is more robust than a case study of a single fire. The fire investigations are already conducted and they are available as fire investigation reports however a proper method to compare the single events with each other to be able to draw cross-event conclusions is needed. Case studies of several fires have been done before in Sweden (e.g. by van Hees and Johansson[9]) but it became clear from these studies that there was need for a systematic and structured way of performing these studies. Case studies can be conducted in a variety of ways and there is no general handbook in how to conducted a case study. The following five components of a research design are important for case studies according to Yin[10]; (1) study questions, (2) study propositions, (3) unit of analysis, linking data to propositions and criteria for interpreting the findings and (5) linking data to propositions.

USING ACCIDENT INVESTIGATION METHODS TO ANALYZE FIRES

In a masters thesis at Lund University, Espenrud & Johansson[11] investigate the possibilities to use accident investigation methods in the fire accident area. One conclusion they draw is that different accident investigation methods can be used to find patterns in similar fires by applying them on existing investigation reports. There are several methods to investigate occurred accidents and they are used in a wide range of fields. Accident investigation methods are highly variable and differ regarding the approach and the focus on what should be investigated. The main purpose of the methods is to investigate the sequence of the accidents events, causes and how the accident could have been avoided. The methods have not been widely used in the fire area and that was the reason for the thesis. In the thesis the following methods are studied: Accident Evolution and Barrier function method (AEB)[12], deviation investigation[13], Events and Causal Factors Charting and Analysis (ECFCA)[2], fault tree analysis[14] and event tree analysis[14]. These methods are used in the thesis since they are general, they can be used to study technical factors in an accident and they use a barrier perspective. Espenrud & Johansson apply them separately on three deliberately lit fires, which are treated as single events. The thesis presents some differences between the methods based on the results from the application and gives some suggestions for further use.

The findings in the thesis showed that all the selected and studied accident investigation methods could be used to investigate a fire accident. However the analysis showed that there are differences regarding the description of the fire development when comparing the results from the used methods. This is because the accident investigation methods have different focus, which means that they give different answers upon what is asked. Nevertheless it is proposed in the thesis that accident investigation methods can be used as a tool to create a better structure in the investigation reports which sometimes lack structure. It is also noted in the thesis that different accident investigation methods can complement each other.

Espenrud & Johansson intention was not to investigate if several events could be structured in an accident investigation method to generalize a phenomenon. However their work indicates that it could be possible. A criterion for doing this is that the method can describe parallel events. The only methods, of the five analyzed in the thesis, that can describe parallel events, which could help when using the method on several fires, are fault trees and event trees. Fault trees and event trees are logical tree methods that are commonly used in fire risk analysis[15].

A fault tree analysis is a deductive system analysis, i.e. it is postulated that a system has failed in a certain way and it is attempted to find modes of system or components that contributed to the failure. A fault tree analysis begins with defining the top event and then faults or events that cause the top event are identified. The faults and events are connected with two types of fault tree gates: *and-gates* (more than one fault must occur) and *or-gates* (one of several faults is only needed). An event tree is an inductive system analysis, an initiation event or fault is postulated and effects on the system are evaluated[12]. An event tree follows the development of the event and different safety functions and barriers, that have either failed or been kept intact, are studied. The event sequences results in several possible consequences. An event tree can not only find the sequences that lead to the accident but also several other possible consequences that could have occurred if some barriers would have responded in another way. One of the two methods can be more appropriate than the other depending on how the problem is defined[14].

OBJECTIVE

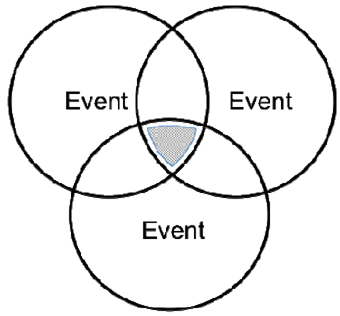
The objective of this paper is to propose and demonstrate a methodology that can be used to synthesise and analyse information from several fires in a way that cross-event conclusions can be drawn from the studied type of fires.

