Fatal Residential Fires

Prevention and Response

Runefors, Marcus

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Fatal Residential Fires

– Prevention and Response

MARCUS RUNEFORS
DIVISION OF FIRE SAFETY ENGINEERING | FACULTY OF ENGINEERING | LUND UNIVERSITY

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-Prevention and Response

Marcus Runefors

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Opponent

Dr. Tuula Hakkarainen
VTT Technical Research Centre of Finland

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Abstract

Fatal fires in residential occupancies show a decreasing trend over time, but are still responsible for taking approximately 90 lives in Sweden each year. Much is known about the victims, but less is known about how these deaths can be prevented. There is research on the effectiveness of different measures, but generally they are population-average effectiveness and, since different groups are known to be subject to quite different scenarios, this effectiveness is not necessarily representative of the effectiveness for any specific group. Therefore, group-specific effectiveness is derived in this thesis. The results indicate that smoke alarms are effective for most groups, but additional measures are needed for some groups. This is particularly true for older adults, for whom synthetic clothes and detector-activated sprinklers are highly effective.

Also, responses to potentially fatal fires in residential occupancies are almost missing from the literature and were therefore analysed in the thesis. The conclusion was that fire services saved 51 lives during the studied year (2017), which indicates that the number of fatalities in residential occupancies would have increased by 58% in that year without fire service responses. Response time was found to be important, but also what the crew could perform on arrival at each scene, because many were developed fires that required breathing apparatus to perform the rescue. In another study, responses by other actors were also included for older adults (65+), indicating that, in addition to the fire service, neighbours are very important, but for the oldest individuals home care also played an important role.

Key words Residential fires; Fatal fires; Fire services; Emergency services; Smoke alarms; Sprinkler system; Prevention; Response		
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Division of Fire Safety Engineering
Faculty of Engineering

Supervisor
Professor Patrick van Hees, Division of Fire Safety Engineering, Faculty of Engineering, Lund University, Sweden

Co-Supervisor
Dr. Nils Johansson, Division of Fire Safety Engineering, Faculty of Engineering, Lund University, Sweden

Opponent
Dr. Tuula Hakkarainen, VTT Technical Research Centre of Finland

Assessment Committee
Adj. Prof. Juan Bautista Echeverria, School of Architecture, Universidad de Navarra, Spain

Dr. Björn Sund, Department of Economics, Karlstad University, Sweden

Prof. Marie Klang Hasselberg, Department of Public Health Science, Karolinska Institutet (KI), Sweden

Prof. Henrik Tehler (deputy member), Division of Risk Management and Societal Safety, Lund University, Sweden

Division of Fire Safety Engineering
Lund University, P.O. Box 118, SE-221 00 Lund, Sweden

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I am also very thankful to my supervisors, Patrick van Hees and Nils Johansson, for your guidance along the way, but also, not least, for letting me try my own ways (and occasionally fail). I genuinely believe that this has prepared me for being an independent researcher. I would also like to thank Håkan Frantzich who have been an informal supervisor in several projects and also provided detailed comments on drafts of this thesis and some of the papers. I am also thankful to other researchers at the division for fruitful discussions, and good company, along the way.

This thesis would not have been possible without the relentless work performed by Mattias Strömgren, Anders Jonsson and Lena Anstensen at MSB in identifying and retrieving data on fatal fires, year after year. Your work has resulted in what I genuinely believe to be one of the best datasets on fire fatalities in the world – and no research can ever be better than the data from which it is derived. I would also like to thank the people who maintain the databases at MSB, not least Joakim Ekberg, who spent several hours retrieving data, especially in relation to Paper V.

I am also grateful to my mentor and friend, Thomas Gell, for his unconditional support both during my time at the National Centre for Learning from Accidents and also, in later years, at Lund University. This level of support is something every PhD student should have! I am also thankful for Erik Almgren, at the consultancy firm Bengt Dahlgren Brand & Risk AB, who allowed me to try my wings as a researcher with a 50/50 division between the company and the university during my first year as a PhD student.

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For research to be of practical use, it is instrumental to have access to the forums where people active in the field meet. For that, I am very grateful for numerous programme committees over the years for conferences such as *Brandkonferensen*, *Förebyggandekonferensen*, *Brandskydd*, *BIV-dagarna*, *Skadeplats* and many more, who have allowed me to regularly present my research to people who can put it into practice. Also, special thanks to Arnt E. Folkevik at Vestfold Brannvesen in Norway for spreading the results to our Norwegian neighbours at several occasions via the *Brannmannen* magazine, and for contributing the photograph on the front of this thesis.

Finally, I would like to thank my family, my wife Elisabet and my wonderful children, Maja, Josef & Olof, for being who you are and for helping me to take my mind of research. I love you all so much!

Summary

Despite a decreasing trend over time, residential fires are still responsible for approximately 90 fatalities each year in Sweden. The victims represent different sections of the population, but a disproportionate number are older adults and people with alcohol abuse problems. This is particularly evident when the individual is also a smoker. Previous research has shown that different population groups are exposed to different scenarios, ranging from small fires where smoking materials ignite clothes (common for older adults) to technical faults that spread to entire houses (common for non-risk groups). It is therefore reasonable to expect that which prevention measures that are effective in preventing fire fatalities also will be different between groups. However, very little published research assesses effectiveness per population group and, instead, population-average effectiveness is often derived, which might not be representative for any individual group. The aim of the current thesis is partly to fill this gap in the literature by assessing the effectiveness of different measures for different groups.

The results indicate that smoke alarms are very effective for most groups, but it is clear that some groups, particularly older smokers, need additional measures. This need for additional preventive measures is also apparent as older (85+ years) smokers have a 45 times higher risk dying in a fire than the average population. For this group, fire resistant clothes are highly effective and could prevent approximately 60% of the fatalities. Since cigarettes are the dominant mode of ignition in these scenarios, a switch to clothes with synthetic fibres could save many lives, since synthetic clothes are very difficult to ignite with a cigarette. This is because synthetic fabric tend to melt away from the cigarette instead of igniting. They also generally give less severe burn injuries if ignited. Also, detector-activated sprinkler systems were highly effective and provided the highest benefit per installation of all measures for that group.

One interesting additional finding was that approximately 20% of the victims of fatal fires could have safely evacuated, but did not, primarily trying to extinguish the fire instead. This might indicate a need to investigate how to alter behaviour so that individuals only try to extinguish a fire when it is safe to do so.

The thesis also include novel findings in relation to the response to potentially fatal fires. One study investigated fire service response, finding that the fire service saved 51 lives during the studied year (2017), which indicates that the number of fire fatalities in residential occupancies would have increased by 58% in that year without a fire service response. The study also found that response time was very important, as were the tasks the unit can perform on arrival at the scene since, in many cases, the crew arrived to a situation that required breathing apparatus to perform the rescue.

The final study investigated response in a broader perspective, with a focus on older adults (65+), but not limited to any specific actor. The result showed that at least 53% of the individuals depended on other actors for successful evacuation. In the majority of those cases (27%) first-responders performed the evacuation, with neighbours as the next largest group (18%). However, neighbours were also very important for notifying the first-responders because they alerted them in 50% of the cases with first-responder-evacuation. This makes cues that might alert neighbours (e.g. smelling smoke or hearing a smoke alarm) very important. Home care performed fewer rescues (8%) but was found to be very important for the oldest group (80+).

Six scientific research papers are appended to this thesis. The research in these papers is presented and discussed in the thesis.

Sammanfattning (in Swedish)

Trots en positiv utveckling över åren orsakar bostadsbränder ca 90 dödsfall varje år i Sverige. Offren kommer från olika delar av befolkningen, men äldre personer och personer med alkoholproblem. Detta gäller särskilt i kombination med rökning. Det är sedan tidigare känt att olika grupper är exponerade för olika typer av scenarier från små bränder med cigaretter som antänder kläder (vanligare för äldre) till tekniska fel som sprider sig till hela hus (vanligare för personer som inte är i riskgrupperna). Det är därför troligt att effektiviteten hos olika möjliga åtgärder också skiljer sig mellan olika grupper. Det finns dock väldigt begränsat med forskning om detta och de flesta studier beräknar en medeleffektivitet som inte med nödvändighet är representativ för någon grupp. Denna avhandling syftar till att delvis fylla detta hålrum i litteraturen genom att presentera effektiviteten uppdelat på olika grupper.

Resultaten pekar på att brandvarnare är mycket effektivt för många grupper, men det är också tydligt att vissa grupper, särskilt äldre rökare, behöver ytterligare åtgärder. Behovet av ytterligare åtgärder blir också tydligt genom att rökare som är 85 år eller äldre har en 45 gånger större risk att omkomma i bränder än befolkningen i allmänhet. För den här gruppen är antändningsskyddade kläder mycket effektivt och kunde förhindra ca 60% av dödsfallen. Eftersom de flesta bränder i kläder antänds av cigaretter så skulle de flesta fall kunna förhindras genom att byta materialet i kläderna till syntetiskt material eftersom dessa är mycket svåra att antända med en cigarett. Även detektoraktiverad sprinkler var mycket effektiv för denna grupp och gav den största nyttan per installation av alla åtgärder för denna grupp.

Ett intressant ytterligare fynd var att ungefär 20% av offren i det studerade materialet kunde ha utrymt, men gjorde ändå inte det, primärt för att istället försöka släcka branden. Detta kan indikera att det finns ett behov av att undersöka hur människors beteende vid brand kan påverkas så att de bara försöker släcka branden när det är säkert att göra det.

Denna avhandling syftar även till att delvis fylla ett annat forskningsbehov och det är insatser kopplade till potentiellt dödliga bränder. En delstudie undersökte räddningstjänstens insatser och fann att 51 personer räddades under det studerade året (2017) vilket indikerar att antalet omkomna i bostadsbränder hade ökat med 58% utan dessa insatser. Studien fann även att responstiden var mycket viktig, men även vilka åtgärder som räddningstjänsten kan göra när de kommer till platsen eftersom många räddningar genomfördes vid bränder där rökskydd krävdes.

Den sista studien undersöker räddningsinsatser i ett bredare perspektiv med fokus på personer som är 65 år och äldre, men som inte är begränsad till någon speciell aktör. Resultaten visar att minst 53% av personerna var beroende av andra för en lyckad utrymning. I de flesta av fallen (27%) så var det responsorganisationer (räddningstjänst, ambulans eller polis) som genomförde utrymningen följt av grannar (18%). Det var dock även tydligt att grannar var viktiga för utrymning utförd av responsorganisationer eftersom grannarna larmade i 50% av de fallen. Detta pekar på att indikationer på brand (t.ex. röklukt eller att höra brandvarnare), som grannar kan uppfatta är mycket viktiga. Hemtjänst genomförde en mindre andel av utrymningarna (8%), men var mycket viktig för den äldsta gruppen (80+).

Sex vetenskapliga artiklar bifogas till denna avhandling. Forskningen i dessa artiklar presenteras och diskuteras i avhandlingen.

List of publications

Papers included in the thesis

The thesis is based on six papers that are included in the annex. Papers I-III and V have been published in international scientific journals while Paper IV is included as a manuscript and VI has been submitted for peer review. The papers are listed below and the author's contribution to each of the papers is described in a table on the next page.

Paper I	Jonsson, A., Runefors, M., Särdqvist, S. & Nilson, F. (2016) *Fire-Related Mortality in Sweden: Temporal Trends 1952 to 2013*, Fire Technology, Vol 52, Issue 6, pp 1697-1707 doi: 10.1007/s10694-015-0551-5
Paper II	Runefors, M., Johansson, N. & van Hees, P. (2016) *How could the fire fatalities have been prevented? An analysis of 144 cases during 2011-2014 in Sweden*, Journal of Fire Sciences, Vol 34, Issue 6, pp. 515-527, doi: 10.1177/0734904116667962
Paper III	Runefors, M., Johansson, N. & van Hees, P. (2017) *The effectiveness of specific fire prevention measures for different population groups*, Fire Safety Journal, vol. 91, pp.1044-1050, doi: 10.1016/j.firesaf.2017.03.064
Paper IV	Runefors, M., Bonander, C. & Jonsson, A. (2019) *Smoke Alarm Effectiveness in Preventing Fire Fatalities – An Assessment Based on Historical Trends and Current Fatalities*, Unpublished manuscript
Paper V	Runefors, M. (2019) *Measuring the Capabilities of the Fire Service to Save Lives in Residential Fires*, Fire Technology, doi: 10.1007/s10694-019-00892-y
Paper VI	Runefors, M., Jonsson, A. & Bonander, C. (2019) *Factors contributing to survival and evacuation in fires involving older adults*, Submitted to international journal

The author's contribution to the papers are presented in the following table.

Paper	Author's contribution
I	MR wrote 1/3 of the discussion and provided comments on the entire paper.
II	MR planned and performed the analysis. NJ conducted an inter-coder test. MR wrote the entire paper. The coauthors provided valuable comments on the manuscript.
III	MR planned and performed the analysis and wrote the entire paper. The coauthors provided valuable comments.
IV	MR planned and performed the analysis and wrote the entire paper. The coauthors provided valuable comments.
V	MR independently researched and wrote the entire paper.
VI	All authors planned the paper. AJ retrieved data from databases and matched individual level data and CB matched it to municipal data. MR performed the analysis and wrote the entire paper except the introduction (written by AJ). The co-authors provided valuable comments.

List of publications not included in the thesis

Publications that are not included in the thesis, but published by the author, are presented below. Two publications were written before the author changed his surname from Johansson to Runefors.

Peer-reviewed papers

Runefors, M., Boström, P. & Almgren, E. (2018) *Comparison of sprinkler activation times under flat and corrugated metal deck ceiling*, Journal of Physics: Conference series, vol. 1107, doi: 10.1088/1742-6596/1107/6/062006

Ek, Å., Johansson, M. & Borell, J. (2014) *Relationships between safety culture aspects – A work process to enable interpretation*, Marine Policy, vol. 44, pp. 179-186, doi: 10.1016/j.marpol.2013.08.024

Non-peer-reviewed international conference papers

McNamee, M.S, McNamee, R., Runefors, M. & Sandvik, M. *Vehicle fire emissions with and without fire service intervention*, Proceedings of the 15th Interflam conference

Runefors, M., Andersson, J., Wahlqvist, J. , Huang, C. & Husted, B.P, (2016) *A comparison of radiative transfer models in FireFoam and FDS*, Proceedings of the 14th Interflam conference

Mowrer, F., deJoseph, J & Johansson, M. (2004) *An analysis of conditions resulting from fires during tunnel boring operations*, Proceedings from Interflam 2004, pp. 1504-1516

Terminology

Some terms that might be considered unfamiliar with regard to the subject or needing an explanation in the context of this thesis are presented below.

Age-adjusted mortality – A measure of mortality that is corrected for changes in the age structure during the studied period.

Barrier – A factor that prevents or limits the progression of an event sequence.

Benefit proxy – Number of lives saved per year and millions in population with a specific measure if it would have a 100% reliability.

Capability (of fire services) – The set of tasks that a specific unit or organization can perform together with its respective response and persistence times.

Detector activated suppression system – A suppression system that activates on smoke activation (possibly in combination with heat).

(Potential) effectiveness – The fraction of fatalities in a population that would have been prevented if the measure would have been installed and had a 100% reliability.

Fatal fire – A fire that lead to one or more fire fatalities (see definition fire fatality)

Fire fatality – A fatality that is caused by either direct effects from the fire (burns and smoke inhalation) or indirectly (falling building members or jump from high altitude to escape a fire. The fatality should occur within 90 days from the fire.

Fire-resistant – An object that either inherently has the property, or has been treated, to prevent the ignition from a specified ignition source.

First-responder – A unit from the fire services, police or ambulance

Major fatal fire – A fire that lead to five or more fire fatalities

Meta-analysis – An analysis performed to combine the results of several performed analyses, e.g. fire investigations.

Mortality – The rate (i.e. the number of events per year) of injuries leading to fatal outcomes.

Odds – The probability that an event will occur in a group divided by the probability that it will not occur.

Odds ratio – The ratio between two odds. Usually between the odds when a group has a property and when it lacks that property.

Preventive measure – A measure that is in place before the fire occurs with the purpose to prevent the fire or limit the consequences.

Reliability (of a measure) – The probability that a preventive measure really fills it purpose, e.g. a smoke alarm activating when a fire starts or a fire-resistant fabric preventing ignition.

Residential fire – A fire that occur in a building where one or more persons live.

Response – The intervention of an actor beside the victim to limit the consequences of a fire.

Risk factor – A factor that, if present, increases the mortality rate for a group.

Stove guard – A device that detects a fire on a stove and intervenes through breaking the current or introducing an extinguishing agent.

Synthetic fabric – A fabric made out of thermoplastic materials, e.g. polyester, polypropylene and nylon.

Thermally activated suppression system – A suppression system that activates based on a thermally sensitive element, e.g. a sprinkler bulb.

Unintentional fire – A fire that was not set on purpose by the victim or any other human being or where the intent was unclear.

Table of contents

[1] Also available in English in section 8.2.

1 Introduction

Residential fires are responsible for 92% of the fire fatalities in buildings in Sweden (2009-2015) [1]. The risk groups in relation to fire fatalities are well known, but less is known about how these cases can be prevented.

This thesis aims to provide additional knowledge to facilitate more evidence-based prevention of fire fatalities in residential occupancies.

This first chapter provide a short introduction into the numbers and nature of fire fatalities and how they can be prevented. It also aim to put the thesis in a wider context.

1.1 Fire fatalities – Frequency and trends

Fire caused approximately 121,000 fatalities worldwide in 2017 [2] and this is approximately twice that of natural disasters (60,000 in average in the last decade [2]) . Therefore, fire can be regarded as a major public health concern.

Global comparison of fire-related fatalities should be performed with great caution since quality and inclusion criteria differs between countries, but data suggest that most Western countries, together with many East Asian and Oceanian countries, have a mortality rate of around 0.5 to 1.5 per 100,000 population [2]. However, some African countries and former Soviet states experience significantly higher numbers. For example, Latvia has a rate of 4.8 per 100,000 population [2]. Russia experienced very high numbers in the beginning of the century, with over 8.0 per 100,000, but has since seen major improvements and is currently at around 3.6 per 100,000 [2]. Interestingly, this is concurrent with a 43% reduction in alcohol consumption from 2003 to 2016 [3] even if causality cannot be proven.

In Sweden, which is the focus of this thesis, the mortality rate was 0.87 per 100,000 population in 2017 [2], out of which 0.72 is unintentional fire fatalities [4]. The statistics for 2018 show a new record, at as low as 0.48 per 100,000 for unintentional fires [4].

The general trend in fire mortality is very positive and the global, age-standardized, rate has declined approximately 47% between 1990 and 2017 (from 2.98 to 1.59 per 100,000) [2]). A similar trend is also seen at a national level in most countries, including the US [5], UK [6] and Sweden (*Paper I*). This trend is also similar to that experienced for other types of accidents [7].

However, there are initiatives to continue decreasing these numbers, for example the formulation of a Vision Zero for fire fatalities and injuries [8] similar to that in place for road traffic in Sweden since 1997 [9].

Below is the age-adjusted mortality rate for unintentional in fires in Sweden 1952-2017[2]. More on the historical trends for fire deaths in Sweden can be found in Paper I and section 4.1.

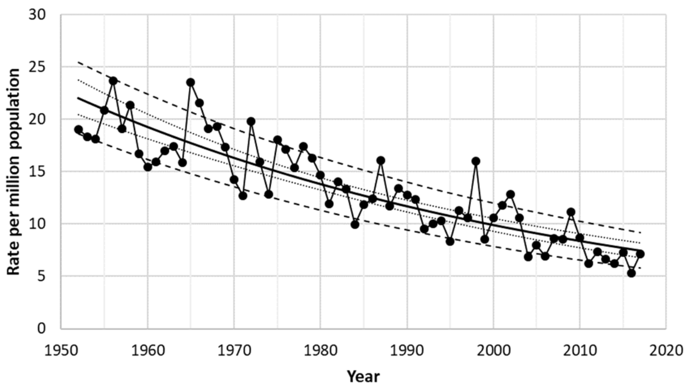

Figure 1.
Age-adjusted unintentional mortality rate for the entire population in Sweden 1952-2017 with 95% prediction interval (dashed line) and 95% confidence interval for the trend (dotted line).

In Sweden between 1999 and 2017, 94% of all fatal fires are single fatality fires (accounting for 84% of fatalities). However, providing a review of major fires may also be relevant. The distribution of catastrophic fires (defined as five or more fatalities) over the decades is shown in Figure 2 and a brief description of the events can be found in appendix A.

[2] Intentional fires (suicide and homicide) and fires with undetermined intent are not convertible over time and have therefore been excluded (see Paper I)

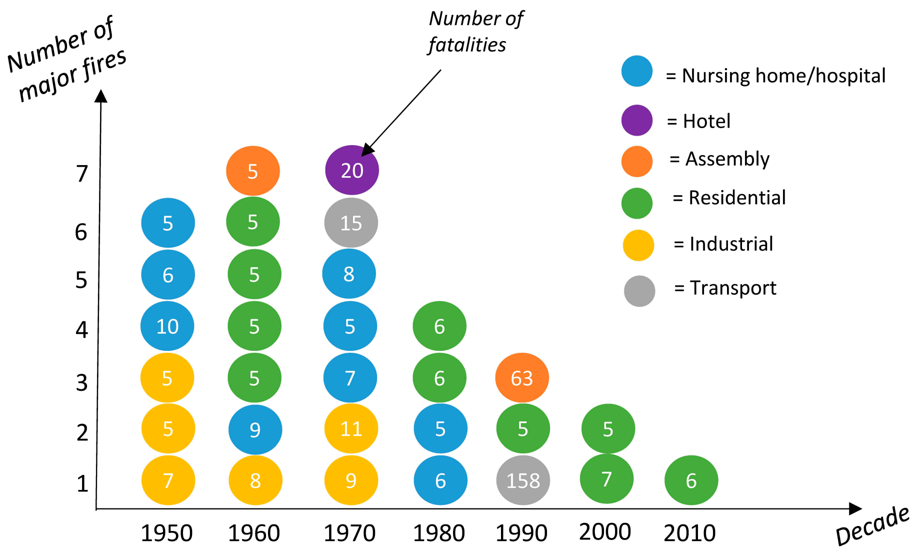

Figure 2.
Major fires 1950-2018 defindes as having at least five fatalities. Note that this follows the MSB-definition of fire fatalities with fires in Sweden regardless of residency (see section 3.2).

As can be seen in Figure 2, two fires with a very high number of causalities occurred in the 1990s. These are a fire in a discotheque in Gothenburg in 1998 with 63 fatalities and a fire on a ferry, the *M/S Scandinavian Star*, in 1990. However, apart from those occurrences, the trend in major fires seems to be following a diminishing trend. Major fires in industrial and nursing home/hospital settings seem to be decreasing.

1.2 Risk groups for fatal fires

The risk groups for fatal fires are well known, and often cited risk factors are: (e.g. [10], [11])

- Old age
- Physical disability
- Mental illness
- Smoking
- Alcohol

The risk factors will not be described in detail in the current thesis and the reader should refer to one of the many informative papers on this topic (e.g. [12]). It is however interesting to note that the fraction of smokers in the population are decreasing in most countries [13]. In Sweden the fraction of daily smokers is less than half of that in the late 1980s [14].

The risk factors seem to be shared by most countries, at least Western countries. However, one exception is young age, which is identified as a risk factor in some countries [15] and used to be a risk factor in Sweden (*Paper I*). This group is no longer considered a risk group in Sweden since the mortality rate is now among the lowest for all age groups (*Paper I*). An interesting study from Spain also indicated that heating equipment and electrical causes was responsible for more fatalities than smoking in Spain particularly for older adults (over 65) [16]. More studies should be performed to further investigate this difference between Spain and most other countries, maybe with the method developed in Paper II.

One important aspect that is a common cause of confusion relating to risk factors is that some risk factors are actually negatively correlated. For example, elderly people are very rarely intoxicated with alcohol at the time of death [12]. There is also anecdotal evidence that dementia reduces the urge to smoke, so that few people with severe dementia continue to smoke [17].

An illustrative way to couple risk factors to investigate how they relate to each other is through cluster analysis. This has been performed by Jonsson et al [12], with variables related both to the victim (e.g. alcohol levels), the setting (e.g. time of day) and the scenario (e.g. cause of fire) being used to classify the cases into different categories/clusters. The technique results in clusters where the cases in each cluster are as similar to each other, and as different to the cases in the other clusters, as possible. The results are illustrated in Figure 3, with the variables that significantly differentiate each cluster in relation to the average for all cases.

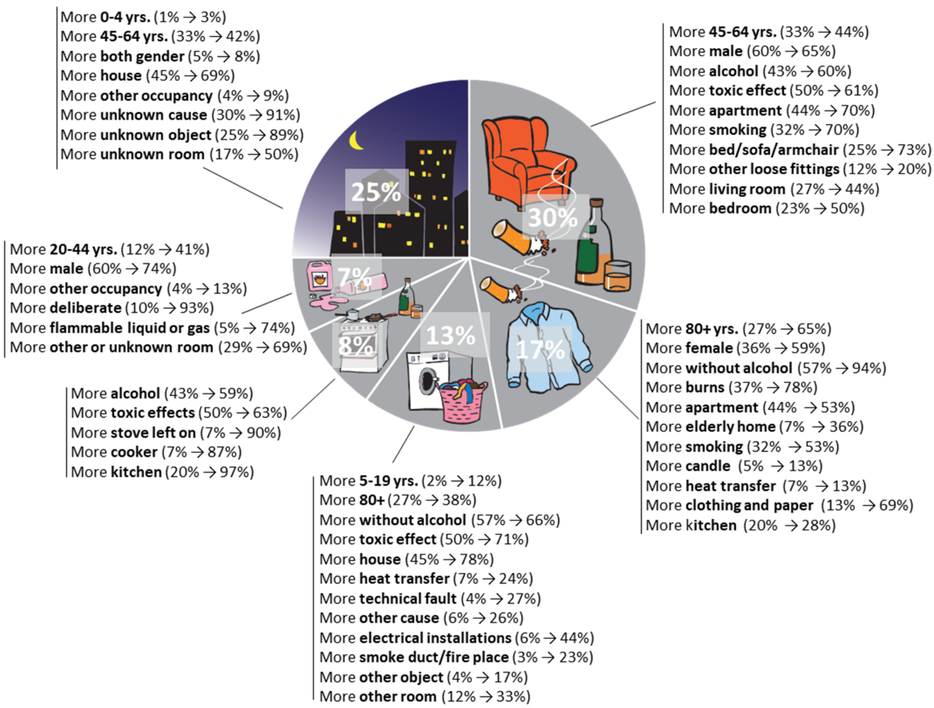

Figure 3.
Cluster characteristics for fatal fires in Sweden 1999 to 2007 with statistically significant ($P<0.05$) characteristics compared to all fatal fires, based on [12].

The results show a strong relationship between individual characteristics, such as age, and the scenario. This indicates that different measures might be effective for different groups.

It should also be emphasized that the risk factors for fatal fires are very different (and often the direct opposite) to the risk factors for residential fires in general, as is apparent in Table 1.