The purpose of making cross-event conclusions from events can be to identify factors that cause some fires in a specific building type to grow large or causes to fatalities in residential fires. This can help to find appropriate measures to prevent or mitigate the consequences of the studied type of fire.

PROPOSED METODOLOGY

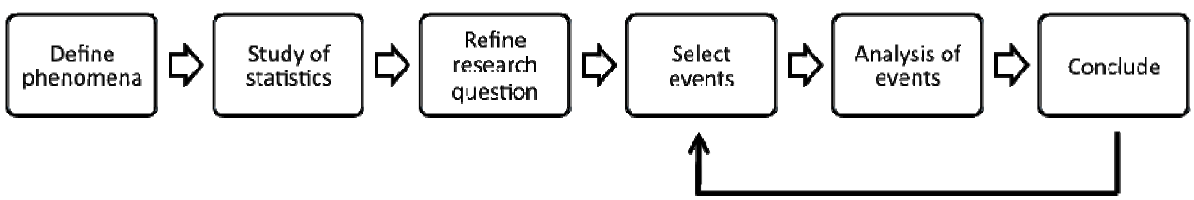
Statistics and studies of fire incidents can be combined in a case study. Instead of analysing single events with the purpose to find answers to an unclear phenomenon can a more systematic approach be used. In countries where fire statistics are available it can be used to find clues on e.g. why some fires are more severe than others or causes for fatalities in fires. Nevertheless the statistics have limitations and do not usually provide details on e.g. building properties or fire spread. Detailed data like this can however possibly be retrieved when studying real events. Yin[7] states that the more events that are studied within a case the more robust the conclusions will be. The proposed methodology assumes that common conclusions can be drawn form different but similar events as illustrated in figure 1.

Figure 1: Illustration of common causes or conclusions.



The methodology proposed consists of six steps as shown in figure 2. In the first step the case is defined, i.e. a decision is taken of what fire phenomena that will be studied. In the second step statistics are studied to obtain a better representation of the case and potential problems related to the phenomena. The analysis of statistics helps to refine the case in the third step. Fire investigation reports that are within the refined case are then selected in the fourth step. The validity of the end result depends on the number of fire investigation reports selected, the more fires that are used the more credible the derived conclusions will be. The number of fires selected can also depend on how broad the refined case is. A broader case may imply that more factors can influence the end result, which means that more events are needed to cover these factors. It is important to describe the events and to state the principles of selection of events. A systematic analysis of the events is preformed with existing accident investigation methods in the fifth step, as suggested by Espenrud & Johansson[10]. Such methods can be fault trees or event trees depending on the research questions, as described above. In the sixth step conclusions are drawn from the analysis. The arrow from the sixth step back to step four illustrates the possibility to select more events to be included in the analysis if it is thought to strengthen or add extra information to the conclusions.

Figure 2: Schematic chart of proposed methodology.



Accidents can be categorized in three major types: frequent but small-scale accidents, medium sized infrequent accidents and rare, large-scale accidents[16]. The events that are analysed with the proposed method are considered to be in the second type. The consequences are large and they occur seldom though with some regularity which means that it can be possible to draw cross-event conclusions.

DEMONSTRATION OF THE METODOLOGY

In this section the proposed methodology, as described in figure 2, is demonstrated by applying it to school fires.

As described previously a few fires contribute to a large amount of the cost of fires in Sweden. In recent years several costly deliberately lit school fires have occurred in Sweden. According to statistics from insurance companies in Sweden[1] is the cost of fires in school buildings around 500 million SEK (72 million USD) annually which are more than 10 % of the total cost of fires in Sweden. This can be compared to the direct cost of 74 million USD annually for fires in nursery, elementary, middle, junior, and high schools in the whole of the US, where the number of fires are ten times as many[17]. The majority of the costs in Sweden originate from just a few school fires[18].

In this demonstration the analysis of events is limited to technical deficiencies and deals not with fire service operations, organizational issues and human factors. It would be desirable to include more issues this would however expand the analysis and since the purpose is to demonstrate the methodology it is not considered to be necessary at this stage.