Table 1.
Risk factors for fatal fires [10] and residential fires in general, either based on fire service interventions [18] or self-reported events [19]

Fatal fies	Residential fires (Fire service response)	Residential fires (Self repported)
Reduced mobility	Young age	Young age
Impaired cognitive ability	Living alone with children	Families with children
Alcohol	Unemployed	High level of education
Mental illness	From another country	
Substance abuse	Low level of education	
Smoker		

1.3 Perspectives on the prevention of fatal fires

As is evident from section 1.2, fatal fires are, in their essence, a social problem, and shares its roots with many other sources of mortality, as stipulated by the 'fundamental cause theory' [20]. Victims of fatal fires are often the socially marginalized [11] and lonely [21] people. One approach for prevention could therefore be to intervene with these root causes by, for example, alcohol abuse programs, more places at care homes and social programs. This perspective, where fire becomes just another symptom, together with other injuries and illnesses that are related to the same set of causes, is very relevant and should receive more attention from both academia and practitioners.

However, society is unlikely to ever fully eliminate these root causes and, for many people involved in fire prevention, they might feel out of their reach. Therefore, it is important to relieve the symptoms through specific prevention measures, despite these not eliminating the root cause. Thus, this thesis does not evaluate the root causes, but instead investigates the effectiveness of fire prevention and response efforts. Just as a physician provides symptom relief for conditions where a cure is not available, fire prevention professionals need to use the available tools to limit the effects of the root causes.

Also, just as for a physician, the "treatment" provided must be based on solid scientific evidence and should also be the most effective available. This is not always the case, because currently the same set of fire prevention measures (smoke alarm, fire extinguisher and fire blanket) are often recommended, regardless of the individual. But, for example, this is clearly not very effective for a completely bedridden person (at least not for someone in a rural area where smoke alarms cannot be heard by neighbours).

1.4 Preventive measures for fatal fires

Historically, significant effort has been put into limiting the fire spreading, first between blocks of buildings, then between buildings and then also between apartments within a single building [22]. This has led to fatal fires in residential occupancies almost exclusively originating within the residential unit where the victim later dies, even if there are some notable exceptions, such as the Grenfell fire [23]. Therefore, preventive measures for further reduction in the mortality rate generally need to be active within the affected fire compartment. The following paragraphs present some of the most important preventive measures, but the list is not exhaustive.

Among these preventive measures, a **smoke alarm** is arguably one of the most important and has a coverage as high as 96% in Sweden in 2018 [24]. It is also the most widely evaluated in academic [25] and, most likely, other forms of publications. There is almost general consensus in the literature that the installation of smoke alarms has significantly reduces risk. Most studies indicate that the level of risk reduction is in the order of 50% for the entire population [26] with a spread in identified studies between 49% and 66% [27]–[31]. However, there are some notable exceptions based on historical data that indicate an effectiveness in the order of 10% [32], [33]. The effectiveness presented is, however, usually population average effectiveness, despite there being reason to believe that the level of effectiveness is quite different between the clusters presented in Figure 3. The only two studies that describe identified differences assesses their effectiveness for children of different ages [34] and differences between apartments and houses [35]. No studies on differences between ionization and photoelectric smoke alarms have been found, despite experimental results indicating that, for people with reduced mobility, ionization alarms may be too slow for smouldering fires and photoelectric alarms too slow for flaming fires [36].

The other preventive measure that has received significant attention in the literature is **residential sprinkler systems**. For this measure, the literature is also in approximate agreement, indicating effectiveness in the order of 69% to 86% ([29], [37]–[39]). However, for this measure too, results for different subpopulations are generally lacking, with only one analysis of the difference between apartments and houses identified in the literature [35]. Since thermally activated sprinkler systems, such as residential sprinkler systems, are generally to slow to save victims who are in the object of ignition [40], a large spread in effectiveness between the clusters presented in section 1.2 can be expected.

While the previous two measures are primarily consequence limiting, it is also possible to reduce the probability of ignition. One way to do this is through modification of the most common ignition source in fatal fires – cigarettes [12]. This has been pursued with the introduction of **RIP cigarettes** (Reduced Ignition Propensity). This can function in a number of ways, such as lower packing density, smaller diameter, or removing citrates from the paper (as these increase the burning rate) [41]. The method that has been implemented into the test standard is, however, the self-extinguishing cigarette; bands of denser paper are usually placed certain distances apart so that the cigarette will extinguish if not puffed. Despite doubts about the effectiveness of such approach in "The Ignition handbook" [42], published in 2003, the first evaluation of the intervention in New York in 2009 was very positive, with up to 40% reduction in smoking-related fire fatalities [43]. The earlier studies were, however, based on rather small data sets and often questionable methods [44]. Later studies have proven the effect to be non-significant based on both US [45] and Swedish data [44]. This is in agreement with recent experimental results which indicate no, or very limited, difference between RIP and regular cigarettes when combined with more realistic fuels than the flat filter paper in the standard test [46]–[48].

To reduce the probability of ignition, it is also possible to modify the fuel. This has been pursued with the introduction of requirements for **fire resistance for upholstered furniture** in some countries, most notably in the UK and some states in the US. An evaluation of the effectiveness of this legislation in the UK indicates a reduction in the mortality rate in the order of 21% [49]. However, there has recently been great debate about the environmental impact of some fire retardants (e.g. [50]), which has led to legislators contemplating rolling back requirements on fire-resistant furnishings. There are, however, other ways to achieve fire resistance such as using inter-liners [51], but substituting cotton-based fabrics on furniture with a synthetic material (such as polyester) will also reduce the risk of ignition by a cigarette from 43%-86% to 2%-5% [52]. It should however be noted that synthetic fabrics on furniture might be more hazardous in relation to a flaming ignition source, since they melt away and expose the foam, so the substitution should be assessed in relation to the expected ignition source. However, it is worth noting that for smokers in the main risk groups, smoking material is the dominant ignition source in general and especially for upholstered furniture (see section 4.3 for a more detailed discussion).

Another common fuel in fatal fires is **clothes**. Also, for flaming sources of ignition, the risk of ignition is often lower for synthetic fibres because they tend to melt away from the heat source instead of igniting [53], [54] unless they are mixed with natural fibres that prevent retraction from the heat source [53]. Also, the degree of burn is generally lower for synthetic fibres than natural fibres, since the melted clothes insulate the skin and therefore limit the deeper burns [55] that are often associated with fatal fires. This indicates that substituting fibres in materials for the risk groups might be an effective alternative to applying fire-retardants. Also, in relation to clothes based on natural fibres, it is worth noting that the smouldering propensity of cotton based fabrics is almost entirely dependent on the presence of alkali metal ions [56]. Since those tend to gradually wash away, the smouldering propensity of cotton can be expected to reduce over time. An interesting recent finding is that the addition of at least 5% spandex to a natural fibre seems to prevent ignition from cigarettes [57]. Also, there are some reports that skin creams containing paraffin greatly increase flame spread in clothes [58]. Both these findings are very relevant for older adults (one of the main risk groups) since comfort is a key requirement [57], which spandex usually improves, and the group can also be expected to use a lot of skin cream much of which is likely paraffin based [17].

There are also a range of preventive measures that have not received the same attention. One example is the **detector-activated suppression** system that is designed to activate at an earlier stage than thermally activated sprinkler systems, and thus be able to save the individual in the ignition object. The manufacturer's website lists 88 cases where the system is believed to have prevented injury and/or property damage [59] for the 1,600 units they have delivered, but no systematic evaluation of its effectiveness is available in the literature.

Another measure is a **stove guard** that is designed to identify and either disconnect the power to the stove or apply an extinguishing agent. A study performed by RISE in Norway [60] concluded that the stove guard prevented ignition of oil in a pot in only 54% of the experiments. However, all these cases were linked to three of the six tested stove guards which indicates that, at that time, there was a large spread in the capability of the stove guards. After these tests were conducted, a European test standard for stove guards, SS-EN 50615, has been developed, which has probably led to higher and more even quality. No systematic evaluation of the effectiveness of those systems has been identified in the literature.

The installation of **ground fault interrupters (GFIs)** is not only a fire prevention measure, but also a measure to prevent electrical accidents. The GFI prevents many electrical fires, but many fires occur due to resistive heating in a poor connection [61] or where the current returns to a circuit after heating another material, and a GFI is not necessarily efficient in these cases. However, many of those faults induce a ground fault as a secondary failure when the insulation on the ground wire melts. No study on the potential effectiveness of GFIs in preventing fire fatalities has been identified, but there is a Danish study [62] on the reliability of GFI that indicates that 9.4% of the 1761 tested GFIs did not work as intended (i.e. did not activate in case of a simulated ground fault).

Despite not falling into the definition of a preventive measure, **fire service response** is a potential measure for reducing fire-related mortality. Saving lives in fires is often considered a central aspect of fire service planning, therefore it is surprising that very few empirical studies are available on how to effectively organize a fire service to maximize effectiveness, or even the numbers of rescues that are performed annually. The only published paper to quantify the number of individuals saved is a study from the Netherlands. This indicates that approximately 5.6 individuals per 1M population are saved from what the authors label as immediate threat to life. Regarding the influence of response time, two recent empirical studies have been identified, Jaldell et al. [63] and Manes et al. [64]. Both indicate a decreasing trend in the possibility of rescue with increasing response time. However, the marginal effect (i.e. the derivative of the probability with time) is different between the two studies. While Jaldell et al. [63] show a strong dependence on time up to around 10 minutes and then a substantially weaker dependence at higher times, Manes et al. [64] show a negligible dependence up to 10 minutes and much stronger dependence at longer times.

1.5 Motivation of thesis

As described in section 1.4, some measures have received substantial attention in the literature, especially smoke alarms and sprinkler systems, but there are also a range of measures that lack a quantification of effectiveness in the literature. Therefore, this thesis provides some more explorative investigations, one of which is to find kinks in the mortality trend that might indicate important changes in society. The thesis also includes an open investigation of fatal fires that take the event, rather than the measure, as point of departure.

Even for the preventive measures that have been assessed in the literature (primarily smoke alarms and sprinkler systems), effectiveness for subpopulations is essentially lacking. This can be expected to be important for many measures, because their effectiveness is very different for different scenarios and there is a strong correlation between scenario and population group [12]. For example, sprinkler systems are, as previously discussed, not effective for scenarios where the victim is in close proximity to the object of ignition [40] and, since clothing fires are more common for older people [12], the effectiveness of sprinkler systems is probably lower for this group. Therefore, this thesis provides some measures of effectiveness for different subpopulations (e.g. age groups and smokers/non-smokers).

Prevention is the main focus of the literature on the subject of fire safety. However, a complementary perspective is to assess the potential for someone to evacuate the individual in a fire. Data on this are essentially lacking in the literature and the current thesis therefore provides an explorative investigation into this field. The scope is not only professional responders such as the fire service, but also non-professional and semi-professional responders such as neighbours and homecare staff.

1.6 Thesis outline

This chapter has presented a brief introduction to the context of the current thesis. In chapter 2, the scope of the thesis is presented through a formulation of a research objective and research question, but also limitations.

Chapter 3 contains discussions on the scientific perspective in the papers, along with a description of the data sources and a brief description of the statistical methods used in the papers. A closer examination of the application of the methods in the different papers, and the strengths and limitations of the methods, are presented later in the thesis.

Chapter 4 presents the main results of each paper. In order to prevent unnecessary duplication of the information from the papers, these are selected to provide the best basis for answering the research questions. However, results omitted from the presentation in chapter 4 are mentioned in the text. This is also the case where minor modifications have been made to the results.

Chapter 5 includes some more detailed reflections on the methods used in the different papers, as indicated above, and then an attempt to answer the research questions and address the research objective is presented in chapter 6.

In chapter 7, there is a discussion on the validity, reliability and generalizability of the results, followed by some conclusions and recommendations on the thesis in chapter 8. The thesis is then completed with formulations of some suggested themes for future research in chapter 9.

2 Research objective and research questions

As discussed in chapter 1, the risk groups in relation to fatal fires are well known, but there is potential to increase knowledge of effective measures that can prevent these fatalities, especially in relation to different population groups. This chapter presents a research objective and, in order to address this objective, five research questions are formulated.

2.1 Research objective

Cases of fire fatalities, and close calls, are explored in this thesis with the overall objective of assessing how fatalities can be prevented through a combination of prevention and response measures.

Based on this overall research objective, five research questions (RQ) are formulated and discussed in the following section.

2.2 Research questions

Research question 1

Even though both the number of fatalities and risk groups are well known, as discussed in chapter 1, investigating the long-term trend in number of fatalities is still of interest. This is also relevant since distinct kinks in the trend may point to specific factors that are important in preventing fatalities. Therefore, the first research question is the following.

RQ1: What is the long-term trend in the risk of dying in unintentional fires and can any shifts be identified? (Paper I)

Research question 2

As discussed in section 1.3, fire-related mortality is primarily a social problem, but while waiting for that to be solved, there is still a need to treat the symptoms, i.e. specific measures that can limit the effect of the socially-related root causes.

For this prevention effort to be effective, the "treatment" that is introduced must be evidence based, which is not always the case at present. Therefore, there is a need for additional data. A number of studies on the topic can be found in the literature (see section 1.4), but generally they are limited to a single or few measures and only presented as an average for the entire population. This results in the next research question.

RQ2: Which measures are effective in reducing fire-related mortality? (Papers II & III)

Research question 3

Smoke alarms are unique among the available measures due to their wide adoption (96% in Sweden in 2018 [24]) and therefore merit detailed attention. The rather smooth and exponentially diminishing trend (familiar from many other accident types [7]) found in relation to RQ1 could be used (and has been in the US [65]) as an argument that the introduction of smoke alarms has had a limited effect on the mortality rate due to the absence of any distinct kinks in the trend. However, closer examination of individual age groups (see Figure 8, p. 28) shows a distinct kink in the trend concurrent with the sudden increase in smoke alarm prevalence in Sweden in the 1980s and early 1990s. It is therefore possible to combine effectiveness for current fatalities that is investigated in relation to RQ2 with the fatalities currently averted due to smoke alarm installation. This is investigated in RQ3.

RQ3: How effective are smoke alarms in preventing fatal fires? (Paper IV)

Research question 4

Together with the previously published research (see [66] for a recent review), the papers published in relation to these questions were believed to provide a comprehensive account of different preventive measures and their effectiveness. However, one factor that was found to be less investigated, is the role of the fire service response in preventing fire fatalities. The author has heard people expressing doubts about whether this occurs on many occasions, and any scientific investigation of this is rare in the literature (*Paper V*). There is therefore a great need to provide scientific evidence about how many lives are saved by fire service interventions.

The frequency of rescues provides an important background for understanding cases in which fire services perform rescues. However, to provide opportunities for intervention (i.e. increase the number of rescues), more knowledge about how fire service planning affects the outcome is needed. This is performed through the concept of capability [67], which is divided into "response time", "tasks" and "persistence". The first part was judged to be relevant, because the fire service must arrive before fatal conditions develop; the second was also believed to be relevant, because it dictates what the fire service can perform after they arrive at scene. The last dimension of capability, persistence, was judged not to be relevant because most rescues are performed in the first few minutes of the response. This leads to the fourth research question:

RQ4: How many people are rescued from fires by the fire service and what response capabilities are needed? (Paper V)

Research question 5

Fire services are not the only ones to perform rescues. What is labelled "interior attack without breathing apparatus" in relation to RQ4 could essentially be performed by anyone. It is therefore interesting to investigate how many people are evacuated by other actors and the characteristics of each actor's intervention. This leads up to the fifth, and final, research question. The scope of this investigation is limited to older adults since they are more commonly physically impaired and therefore believed to be more dependent on evacuation by others.

RQ5: Who evacuates older adults at risk from fires and what are the characteristics of these scenarios? (Paper VI)

These five research questions, along with previously published literature in the area, are believed to provide a comprehensive background for addressing the overarching objective presented in section 2.1.

2.3 Limitations

As with all studies, the current study is subject to several limitations. One of the more obvious limitations is that all studies are performed in a Swedish context. Any application of the results to other countries is dependent on generalizing the results. The influence of this limitation is discussed in section 7.3.

A second limitation is the sample size, although for the preventive measures the small sample size in Paper II is somewhat compensated by the larger dataset in Paper III, which gave a very similar result for the included measures. For the paper on fire service response (Paper V) the small sample is believed to be more detrimental, but this uncertainty is quantified. Paper V includes a more thorough discussion of this topic.

A third limitation is the high level of unknown variables in the data used. Fires are inherently destructive events and therefore naturally lead to a high level of unknown factors. The proportion of these unknowns could probably be reduced significantly with a deeper knowledge of fire service investigations, but the data used in this thesis remains subject to this high level of unknowns. Section 3.2 includes a more detailed discussion of the different data sources used in the thesis.

3 Scientific methodology

This chapter describes the overall research methodology, followed by a brief description of the data and statistical methods used. Interviews are described in relation to the reflection on the methods for Paper V in section 5.5.

3.1 Overview of methodologies

A fundamental division in scientific methodology is that between experimental and observational methods. In experimental methodology, one or a few variables are modified and the effect on the outcome is analysed. This is the preferred method in most sciences because it provides reliable results (given the bounds of the experimental set up). It has been used in the field of fatal fires with regard to smoke alarms, where smoke alarms were installed in a random set of occupancies and their effect on the mortality rate analysed [68]. However, since fatal fires are rare events, a very comprehensive study is needed to provide a sufficiently large dataset.

In the other approach, observational methodology, a phenomenon is observed without manipulation and causality is inferred through theoretical reasoning. The data in observational studies are often divided into qualitative and quantitative. Qualitative research is concerned with analysis of data that are not numerical. Qualitative analysis has been performed in some of the papers in this thesis (namely Papers II, V and VI) where investigation reports (Paper II), semi-structured interviews (Paper V) and free text in incident reports (Paper VI) have been used as the basis for analysis. There are a range of methods available for qualitative research, ranging from structured methods such as content analysis [69] to more interpretative methods such as ethnographic methods [70]. The papers included in the current thesis lean more towards the interpretative perspective without being ethnographic. The reasons for this choice of perspective are detailed in chapter 5, in the reflection on the methods used.

Even though qualitative methods are used for data generation and categorization of cases in some papers, the overarching perspective for all papers is quantitative. However, the contextual knowledge gained through qualitative analysis has been very instrumental in interpreting the findings. For the quantitative analysis, several different types of statistical methods have been used, for example Poisson regression and logistic regression, refer to section 3.3 for a brief presentation of these methods and to chapter 5 for a more detailed discussion.

In the thesis, case studies are the starting point of the investigation, with the results informing and generating data for statistical data analysis. This is a different perspective to the method of combining case studies and statistics, as previously published in the field of fire science [71], where statistics are used to inform the selection of case studies.

The approaches of the different papers can be found in Figure 4. For the paper in the category of case studies, the textual data for each case was generated by the researcher (through interviews). Meta-analysis refers to the abstraction from a single case to several cases, which was performed by coding the different cases. The statistics category refers to the analysis of quantitative data using statistical methods.

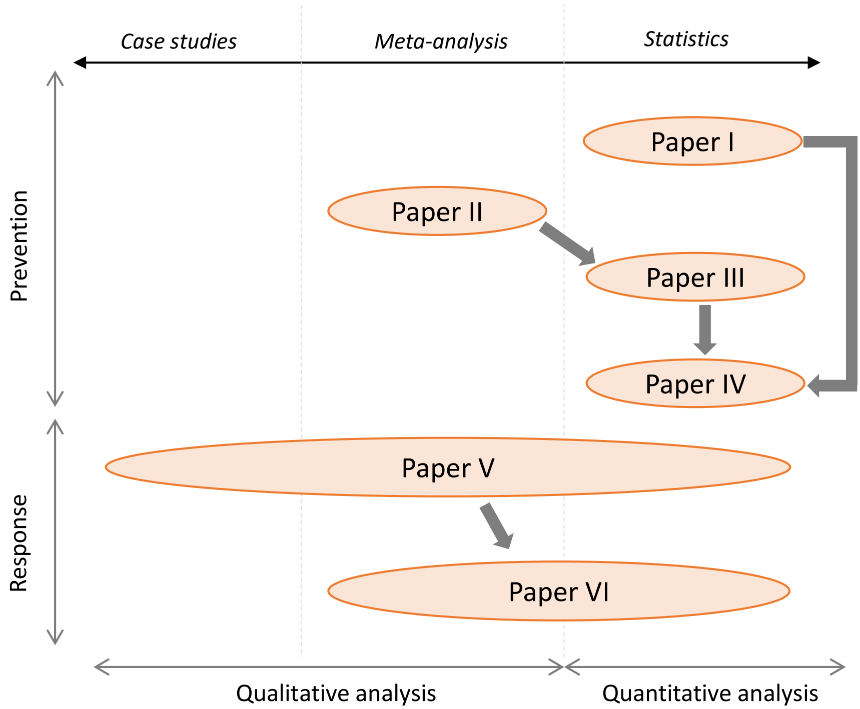

Figure 4.
Methodological approach in the different papers and the information transfer (grey arrows) between papers.

A more detailed discussion about the methods in the different papers is available in chapter 5, and the validity, reliability and generalization of the results are discussed in chapter 7.

3.2 Data used in the papers

This section presents the data used in the papers. The reader should exercise caution, because the cause of death registry and fatal fires database each have a slightly different scope. The former includes all Swedish residents, regardless of the country in which the death occurred, while the fatal fires database includes all fatalities in Sweden regardless of the victim's residency. However, given the focus on residential fires in the current thesis, this difference will be negligible because almost no one in the data dies in someone else's residential unit (and especially not in another country).

3.2.1 Cause of death registry (Paper I and IV)

The cause of death registry is maintained by the National Board of Health and Welfare (*Socialstyrelsen*) and covers all fatalities by Swedish residents, regardless of where the fatality occurred. In Sweden, all accidental deaths are subject to a full autopsy and therefore a forensic physician classifies fire as the direct cause of death.

The cause of death registry covers the period since 1952, which was the year the first version of the International Classification of Diseases (ICD) system was adopted in Sweden. Before that, since 1749, mortality data was collected by Statistics Sweden (*Tabellverket*). Since the introduction of the ICD system, classifications have been changed several times, from ICD-6 to ICD-10. The codes for unintentional fire deaths are presented in Table 2.

Table 2.
Codes for unintentional fire fatalities in different versions of the ICD-system.

Years	ICD-version	Codes for unintentional fire fatalities
1952-1957	ICD-6	E916
1958-1968	ICD-7	E916
1969-1986	ICD-8	E890-E899
1986-1997	ICD-9	E890-E899
1997-present	ICD-10	X00-X09

Due to the changes in the coding scheme between different versions of the ICD system, suicide by fire (X76 in ICD-10), assault by fire (X97) and fires of undetermined intent (Y26) were excluded from the analysis[3] since they could not be followed over time.

3.2.2 Fatal fires database (Papers II, III, V and VI)

Data on fire fatalities has been collected for a very long time. First by the Swedish Fire Protection Association (*Brandskyddsföreningen*), then by the Swedish Rescue Services Agency (SRV) and, finally, by the Swedish Civil Contingencies Agency (MSB).

Traditionally, cases were collected through contact with the fire services and media channels. However, as shown in [72], this results in substantial bias in the data because later deaths in hospital are often missed, and cases in which a medical condition caused the death and the fire was secondary are included. Also, some fires are not attended by the fire service and are therefore not included.

An effective method for correcting those biases is cooperation with the agency that performs autopsies for all accidental deaths, the National Board of Forensic Medicine (RMV). This cooperation has been in place since 2009 and data since 1999 has been corrected. Unfortunately, in 2016 the RMV disbanded the cooperation due to confidentiality issues surrounding personal information under the EU's new GDPR legislation [73]. This is the reason why some studies do not use cases after 2015 in situations where the above-mentioned bias was judged to be more detrimental to the analysis than possible recent changes in the nature of fire mortality.

After cases have been identified through fire services, media or the above-mentioned cooperation with RMV, a simple Word form is filled in, usually by personnel at the fire service or police. Employees at MSB make sure that a form is filled out for every case and this information is then entered into the database. Although not formally part of the database, MSB also regularly collects fire investigation reports from these cases.

The database contains information on the location, type of building and the cause and origin of the fire. The database also includes information on the presence and functionality of smoke alarms, fire extinguishers and other extinguishing systems. For each victim, the database also includes variables that describe the victim (e.g.

[3] Note that the focus on unintentional fires are shared by all prevention related papers (Paper I-IV), but not the response focused papers (Paper V-VI).

age, disability, living conditions), where the victim was found and whether evacuation or rescue was attempted.

3.2.3 Fire investigations from fire service and police (Paper II)

The fire services are legally obliged to investigate the "the causes of the accident, the course of the accident and how the intervention was carried out" (SFS 2003:778, Paragraph 10). It is worth noting that this requirement is for all accident types, not only fires. In many cases, the incident report sheet (see section 3.2.4) is seen as sufficient, but for some accidents, fatal fires often being one of them, a full investigation is often carried out. Some of those are sent to MSB and, in the case of fatal fires, the local fire service is contacted by personnel at MSB and asked to submit their investigation. Also, the police regularly investigate fires where a crime, such as arson or negligence, can be expected.

Investigators at the fire service and the police have joint training in fire investigation from the Swedish National Forensic Centre (NFC) which is part of the police. The course covers three weeks of training, including both theoretical descriptions of fire dynamics and common causes of fires, as well as the practical investigation of prescribed burns.

The level of experience is, however, very different between different investigators, which is apparent from the great variation in the quality of the reports. Sweden has no certification system similar to the IAAI-CFI-system [74] in the US so, in practice, everyone can perform a fire investigation, but the three-week course mentioned above is often used as a minimum.

3.2.4 Incident reports from fire service (Paper V and VI)

Incident reports are computerized forms that are filled out after almost all fire service calls. Typically, all but a few small municipalities fill out the form so the coverage is normally well over 99% of all calls nationally [75]. The form has been developed by the Swedish Civil Contingencies Agency (MSB), which also collects the forms and makes the results available via an online platform called IDA (http://ida.msb.se).

This system of incident reports has been in place since 1996 and has remaining unchanged apart from a minor revision to the form in 2005 and a major revision in 2016-2017 [76]. The data used in the current thesis is all from the latest version of the form and therefore not affected by those changes. The reason only the latest version was chosen is that prior to that, the age of injured individuals was not included (instrumental in Paper VI) and the data was stored locally at the fire service rather than on MSB's server. The transition to an online form was instrumental to Paper V, because before that each fire service sent in its reports annually (as a file attached to an e-mail). With the introduction of the online forms, MSB could send information about the event very close to the actual event (typically within a few days), allowing interviews to be conducted in reasonably close proximity to the event.

The form includes information about the tasks performed by the fire service and the resources used. It also includes the time of the incident and when different units arrived on the scene. The form also has sections relating to the expected cause of fire and room of origin, as well as general information about type of building and location [77].

The individual filling out the form is typically the highest commander during the event and in many cases, lower level commanders add to the information. The information in the incident report is not always updated if there is a fire investigation, so cause determination, etc. (used in Paper VI), is based on the impression of the commander, which is not always accurate. The data used in Paper V are more related to the interventions by the fire service and therefore a higher level of accuracy can be expected.

3.3 Short description of the statistical methods used

This section aims to provide a short description of the two main statistical methods used in the thesis for readers who are not familiar with them. Details about how they are applied in the current thesis are presented in each paper and are discussed in chapter 5.