Step 1 – Defining the studied phenomena

In this first step the case is defined. The case is followed by a research question that is supposed to be answered in the case study.

Case: Severe fires in Swedish school buildings

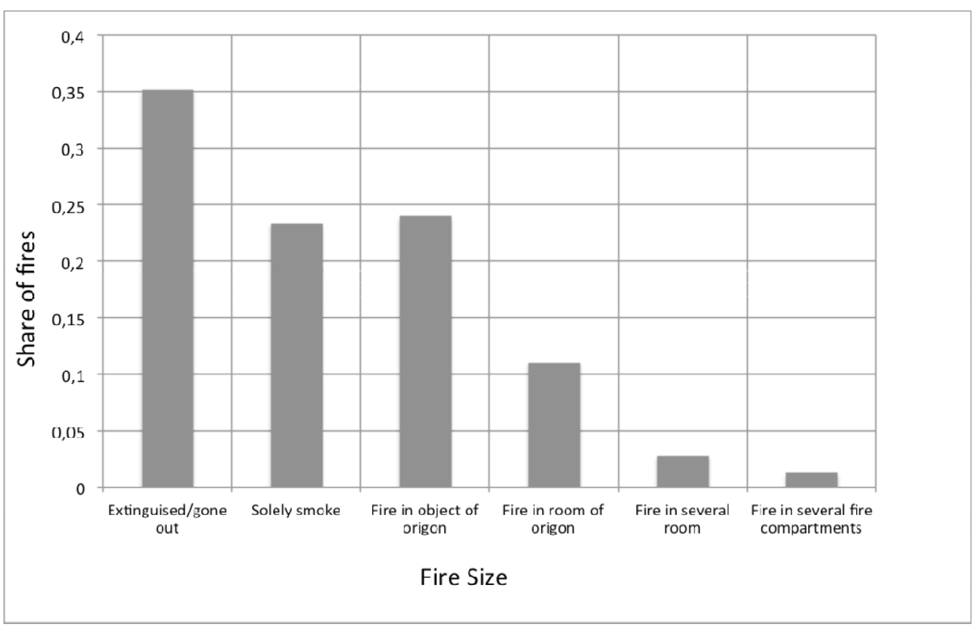
Research question: What are the technical factors that cause that some fires in Swedish schools grow to large fires with high costs?

Step 2 – Study of case relevant statistics

In several countries fire statistics are published and made available annually[7, 17, 19]. In this case the statistics can be used get a first idea of the answer to the research question. This rough idea can help to refine the research question in a way that it is possible to answer it by studying actual events.

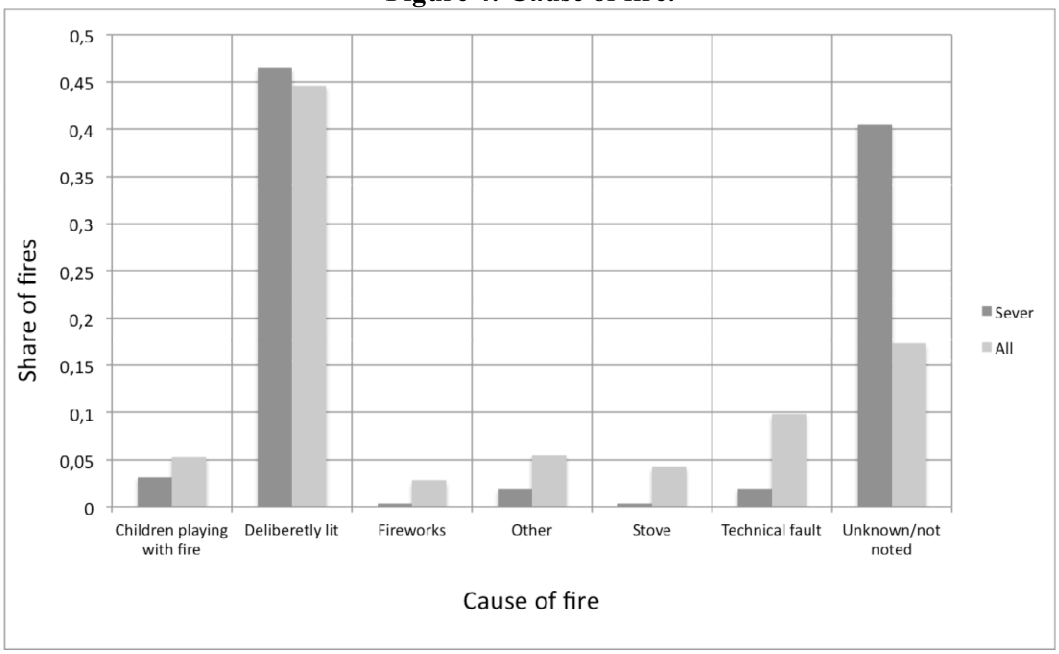
In this case the relevant statistics are retrieved from the Swedish Civil Contingencies Agency[7]. Previous statistical studies on school fires in Sweden[20] had focus to give general indications and trends. In this case, statistics of school fires in Sweden between 1996-2009 are presented and studied to fit in the methodology. In the following figures, the study of statistics is focused on fire size statistics since the case covers severe fires, which is assumed to be analogues with fire damage, i.e. fire size.