3.3.1 Poisson regression (Paper I and IV)

Poisson regression is a method for the regression of Poisson distributed data. Poisson distribution is a discrete probability distribution that describe the number of randomly occurring events per unit of time or space [78, p. 115]. The requirement of random events results in the correlation of events that increase the probability of a second event generally not being allowed. For example, in suicide there is a certain copy-cat effect, where a suicide might trigger a second suicide [79]; this violates the assumption of independence and the result is therefore not exactly Poisson distributed.

The probability density function (PDF) of a Poisson distributed variable *X* has the following formula [78, p. 117].

$$P(x) = \frac{e^{-\mu}\mu^{x}}{x!}$$

Where *P(x)* is the probability of *x* number of events during one unit of time or space and μ is the expected (or average) number of occurrences. The variance of a Poisson distributed variable is equal to the expected value.

When studying Poisson distributed events that take place during a time interval of length *t,* the expected value of occurrences, μ, can be parametrized into an intensity, λ, and the time, so that μ= λt. If the intensity is a function of time, the expected number of events between time t_0 and t_1 can be calculated as follows:

$$\mu(t_0, t_1) = \int_{t_0}^{t_1} \lambda(t)dt$$

Where the intensity is not constant over time, the intensity as a function of time can be estimated using a generalization of linear regression called the GLM framework [80], which is a family of expectation maximization techniques. In GLM, exponentially distributed functions (including the Poisson distribution) are transformed into a linear regression through a mathematical function called a link function which, in case of the Poisson regression, is the log-link-function. After the predictor variables have been calculated, the intensity of events (i.e. the number of events per unit in time), λ, at time *t* can be expressed as follows:

$$log(\lambda) = \beta_0 + \beta_1 \cdot t$$

Where β_0 and β_1 are the two regression parameters.

3.3.2 Logistic regression (Paper V and VI)

Logistic regression is a regression method for predicting the probability of the presence (or absence) of a property based on independent variables that can be continuous, discrete, dichotomous or a mix [81, p. 437]. The probability that a certain observation has the property defined as the dependent variable, *Y*, can be calculated from a linear combination of the independent variables, $f(\boldsymbol{X})=f(x_1,x_2,\ldots,x_k)$, according to the following link-equation (called the logit-link-function).

$$Y = \frac{e^{f(\boldsymbol{X})}}{1 + e^{f(\boldsymbol{X})}}$$

$$f(\boldsymbol{X}) = \beta_0 + \sum_{i=1}^{k} \beta_i x_i$$

The regression parameters are estimated using a Maximum likelihood approach.

In many cases, the odds of having a property are presented, rather than a probability. The odds are the probability of having the property divided by the probability of not having that property. The natural log of the odds can be calculated according to the following equation.

$$\ln\left(\frac{Y}{1-Y}\right) = \beta_0 + \sum_{i=1}^{k} \beta_i x_i$$

The ratio between the odds, with different values for the independent variable, called the odds ratio (OR), is useful when comparing the influence of the independent variable on probability. If the odds ratio is significantly over or under unity, the independent variable has a statistically significant effect on the outcome.

4 Brief presentation of the appended papers

The following sections present some of the main results from the various papers. This description is not exhaustive, so the reader is referred to the paper for a full account. The results below are also, to some extent, complemented with newer data and discussion. This is noted in the text where applicable.

It should be noted that Paper I includes all unintentional fatal fires, Papers II-IV include unintentional residential fatal fires, while Papers V-VI include all residential fires. Paper VI, however, excludes fatal fires in care homes since the response was expected to be quite different with personnel available on site.

Since both the population and data sources vary slightly between papers, a summary of cases and controls are given in Table 3.

Table 3.
Summary of cases and controls, where applicable, in the different papers.

	Case	Control
Paper I	Unintentional fire fatalities 1952-2013 from the cause of death registry (*N=7,065*)	N/A
Paper II	Unintentional residential fatal fires 2011-2014 in the fatal fires database with fire investigation (*N=144*)	N/A
Paper III	Unintentional residential fire fatalities 2009-2015 in the fatal fires database (*N=611*)	N/A
Paper IV	Unintentional fire fatalities 1952-2017 from the cause of death registry (*N=7,323*)	N/A
Paper V	Fires with rescued individuals from all residential fires in 2017 based on incident report and interviews (*N=42*)	Fires with fatalities in residential occupancies in 2009-2015 in the fatal fires database (*N=551*)
Paper VI	Injured, but not killed, older adults (65+) in residential fires in 2017-2018 based on incident reports (*N=345*)	Fatal fires among older adults (65+) in residential occupancies in 2012-2017 according to the fatal fires database (*N=269*)

4.1 Paper I – Trends in unintentional fire mortality

Paper I analyses trends in the absolute number of fire fatalities between 1952 and 2013, along with the age-adjusted mortality rate for the same time period.

Since Sweden's population has grown from 7.2 million in 1952 to 9.6 million in 2013, and the proportion of the population in the oldest age-group (80+) has increased from 1.5% in 1952 to 5.2% in 2013, it is difficult to draw any conclusions from absolute numbers. Therefore, data on absolute numbers of fire fatalities are not presented in this summary and the reader should refer to Paper I.

The numbers and graphs presented in this section include the years that have become available since the publication of the paper (2014-2017). The confidence intervals also account for the overdispersion in the data by the transition from Poisson regression to quasi-Poisson regression (see section 5.1).

In Table 4, the changes in age-adjusted rate of unintentional fire mortality per population group are presented and tested for statistical significance and, in Figure 5, the age-adjusted mortality rates for 1952 and 2017 are displayed, based on the regression results.

Table 4.
Changes in age-adjusted mortality rate (per million in population) from 1952 to 2017

		Incident rate ratio[b]		Incident rate[c]	
		1952 to 2017	Per year	1952	2017
Total		0.34 (0.17 to 0.51)	0.983**	22.0	7.5
Gender	Male	0.32 (0.13 to 0.51)	0.983**	30.6	9.9
	Female	0.38 (0.13 to 0.62)	0.985**	13.9	5.2
Age	0-4 yrs.	0.07 (0.00 to 0.28)	0.959**	22.1	1.6
	5-19 yrs.[a]	0.34 (0.00 to 1.15)	0.983**	4.1	1.4
	20-44 yrs.	0.23 (0.00 to 0.47)	0.977**	13.5	3.1
	45-64 yrs.	0.39 (0.08 to 0.71)	0.986**	22.1	8.7
	65-79 yrs.	0.42 (0.11 to 0.73)	0.987**	37.8	16.0
	80+ yrs.	0.37 (0.02 to 0.71)	0.985**	89.4	32.8

[a] Fatalities from the discotheque fire in 1998 has been omitted (see section 4.1)
[b] Incident rate ratio, predicted from regression (95% CI)
[c] Incident rate, predicted from regression
* $p < 0.05$, ** $p < 0.01$

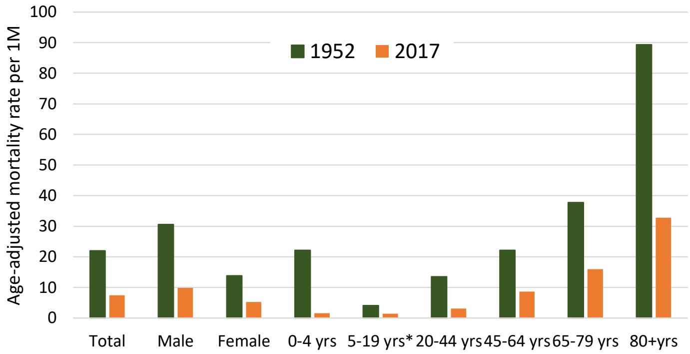

Figure 5.
Comparison of the incident rates in 1952 and 2017 based on regression for different groups. * The discotheque fire in 1998 has been omitted (see section 5.1).

The following three figures present the mortality rate for each group along with the regression line and a 95% prediction interval. In Figure 6, beside the prediction interval, also a confidence interval for the trend can be found. A prediction interval is an interval that contains 95% of the observations while the confidence interval illustrate the level of uncertainty in the trend. Note that the confidence intervals in the figures are based on quasi-Poisson regression and not standard Poisson, as in the paper, which makes them wider (see section 5.1 for a detailed discussion).

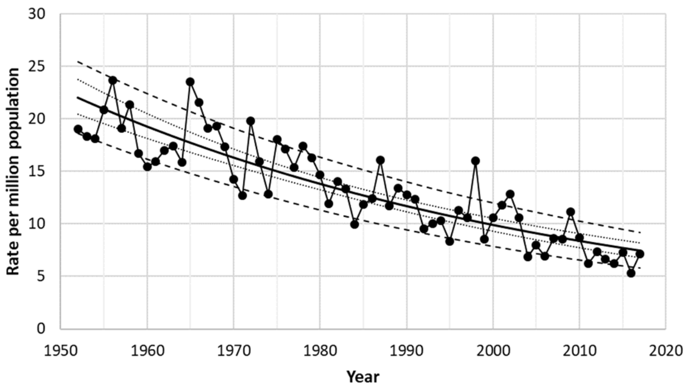

Figure 6.
Age-adjusted unintentional fire mortality rate for the entire population 1952-2017 with 95% prediction interval (dashed line) and 95% confidence interval for the trend (dotted line).

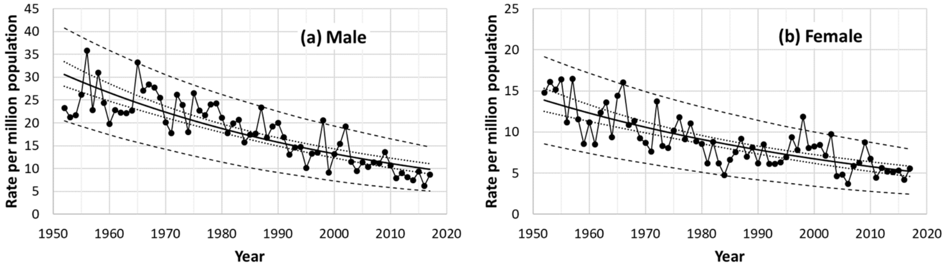

Figure 7.
Age-adjusted unintentional fire mortality rate for men and women 1952-2017 with 95% prediction interval (dashed line) and 95% confidence interval for the trend (dotted line).

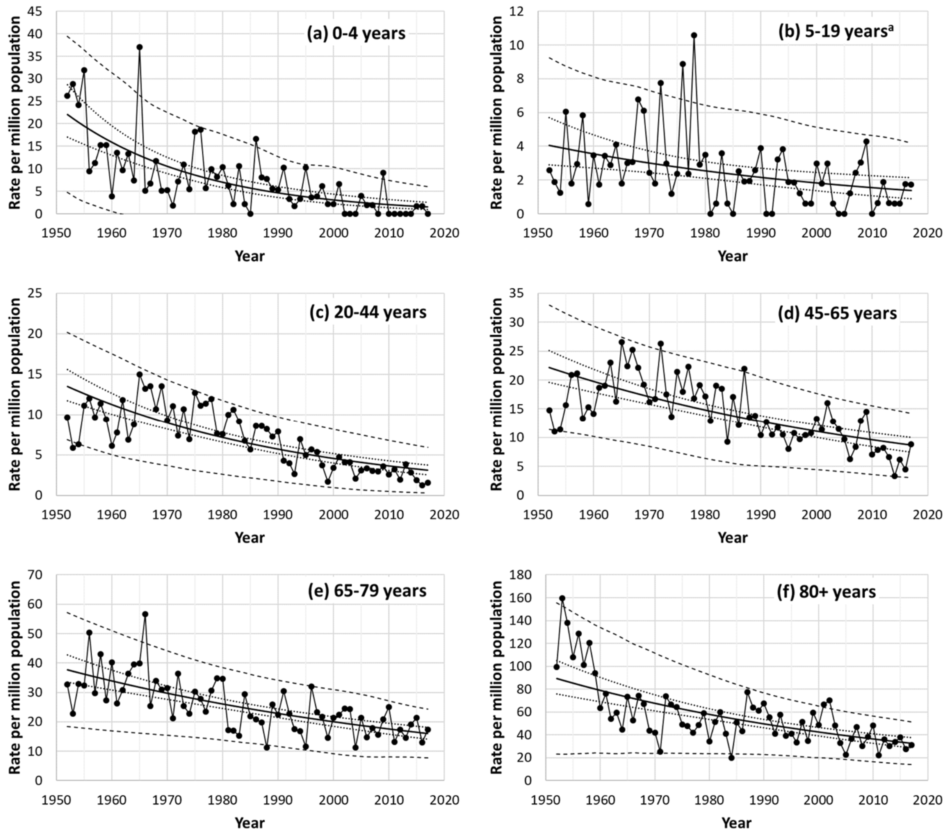

Figure 8.
Age-adjusted unintentional fire mortality rate for different age groups 1952-2017 with 95% prediction interval (dashed line) and 95% confidence interval for the trend (dotted line).
([a] fatalities from the discotheque fire in 1998 have been omitted)

One factor that was not discussed in the paper, but later motivated paper IV, is the sudden decrease in the trend during the 1980s and later, visible in Figure 8, for all groups except the oldest and maybe the youngest group. This occurred concurrently with the introduction of smoke alarms in Sweden (see more in section 4.4).

It appears from Figure 8 that the trend for some of the age groups (especially 0-4 yrs. and 80+ yrs.) might be very dependent on the choice of period included in the regression, because the mortality rate during the 1950s is much higher than in subsequent decades. This has been investigated in section 5.1 and the results indicate that they are rather robust in relation to the first year in regression for those groups too.