Figure 3: The size of fire when the fire service arrives in qualitative terms.



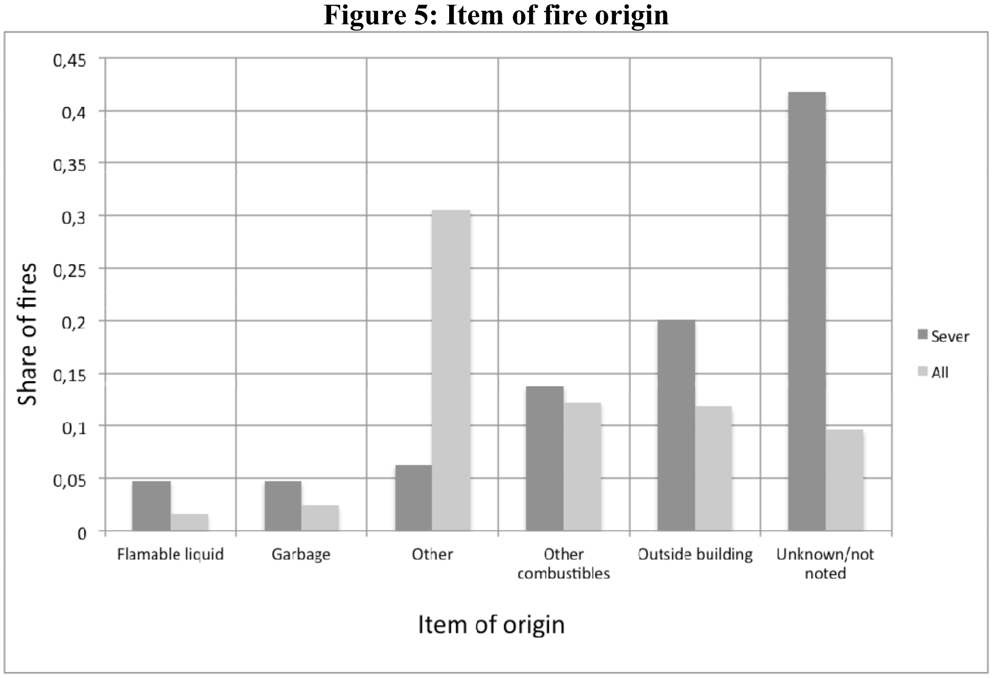
Only about 5 percent, or approximately 250 fires, have spread from the room of origin when the fire service arrived. These fires are studied in detailed in the following figures. They are of interest since it is assumed that large fire damage corresponds to a large fire loss.

Figure 4: Cause of fire.



The “Severe” fires correspond to the 250 fires that have spread from the room of origin. “All” fires correspond to all fires in schools and kindergartens. Figure 3 clearly demonstrates that the cause “Unkown/not noted” is more common in the “severe” fires.