The decrease during the late 1950s for the two groups described in the previous paragraph (0-4 yrs. and 80+ yrs.) is not expected to be due to changes in coding practices but to an actual decrease (Paper I). For the youngest group, this might be due to changes in childcare practices, since it used to be common for younger children to be left alone or with older siblings at the beginning of this period [82]. No explanation has been identified for the reduction in the oldest group.

Beside the general mortality trend, it is interesting to note that burns as the primary injury diagnosis has decreased more than carbon monoxide injuries (age-adjusted), Comparing 2013 with 1972[4], the decrease for burns is 69% (95% CI; 62-76%) while the decrease for carbon monoxide is 46% (95% CI; 31-57%). No definitive reason for this has been found, but one likely factor is the increased quality of burns care; victims of carbon monoxide often die at the scene, but it is more common for burns victims to survive for some time and thus benefit from improvements in healthcare. There are also other potential factors more closely related to fire science. One is that even if the introduction of synthetic polymers in homes started about 20 years prior to the studied period [83], the prevalence of natural fibres is likely to have decreased over the studied period. Fire growth rate in furniture with synthetic padding is much faster than for natural stuffing [84], giving the victim less time to evacuate or extinguish the fire. This could therefore potentially reduce the decline in cases related to carbon monoxide poisoning.

Synthetic fibres have probably also become more common in clothes, which are one of the primary objects of ignition for burn-related fatalities [12]. Research has shown that clothes made of synthetic fibres are less likely to ignite since they tend to melt away from the heat source [54], unless they are mixed with natural fires that prevent

[4] The first year in which primary injury diagnosis was available.

retraction [53]. Also, if the clothing does ignite, the injuries sustained by the victim are generally less severe [55]. This might also partly explain why burn-related injuries have decreased more than carbon monoxide injuries.

4.2 Paper II – Effective measures for the entire population

The second paper included is based on an analysis of 144 cases of fatal residential fires, with a total of 160 fatalities. The analysed data were fire investigations from the fire service and/or police and other data, such as autopsy reports and pictures where available.

The overarching question in the paper was "*What could have prevented the fatality?*". This was answered using the rich data available in the investigation reports. To help this analysis, a simple event sequence based on event analysis [85] was used (also known as MTO analysis).

The paper's main results are presented in Figure 9. In the figure, the broken barriers to the left are ones that could have prevented the fatality in the percentage of cases presented next to the barrier. The unbroken barriers to the right are barriers that prevented successful evacuation.

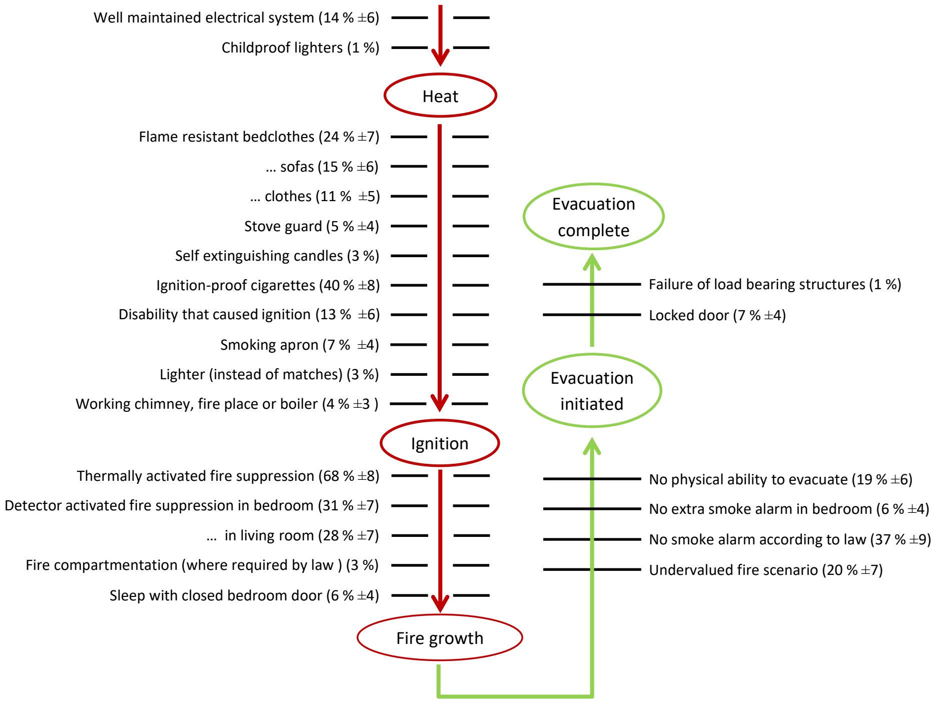

Figure 9.
Generalized event sequence for fatal fires with the potential effectiveness of each measure with 95 % confidence interval where available.

The percentages represent potential effectiveness, which is the fraction of fatal fires that could have been prevented assuming the measure is 100% reliable.

Many of the preventive measures that had previously been analysed in the literature (i.e. smoke alarms, thermally activated sprinklers and, to a lesser degree, fire-resistant furniture) showed a similar level of effectiveness in the current paper (see section 1.4), which gives the study validity.

However, there were some results that had not been previously identified in the literature. One of the more interesting ones was that approximately 20% of victims died because they underestimated the fire's development. In these scenarios, the victim did not attempt evacuation but instead tried to extinguish the fire (82% of the cases), save other residents or pets (9%) or call the fire service prior to evacuation (9%).

Previous research has shown that people have great difficulties in extrapolating fire progression [86]. Future research should also investigate whether people can improve their ability to extrapolate fires through some type of intervention, such as education (see section 8.2).

The effectiveness of smoke alarms is another thing that has caught the interest of many in the audiences at various practice-oriented conferences (e.g. *Förebyggandekonferensen 2017*) where these results have been presented. The number was generally perceived as very low, despite being in line with previous research (see section 1.4). The reason why a smoke alarm was judged not to be effective differed between the cases, although the most common reasons were that the victim was awake and close to the fire (~45%) or was bedridden and not able to evacuate (~20%). It was also common that the victim was known to have a working smoke alarm (~20%) or was behind a closed bedroom door (with a smoke alarm in the adjacent room) (~10%).

Another important conclusion was that effectiveness differed greatly between individuals. For example, elderly people with home care were found to benefit more from other measures, such as fire-resistant clothing and detector-activated suppression, compared to other groups, but less from smoke alarms and thermally activated sprinklers. This was the main motivation for Paper III, in which a bigger dataset was assessed so that effectiveness could be presented for different groups.

Most of the remainder of the paper focused on the nature of the preventive measures in relation to previous research. This is not reiterated in this chapter, so the reader should refer to the paper. The findings, however, still provide a basis for discussion in relation to the research questions (see section 6.1) and, not least, the recommendations for practice in section 8.2.

4.3 Paper III – Effectiveness of measures for different groups

In Paper III, the effectiveness of nine of the preventive measures, identified in Paper II, was analysed for a larger data set with 611 cases. This was performed using a form of extrapolation described in section 5.3.

The preventive measures that were chosen for this extrapolation were the ones that was judged as possible to capture with the variables available in the fatal fires database (see chapter 3.2.2). The measures included in the analysis were:

- Well-functioning electrical system
- Fire resistant bedding
- Fire resistant sofas
- Fire resistant clothes
- Stove guard
- Quit smoking (or safe cigarettes)
- Thermally activated suppression
- Detector activated suppression
- Smoke alarm

When the results in Paper II were translated into fraction of fire fatalities that could have been prevented (in contrast to the fraction of fatal fires) the percentage showed a very high level of agreement, see Figure 24 (p. 82). This was regarded as a successful triangulation [87], which both shows the appropriateness of the method for extrapolation and increases the credibility of the results in both studies.

Theoretical effectiveness was presented for the following groups:

- Different age groups
- Individuals above 50 years old who live alone
- House or apartment
- Smoking or non-smoking related fires

The division into age groups was based on the effectiveness within each group being as similar as possible and as different as possible from other groups. The method for finding this division is presented in section 5.3. Different numbers of age groups were tested in the analysis, but according to the discussion in the paper, four groups were seen as a useful number. The resulting division into age groups was then 0-34 years, 35-49 years, 50-84 years and 85+ years.

As a complement to the effectiveness, another measure, labelled "Benefit proxy", was included in the tables. In practice, this measure is the effectiveness multiplied by the individual risk for the group. This could be used in cost benefit analysis and is defined below, where $BP_{A,B}$ is the benefit proxy for group A and measure B. The variable R_B is the reliability and C_B the cost of the measure. The value of life is annotated with V and i is the discount rate during the lifetime of the measure, T.

The result is the benefit/cost-quota for group *A* and measure *B*, $BC_{A,B}$ which should be over unity for the measure to be motivated (given a utility-based risk perspective).

$$BC_{A,B} = \frac{BP_{A,B} \cdot R_B \cdot V}{C_B} \cdot \sum_{t=0}^{T} \frac{1}{(1+i)^t}$$

However, this measure is also of direct relevance because it replies to a different type of question than effectiveness does. While effectiveness indicates what measure a group would most benefit from, the benefit proxy indicates the groups that would benefit most from a specific measure. Therefore, they are complementary to each other.

The full range of results are not presented in this section, so the reader is referred to the paper. Table 5 below, however, presents the effectiveness and benefit-proxy for each age group. In the paper, the age group for 50-84 years was divided into men and women, but they are combined in the table below since dividing that group into two made communication more difficult. The division was performed in the paper because the group was judged to be sufficiently large for such division, but, since most results were similar, the division was not really necessary.

Table 5.
Effectiveness of different measures per age group together with the relative risk compared to the entire population. The benefit proxy (i.e. benefit per individual) is presented in parenthesis

	All	0 to 34 yrs.	35 to 49 yrs.	50 to 84 yrs.	Over 85 yrs.
Relative risk	*1 (Baseline)*	*0.28*	*0.56*	*1.86*	*4.59*
Measure					
Well-maintained electrical system	14 % (1.3)	30 % (0.7)	12 % (0.6)	10 % (1.8)	19 % (7.9)
Fire resistant bedding	20 % (1.9)	6 % (0.1)	33 % (1.7)	22 % (3.9)	15 % (6.3)
… sofas	15 % (1.3)	8 % (0.2)	9 % (0.5)	19 % (3.8)	5 % (2.1)
… clothes	11 % (1.0)	2 % (0.0)	0 % (0.0)	11 % (1.7)	30 % (12.5)
Stove guard	6 % (0.6)	4 % (0.1)	14 % (0.7)	6 % (1.1)	5 % (2.1)
Ignition-proof cigarettes/ quit smoking	39 % (3.5)	13 % (0.3)	33 % (1.7)	45 % (8.2)	37 % (15.4)
Themally activated suppression	76 % (6.9)	95 % (2.4)	94 % (4.8)	71 % (13.3)	63 % (26.3)
Detector activated suppression in bedroom and livingroom	60 % (5.4)	64 % (1.6)	56 % (2.9)	58 % (10.5)	70 % (29.2)
Smoke alarm (according to law)	43 % (3.9)	66 % (1.6)	69 % (3.5)	41 % (7.8)	13 % (5.4)

Some interesting results can be identified in the table. One is that the effectiveness of both smoke alarms and thermally activated sprinkler systems decrease with increasing age, but risk increases more rapidly for thermally activated sprinkler systems causing the benefit per installation to increase with age. For smoke alarms, however, the benefit reaches a maximum for the group aged 50 to 84 years. Well-maintained electrical systems are most important for the youngest (0-34 yrs.) and oldest (85+ yrs.) group.

An interesting pattern can be identified in relation to the different possible targets of fire resistance, where beds are most important for the group aged 35 to 49 years, sofas for the group aged 50 to 84 years and, finally, clothes for the oldest group (80+ yrs.).

Stove guards are most effective for the group aged 35 to 49 years, but the benefit per installation still increases with age. The effectiveness of ignition-proof cigarettes (or quitting smoking) are approximately equal for all groups above 35 years of age, but the benefit increases with age due to a higher risk.

One analysis that was not included in the paper was the division into smokers and non-smokers of different age groups. This is judged to be very useful, given that smoking is such a major risk factor and is also related to a specific set of scenarios, so it is very likely to have a large effect on the effectiveness of the different measures. This translation can be performed using;

i. The effectiveness of measures for smoking and non-smoking related fires from Tables 5 and 6 in the paper.

ii. The probability that, if a smoker dies due to a fire, it is caused by smoking from Table 4 in the paper (the same percentage as the effectiveness from "quit smoking").

iii. The individual risk of smokers and non-smokers calculated by the fraction of smokers in each group (from Table 4 in the paper) and given the assumption that smokers and non-smokers are equally exposed to non-smoking related fires.

The comparison is only judged to be of interest for the two oldest age groups (50-84 yrs. & 85+ yrs.) since it is only for these groups that smoking is a dominant risk factor. The results can be found in Table 6.