Figure 5: Item of fire origin



The item of fire origin is unknown or not noted in almost half of the “severe” fires compared to only a tenth of the all fires in school and kindergartens. Another item that stands out is “outside building”. “Outside building” is almost twice as common for the “severe” fires as for “all” fires.

Figure 6: Room of origin.

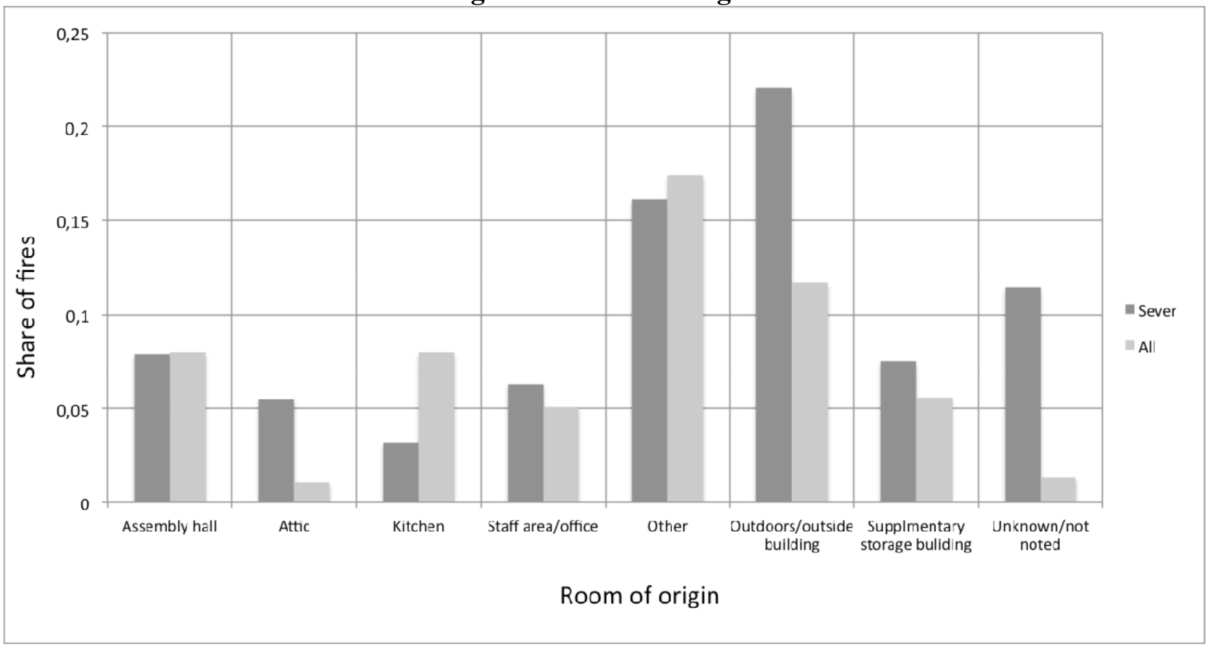


Figure 6 shows that there are differences between the “severe” and “all” fires regarding the room of origin. Fires that start outside the building and in attics tend to become more severe while fires in kitchens are less common among the “severe” fires than in “all” fires.

The following can be concluded from step 2, study of statistics:

- Fires that start outside the building and in attics tend to become more severe
- Fires that starts on the outside of the building tends to become more severe
- Unknown/not noted cause is more common in severe fires.
- Unknown/not noted material of origin is more common in severe fires.

Step 3 – Refine research question

The bullet points in step 2 are valuable conclusions but they do not give much detailed information on the underlying factors that causes some fires in schools to become very large. However they can be used to refine the research question (step 3 in figure 2).

Refined research question: What are the technical factors that cause that some ***outdoors*** *fires in Swedish schools grow to large fires with high costs?*

The refined research question is better defined and limits in that way the number of events that has to be selected in step 4. On the base of the refined case the events to be analysed are chosen.

Step 4 – Select events to analyse

The events that now needed to be studied are different fires that reflect the case and the refined research question. The number of events can be large depending on the case. A reasonable number is needed and if it is thought that not all types of events are covered more can be added in a later stage (see arrow in figure 2 from step 6 to 4). For demonstration of the methodology are only three fires studied.

Three different fires in school buildings in Sweden are selected in this demonstration. Events that differ as much as possible from each other are selected in order to be able to cover as many underlying factors as possible. The fires are selected among the fire investigation reports that were collected by MSB. The principles of selection are that the fires have spread to the attic or roof construction in a school building and that the fire damage was severe. Severe fire damage is defined as fire spread from the object in to the school building.

Fire 1
In November 2009 a fire occurred in a school building in Gothenburg, Sweden. The building was erected in 1970-72 but was refurbished in 1999. The building had one-storey and was fitted with an empty attic. The construction was made of wooden timber and the exterior walls had wooden panelling. The entire school (including the attic space) was fitted with smoke detectors. The fire started in a passenger vehicle that stood parked three meters from the building facade. After some time the vehicle started to roll towards the building. The facade caught fire and the fire spread into building and later up in the attic where the fire could spread over the entire building. The entire school was destroyed in the fire. The fire is well documented in three different reports, with different focus, conducted by the rescue service in Gothenburg[21], by a consultancy firm[22] and by SP Fire Technology[23]..

Fire 2
A school building in Västerås, Sweden was involved in a fire in April 2010. The building was erected in the mid-nineties and had one story building with no attic. The roof construction was made of roof elements that were put directly upon the load bearing glulam beams. The roof elements were made of 150 mm expanded polystyrene (EPS) and a 150 mm thick ceiling plate made of pressed cement bound wood wool. A 15 mm layer of cement bound wood wool had been placed on the EPS to protect it from the top. The roof element had been rated as a REI30 fire resistance[24] construction. The fire started after school hours and was probably deliberately lit according to the fire investigation report. The heat from the fire caused the EPS to melt and drip down into the classroom where it was ignited. The building was fitted with an automatic fire alarm system, however the detectors were placed in adjacent rooms and not in the classroom. The fire caused complete damage to only one classroom due to good fire compartmentation, smoke spread however to some extent to other rooms. Parts of the roof above the classroom were destroyed but the fire service could prevent the fire from spreading over the entire roof. The fire is documented in one fire investigation report conducted by the responding fire and rescue service[25].

Fire 3
A fire occurred in a school building in Södra Sandby, Sweden in February 2009. The building, erected in 1982, was a one-storey school building fitted with an empty attic. The main construction was made of wood and the façade was made of brick. The attic was fitted with non-combustible isolation. The ground floor was divided in fire compartments in class EI30. The attics joist floor had a REI30 class. The building was fitted with an automatic fire alarm system connected to smoke detectors that were placed in the escape ways. A piece of firework was placed in a small greenhouse that stood next to the façade. The greenhouse was used as a storage space during wintertime for outdoor furniture, which meant that combustible material was present. The firework ignited the combustibles and the fire spread to school building attic though a combustible eave right above the greenhouse. The fire spread across the entire attic and the joist floor collapsed, which meant that the fire could spread to the first floor. The fire was detected at a late stage since no detectors were present in the attic. The fire is documented in one fire investigation report conducted by the responding fire and rescue service[26].