Table 6.
Effectiveness of different measures for smokers and non-smokers together with the relative risk compared to the entire population. The benefit proxy (i.e. benefit per individual) is presented in parentheses

	Woman 50-84 yrs.		Men 50-84 yrs.		All 85+ yrs.	
	Smoker	Non-smoker	Smoker	Non-Smoker	Smoker	Non-smoker
Relative risk	*5.4*	*0.6*	*9.4*	*1.4*	*45.2*	*2.9*
Measure						
Well-maintained electrical system	3% (1.4)	24% (1.4)	2% (2.0)	15% (2.0)	2% (7.6)	29% (7.6)
Fire resistant bedding	39% (19.2)	12% (0.7)	37% (31.5)	8% (1.0)	20% (83.8)	11% (2.9)
… sofas	18% (8.7)	9% (0.5)	34% (29.4)	14% (1.8)	7% (28.0)	4% (1.1)
… clothes	20% (9.8)	13% (0.7)	9% (7.3)	6% (0.8)	61% (250.0)	13% (3.4)
Stove guard	1% (0.4)	7% (0.4)	2% (1.6)	12% (1.6)	1% (2.1)	8% (2.1)
Ignition-proof cigarettes	88% (43.2)	0% (0.0)	85% (72.5)	0% (0.0)	94% (385.2)	0% (0.0)
Themally activated suppression	48% (23.3)	83% (4.8)	49% (41.9)	88% (11.5)	25% (101.9)	80% (21.0)
Detector activated suppression in bedroom and livingroom	78% (38.4)	52% (3.0)	82% (69.7)	40% (5.2)	65% (265.5)	72% (18.9)
Smoke alarm (according to law)	38% (18.7)	33% (1.9)	39% (32.9)	47% (6.1)	1% (4.7)	18% (4.7)

The results proved the fundamental importance of smoking when addressing the effectiveness of the different measures, at least for the age groups above 50 years. For example, smoke alarms, which were found to be effective in 14% of the cases for all people at 85 or above, were found to have a very low effectiveness for smokers (1%), while being more effective for non-smokers (18%). Also, fire resistant clothes were found to be very effective for smokers aged 85 or above (61%), while being less effective for smokers in the younger group, at 20% and 9% for woman and men respectively. For the younger group, fire resistant bedding was more effective at 39% and 37% for women and men respectively, while fire resistant sofas were primarily effective for men in the younger group, at 34%. The cause of the differences is probably differences in smoking habits, which has major implications for prevention, see section 1.2. However, it is worth noting that the benefit proxy for fire resistant bed is higher for the oldest group, so the cost/benefit-ratio would be better for that group due to the higher risk.

For non-smoking related measures, it is worth noting that a well-maintained electrical system is more important than stove guards for the oldest group, with almost four times the benefit proxy. This contrasts with the common idea that dementia is a major cause of stove-related fire deaths, which is often heard by the author.

4.4 Paper IV – Smoke alarm effectiveness

Paper IV assesses the effectiveness of smoke alarms using a novel technique. The purpose of the study was twofold: first, if the results were similar to previous results, the analysis would reinforce current knowledge because different methods were used to reach the same conclusion. If the results were different to previous results, the study would motivate further investigation of the true effectiveness. Secondly, effectiveness was calculated for different age groups, which is scarce in the literature (see section 1.4).

The method was based on a combination of currently prevented fatalities, assessed using Poisson regression of historical mortality trends (from Paper I), combined with current fatalities based on the results in Paper III.

The analysis of historical data showed similar patterns, as did the studies of current fatalities in Paper III (see section 7.1). Smoke alarms had a very significant effect for the two younger groups, 20-44 years and 45-64 years, with a reduction of 84% and 62% respectively. The reduction in the oldest included group, 65-79 years, was much lower, 18%. It should, however, be noted that the results for the oldest group are quite uncertain, see the paper for a discussion. The regression model was also used to predict the mortality rate without the introduction of smoke alarms.

The results in Figure 10 show that the reduction in the mortality rate for the younger groups during the period can largely be explained by the introduction of smoke alarms. The trend without smoke alarms shows a plausible appearance (i.e. no sudden, unexplainable, deviations from the trend prior to the intervention) which indicates that the results are reasonable.

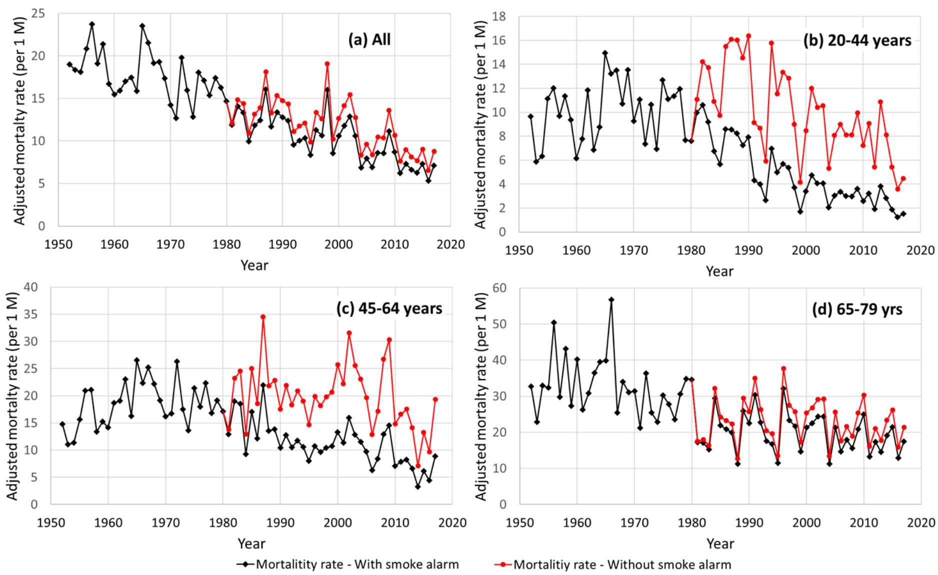

Figure 10.
Age-adjusted mortality rate for unintentional fire mortality 1952-2017 per age agroup and predicted mortality rate without the introduction of smoke alarms.

After historical effectiveness was used to assess the reduction that was due to the historical increase in smoke alarm prevalence from 0% to 95% (the prevalence in 2014), it was combined with the effectiveness among current fatalities. This was performed in order to calculate the population average effectiveness for each group, which was defined as the percentage of reduction in the mortality rate between a situation with no smoke alarms in the groups compared to all individuals in the group having a smoke alarm.

The conclusion was that the population average effectiveness was 47% for the entire population, 93% for 20-44 years, 79% for 45-64 years and, finally, 49% for 65-79 years. The 95% confidence interval is roughly ±10% for the two younger age groups and ±30% for the oldest group and ±20% for the entire population.

4.5 Paper V – Fire service rescues

The main aim of the paper was to assess the number of rescues performed in Sweden over one year (2017) and the capabilities needed by the fire service to perform those rescues. A rescue was defined as;

"At least one individual would be severely injured or killed if the fire department would have arrived 30 min later at the scene."

During the year, 51 rescues were performed (5.1 per 1M population). This is similar to the results in a study of rescues in the Netherlands [88] if only rescues from what is defined as "immediate threat to life" are included, which was 5.6 per 1M population. This is, unfortunately, the only other systematic study on the number of rescues identified in the literature.

The 51 rescues should be put in relation to the 88 fatalities in residential fires in buildings that year, which indicates that the number of fatalities could increase by 58% in the absence (or significant delay) of fire service intervention.

The capability concept that was applied has been described by the author in a previous publication [67]. This concept divides capability into "Response time", "Tasks" and "Persistence". The last dimension was judged not to be relevant since a rescue is performed very early into the intervention. The response time, however, was found to be highly significant ($p<0.01$) even after accounting for differences between fatalities and rescues. The probability of rescue was derived through logistic regression and is presented in Figure 11.

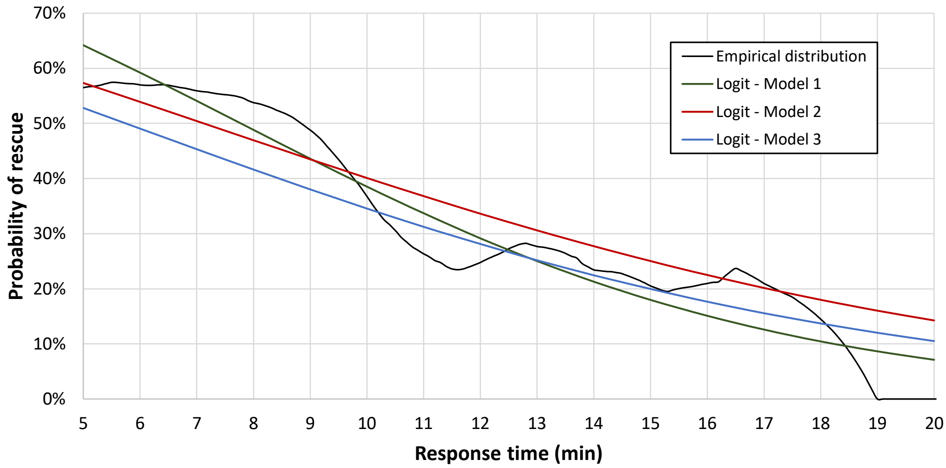

Figure 11.
Probability of rescue for different response times. Empirical distribution is based on a 5 min moving average with triangular weighting and compared to logistic regression according to the three models.

In Figure 11, Model 1 only accounts for response time, while Models 2 and 3 also account for differences in scenarios between fatalities and rescues. Model 3 accounts for more variables than Model 2 (see section 5.5). Models 2 and 3 are multidimensional and the graph only shows the results for the average values of the other independent variables. Models 2 and 3 provided an approximately equally good fit to the data (as measured with two different pseudo-R^2-measures), but Model 3 was ultimately chosen.

The probability calculated in Figure 11 is based on the current availability of tasks for the first unit(s) at scene. However, to be able to analyse the influence of changes in task availability (e.g. substitution of a full crew by a small unit), the possibility of a successful rescue given a certain set of tasks was derived from the interviews, where the interviewee was asked which task could be used to perform the rescue. The result is presented in Figure 12 in the form of a Venn diagram, where the unity of the different sets can be used to derive the total effectiveness of a specific unit depending on the task that it can perform.

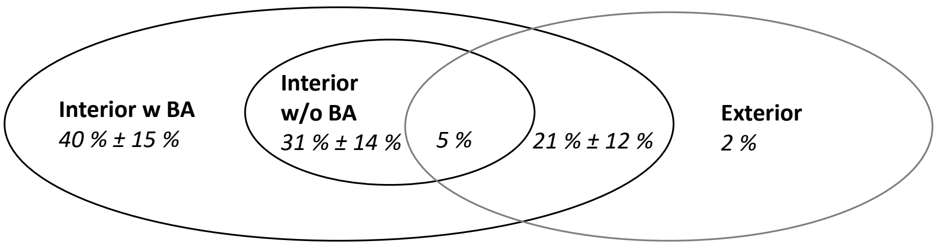

Figure 12.
Venn-diagram of tasks that could have been used by the fire service in the 42 different cases. Values fitted with 95% confidence interval where possible.

The set of available tasks already varies depending on the first unit to respond. Therefore, an ideal case with 100% effectiveness of the unit was first calculated and then the joint effectiveness (i.e. the unity of the Venn diagram of the tasks available to the unit) could be used to calculate the probability of successful rescue.

The probability of successful rescue for unit *A*, $p_{rescue,\ unitA}$, is then given a certain effectiveness for the unit(s) responding, E_{UnitA}, and response time, *t*.

$$p_{rescue,Unit\ A} = E_{Unit\ A}\frac{1.089e^{0.864-0.150t}}{1+e^{0.864-0.150t}}$$

In reality, the response time is a random variable and the probability distribution should be calculated with Monte Carlo analysis.

The results could also be integrated into a GIS environment so the capability in different geographical areas could be assessed, both under normal conditions and during larger events that might make units unavailable (or displaced).

4.6 Paper VI – Evacuation of older adults

Paper VI compares factors that increase or decrease the probability of survival of older adults (65+). Also, different modes of evacuation in the cases are classified and the factors the affect the probability of that mode of evacuation are analysed. In total, the effect of 46 different factors was assessed.

The result was presented as an odds ratio with confidence interval. The results for survival are found in Figure 13.

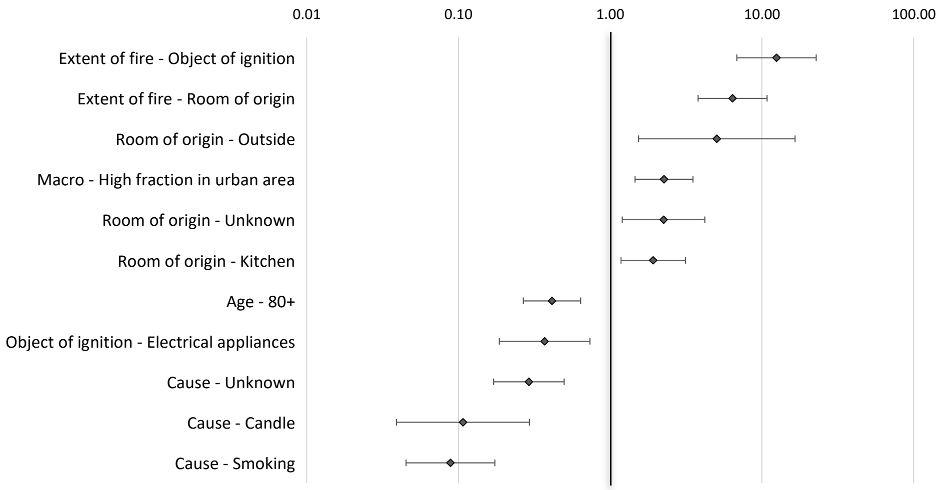

Figure 13.
Multivariate odds-ratio for factors that significantly (P<0.05) affect the probability of survival with injury compared to fatality.

Figure 13 shows that the probability of survival is greatly increased if the fire is small (i.e. confined to object of ignition (OR=12.5; 95% CI, 6.8 – 22.8) or room of origin (OR=6.4; 95% CI, 3.8 – 10.8)) or occurring in a room where the victim tends to be awake if present (e.g. kitchen (OR=1.9; 95% CI, 1.2 – 4.2) or outside (OR=5.0; 95% CI, 1.5 – 16.5)). This is in line with previous findings, which found that fires that are intimate with the victim to be more hazardous [31]. It will also probably give other actors such as neighbours and fire services an increased time frame to evacuate the individual.

Interestingly, one of the macro-level variables, high fraction living in urban areas (OR=2.3; 95% CI, 1.5 – 3.5), is a significant predictor of survival. As when the mode of evacuation is analysed, this might be a combination of proximity to neighbours and short response time for first responders.