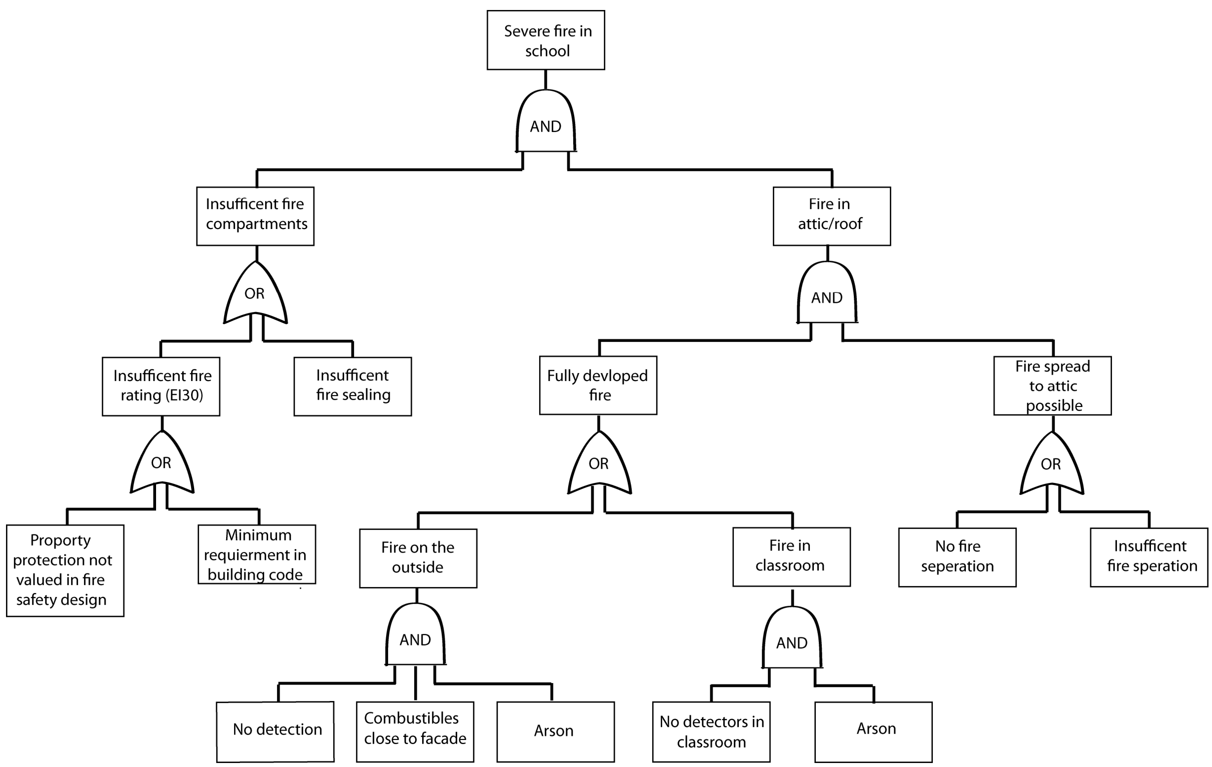
Step 5 - Analysis of events

Several events are studied to be able to draw cross-event conclusions. Factors that cause some fires to grow large are sought and a fault tree is considered to be most appropriate method to use since the common top event of the three fires is a severe damage to a school building. An event tree would be more suitable if possible consequences of an initial event were sought (inductive analysis) i.e. possible consequences for a fire outside a school.

A simplified fault tree is used to structure the events and to get an overview of the problem. Failure frequencies as commonly used in fault trees are not included. The analysis of events is conducted in two steps. In the first step each event is structured with a fault tree. In the second step the fault trees are merged into one fault tree that can represent parts of all the constructed fault trees.

The results from the analysis are presented graphically. The merged fault tree is presented in figure 7.

Figure 7: Fault tree that represents the three studied fires.



Other factors can of course contribute to the top event for other events, however figure 7 describes a generalization of the faults that are common for the studied fires. There are specific factors for each fire that is not shown in the figure, e.g. the weather conditions in fire 1. These factors are important for the individual fire but are not part of the general picture.

Step 6 - Conclusion

The three studied events yielded in some general factors that are shown in figure 7. Insufficient fire compartments that are results of insufficient fire sealing or insufficient fire rating are underlying factors in the studied fires. An other general conclusion is that the initial fires, caused by arson, are allowed to grow large and spread to the roof or attic due to insufficient detection and lacking or insufficient fire separation. No analysis of insurance costs has been done since it is assumed that large fire damage corresponds to a large fire loss. Such a connection might need to be added in the future if the procedure is applied to other types of scenarios e.g. electronic component production, nuclear power plants where a limited fire can be associated with large costs.

More fires can be selected to verify or complement the conclusions (according to the arrow from step 6 to step 4 in figure 2).

DISCUSSION

Much information has been gathered through the years from fires in fire investigation reports or as statistics. The information might have been collected centrally by an agency or locally by the local fire service. The information can be used to learn from these events and to improve the fire safety in buildings. In this paper a first attempt to present a methodology to find technical deficiencies in fire safety in buildings is presented. The methodology offers a systematic way of presenting several events to be able to draw cross-event conclusions that can represent a systematic problem in the studied system.

In this paper the proposed methodology is applied to school fires in Sweden. However it could possibly be used for other types of fires and also in other countries where technical deficiencies that contribute to the course of fires are sought. Step 2 – Study of case relevant statistics helps to refine research questions to narrow down the case to be able to draw more solid conclusions. If no proper statistics are available this step could be replaced by interviews or surveys. The proposed methodology could also be used for other types of fires where fire investigation reports are available, e.g. fatal residential fires or fires in attics.

The results that are derived with the methodology can be strengthening by looking at more events to verify the conclusions drawn. In the example, presented in this paper, this can be done by studying more fires with the same top event and verify if they fit in the fault tree. If there are differences the fault tree can be complemented with more *and-* and *or-gates*.

The example used in this paper could be further analysed if the fire service operations or organizational issues would be included in the scope. This is however not done since the purpose of the demonstration is to help presenting the proposed methodology and the stability of the method need to be investigated first for one type of issue.

The choice of accident investigation method will affect the investigation results, when conducting an accident investigation, according to the What-You-Look-For-Is-What-You-Find principle[27]. This also applies in this case since the choice of events to analyse will affect the end results, e.g. if there is a predetermined feeling of the answer to the research question might events that coincide with that feeling be selected. This is something that the analyst must keep in mind.

The same people that have conducted the fire investigations that are used in step 5 should not make an analysis with the proposed methodology. The strength with this is that the analysis will be less biased. When several different but similar events, which are documented by different fire investigators, are analysed will different views on a similar phenomena be investigated which is believed to give more insight to the problem.

It is important to distinguish between data and experience. Data can easily be collected in a database, e.g. number of fires in a country and the cause of these fires[28]. A prerequisite to use the proposed methodology is that data in the form of investigations reports are available. It is believed that the methodology can be a useful tool to in helping to draw conclusions on a more general level from previously collected data.

CONCLUSION

The objective of this conference paper has been to propose and demonstrate a methodology that can be used to synthesise and analyse information from several fires in a way that cross-event conclusions can be drawn from the studied type of fires.

The methodology consists of six steps that are preformed in a systematic manor. In the first steps data (statistics, results from surveys etcetera) are studied to retrieve information that helps to selected events to study. In the analysis step the events are analysed systematically with a fault tree or event tree, depending on the studied phenomena, from which conclusions can be drawn.

The methodology is demonstrated in the article with a study of severe school fires in Sweden, with the purpose to find underlying factors that causes some fires to grow large. The methodology is shown to be useful and some factors are identified.

If the methodology is used, as in the demonstration, to find underlying factors or causes to fires it is believed to be a useful tool. When the factors or causes are identified proper measures to prevent or mitigate the consequences of the fires can be taken.

ACKNOWLEDGMENTS

The research presented in this article has been conducted within a project “Varför blir små brander stora?” and is financed by The Swedish Fire Research Board (Brandforsk). The purpose of the project is to find underlying factors to why some fires grow large.

Parts of this research are also part of a larger multidisciplinary project dealing with arson fires. The project is also initiate by Brandforsk and financed by The Swedish Civil Contingencies Agency, The City of Malmö, Svenska Kommun Försäkrings AB, Kommunassurans Syd, Länsförsäkringar, Trygg-Hansa, Göta Lejon, St Eriks försäkring, Stockholmsregionens Försäkrings AB, Förenade Småkommuners Försäkringsbolag and KommuneForsikring which all are gratefully acknowledged.

Simon Espenrud and Joel Johansson are also gratefully acknowledged for their work with investigating the use of accident investigation methods in the fire accident area.

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