Many well-known risk factors are found among the factors that reduce the probability of survival. These include high age (80+) (OR=0.41; 95% CI, 0.27 – 0.64) and causes of fire where the victim is often intimate with the fire (such as smoking (OR=0.089; 95% CI, 0.045 – 0.174) and candles (OR=0.11; 95% CI, 0.04 – 0.29) which often ignite clothes [89]. Electrical appliances (OR=0.37; 95% CI, 0.19 – 0.74) which has previously been found to be a major risk factor in the absence of smoking [89] can also be found.

Based on the mode of evacuation, a flow model was developed and is presented in Figure 14.

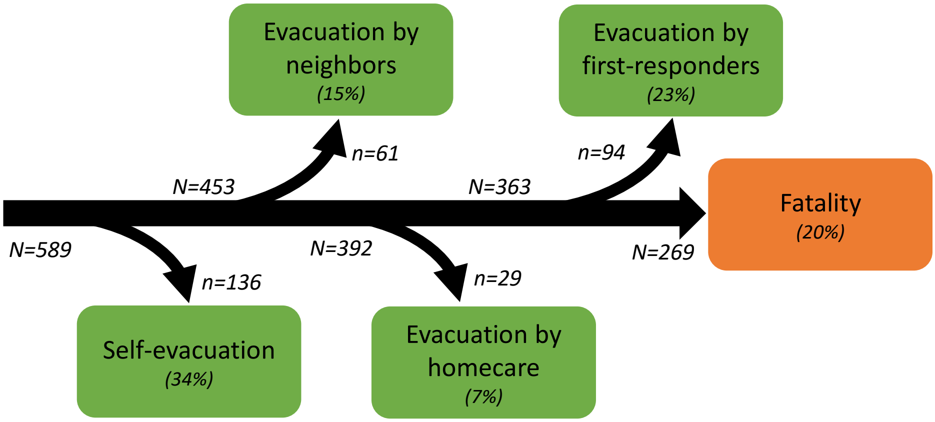

Figure 14.
Flow model for older adults (65+) injured by residential fires. Cases with unknown mode of evacuation (N=25) have been excluded

Not all the factors that contribute to each mode of evacuation are presented in the current chapter, so the reader should refer to the paper. However, a few points are worth noting.

Two macro level (i.e. municipal level) variables that relate to proximity of people, “Fraction in urban area” and “High population density”, have a significant effect on general survival and neighbour evacuation respectively. This might be because it increases the odds that a neighbour will notice the fire and be able to intervene. This effect was not significant for first responders, which might be due to the response time being explicitly included in the analysis (and significant).

High age (80+) is a factor that decreases the probability of all modes of evacuation except homecare evacuation, where it increases the probability. This indicates the importance of this actor in potentially successful evacuations. It is also worth noting that in at least 41% of these rescues, the victim pressed a safety alarm, of the type that disabled older adults often wear to notify homecare personnel.

The results also show a strong significance for response time for first-responder evacuation, which is in agreement with Paper V.

5 Reflections on the methods used

The methods used in each paper are presented in the methods chapter of the paper. This chapter presents some additional details about the methods, as well as a closer examination of the strengths and weaknesses of each method.

5.1 Methods in Paper I

In Paper I, the trends in both absolute number of fire fatalities and age-adjusted mortality rate[5] for fire fatalities were analysed for Sweden from 1952 to 2013. This was performed for the entire population and for different age groups and genders. Because the data was count data, the natural choice of method was Poisson regression.

If $F_{A,k}$ is the number of fatalities in group A during year k, the regression model is as follows:

$$log(F_{A,k}) = \beta'_0 + \beta'_1 \cdot k$$

For the age-adjusted mortality rate, the number of fire fatalities was first adjusted for the difference in age structure between 1952 and 2013. This was performed by translating the number of fatalities in each year to the population size and age distribution in 2013 with the equation below:

$$F_{A,k}^{adj} = \frac{F_{A,k}}{N_{A,k}} \cdot N_{A,2013}$$

In this equation, $N_{A,k}$ is the population in group A in year k. The age-adjusted mortality rate is thus:

[5] This is the mortality rate (fatalities per 1M population and year) corrected for changes in the distribution of the population between age groups. The standardization is necessary to correct for changes in population size and age structure when following the trend over longer periods.

$$M_{G,k}^{adj} = \frac{\sum_{\forall A \in G} F_{A,k}^{adj}}{N_{2013}}$$

The age-adjusted mortality rate is not actual count data, because it is not only integers. However, it has been shown that a Poisson regression can also be performed on rate data using the denominator as an offset [90]. Also, the nominator is not pure count data since the correction for age structure might result in non-integer numbers. However, this could be treated as count data since the unit is still number of fire fatalities. The implemented regression model is then:

$$ln\left(M_{G,k}^{adj}\right) = \beta'_0 + \beta'_1 \cdot k$$

$$ln\left(\frac{\sum_{\forall A \in G} F_{A,k}^{adj}}{N_{G,2013}}\right) = \beta'_0 + \beta'_1 \cdot k$$

$$ln\left(\sum_{\forall A \in G} F_{A,k}^{adj}\right) = ln\left(N_{G,2013}\right) + \beta'_0 + \beta'_1 \cdot k$$

In this equation, $ln(N_{G,\,2013})$ is the offset parameter for the group G which consists of several subgroups A. In the paper, the subgroups, A, were five-year groups from 0 to 100+ years per gender. The larger groups, G, were 0-4, 5-19, 20-44, 45-64, 65-79 and 80+ years, also per gender.

The sum on the left is the dependent variable and, to present the results, this was divided by $N_{G,\,2013}$ to derive a mortality rate.

Impact of overdispersion

As described in section 3.3.1, a central feature of the Poisson distribution (and therefore the Poisson regression) is that the variance is equal to the average. If this is the case, it can be assessed using the Pearson Chi-Square divided by the degrees of freedom, which is equal to one if the variance and mean are equal. The overdispersion for the different populations is presented in Table 7.

Table 7.
Overdispersion of the data sets (Pearson-χ^2 divided by degree of freedoms, df).

Population		Pearson-χ^2/df
Total		3.244
Gender	Male	3.116
	Female	1.905
Age	0-4 yrs	2.009
	5-19 yrs	15.901
	5-19 yrs[a]	2.621
	20-44 yrs	2.208
	45-64 yrs	2.312
	65-79 yrs	1.671
	80+ yrs	1.411

[a] Fatalities in the discotheque fire in 1998 have been omitted, see discussion later in chapter.

As can be seen in Table 7, the Pearson-χ^2/df substantially deviates from unity for most populations. This indicates that a Poisson regression, which was the method employed in Paper I, is not recommended. It will give correct parameter estimates, but the confidence intervals will be to narrow.

There are two main methods for dealing with overdispersed data, negative binomial and quasi-Poisson [91]. The main difference between the two methods is that the former assumes that overdispersion increases with the square of the predicted value, while quasi-Poisson assumes that overdispersion is independent of the predicted value [92]. Since the data showed no evidence that overdispersion increased with the predicted value, the quasi-Poisson method was chosen. The quasi-Poisson is identical to the normal Poisson distribution except that the variance is multiplied by the Pearson-χ^2 divided by the number of freedoms [92].

Overdispersion of count data usually originates in either the population being heterogenic in terms of the rate for different parts of the studied populations, or that the events are not independent [93]. The first is easy to predict, because the fire fatalities originate in many different scenarios (including about 10% suicide [12]). It is reasonable to believe that the different scenarios are actually different events, each of which has a Poisson distribution.

The other potential source of overdispersion, non-independent events, is also present in the data. This is because the data is on the number of fire fatalities and not the number of fatal fires. Since each fatal fire may lead to several fire fatalities, data on fire fatalities are not independent. It would be ideal if it were possible to identify historical numbers of fatal fires, but this is almost impossible for such long time series because this was not systematically collected until 1999. Even if there are archives at the various agencies that collected fire data for a long time (i.e. the Swedish Fire Protection Association), the quality of the data will be substantially lower than the data used in the study. The effect of the lower quality data in those databases is likely to quickly overpower the negative influence of slightly dependent events. It should also be noted that the vast majority of fatal fires only lead to a single fatality (see Figure 15) and the interdependence between fatalities will therefore be rather low.

The distribution of fire fatalities per fatal fire between 1999 and 2017 is presented below.

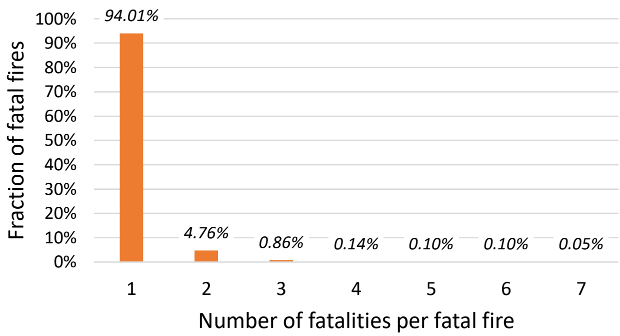

Figure 15.
Distribution of number of fire fatalities per fatal fire in Sweden between year 1999 and 2017

Prior to 2008, there was no systematic collaboration between the Swedish Civil Contingencies Agency (MSB) and the National Board of Forensic Medicine (RMV), resulting in some cases being missing from the database. This has been corrected from 1999 and onwards and the cases added at a later time (see [72]). However, the number of fire fatalities per fire is still unknown if the fire service did not respond to the fire (since the fire was therefore not included in the MSB incident report database) or became aware of the fire in another way and decided to inform MSB. However, cases since 2009 strongly indicate that fires without fire service responses are dominated by single fatality fires and, therefore, these cases are included in the single fatality fires in Figure 15. This assumption is reinforced by the fraction of single fatality fires being 94.17 % between 1999 and 2007, and 93.82 % between 2008 and 2017 after this correction.

To analyse the effect of this interdependence between events, the fit to the Poisson distribution of the number of fatal fires and number of fire fatalities between 1999 and 2017 were analysed using the one-sample Kolmogorov-Smirnov test [94]. The result was that the p-value was 0.170 for number of fire fatalities and 0.249 for the number of fatal fires. This shows that neither deviates significantly from the Poisson distribution, but that the number of fatal fires more closely resembles a Poisson distribution than does the number of fire fatalities. However, both deviate to some extent from the Poisson distribution (probably due to the reasons discussed above).

To single out the effect of the interdependence of events, a Poisson distribution with the total average mortality rate between 1999 and 2017 ($\Lambda_{fatalities}$=119.5 fatalities per year) was simulated using Monte Carlo simulation with 10,000 samples. This is the benchmark distribution, called *A*. The second distribution, *B*, is the sum of seven independent Poisson distributions of the number of fires each with a different number of fatalities. If this has a large influence on distribution, the choice of number of fire fatalities as a dependent variable, instead of number of fires, will have a major impact on the results.

$$Poi(\Lambda_{fatalities}) \qquad (A)$$

$$\sum_{i=1}^{7} i \cdot Poi\left(P_{n=i} \cdot \Lambda_{fires}\right) \qquad (B)$$

Where Λ is the expected number of events per year, $P_{n=i}$ is the probability of a fatal fire having *i* number of fatalities (see Figure 15).

The distribution plot in Figure 16 shows that it will not distort the average, but will be a source of over-dispersion, since the variance of distribution *B* is 25% higher than for distribution *A*. This would lead to an increase in the confidence interval of 12%.

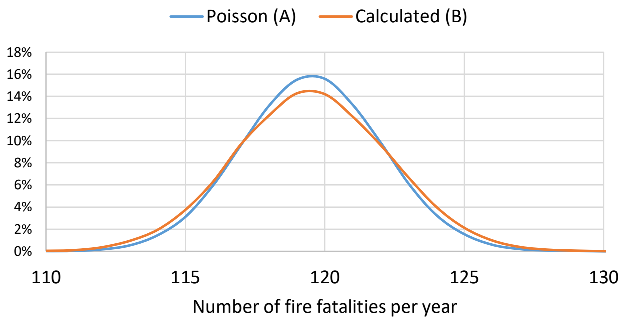

Figure 16.
Distribution of number of fire fatalities per year for perfect Poisson distribution (A) and for a sum of independent Poisson distributions of fires with different numbers of fire fatalities (B)

Therefore, this interdependence can be seen as a source of over-dispersion together with other, previously discussed, sources. The effect will therefore be accounted for by the quasi-Poisson regression.

Impact of large events

A second interesting factor regarding the method in Paper I is the potential impact of large fire disasters. During the studied period, a number of major fires occurred that could influence the presented trends. The distribution of major events can be found in chapter 1.1. Note that the figure includes fatalities in Sweden regardless of nationality of the victim, while the data in the paper includes all Swedish residents regardless of the location of the fire (see section 3.2).

Two fires stand out as very large events. The first is the fire on the *Scandinavian Star* ferry in 1990, in which 158 people died [95]. Among these individuals, however, only three were Swedish nationals, so only these people are included in the data used in this paper.

The second large event is the Gothenburg fire in 1998, which was in a discotheque and had 63 fatalities [96]. Also, the age distribution among the fatalities is such that all but one came from the age group with the lowest mortality rate (5 to 19 years). The distribution of gender and age among the fatalities is presented in the table below, based on the fatal fires database.

Table 8.
Age- and gender-distribution of the fatalities in the discotheque fire in Gothenburg in 1998

	Male	Female	Total
12 years	0	1	1
13 years	0	0	0
14 years	1	6	7
15 years	4	9	13
16 years	8	9	17
17 years	9	4	13
18 years	7	0	7
19 years	4	0	4
20 years	1	0	1
Total	33	29	63

The effect is also very apparent from the graph of the age-adjusted mortality rate for the 15-19 age group presented below.

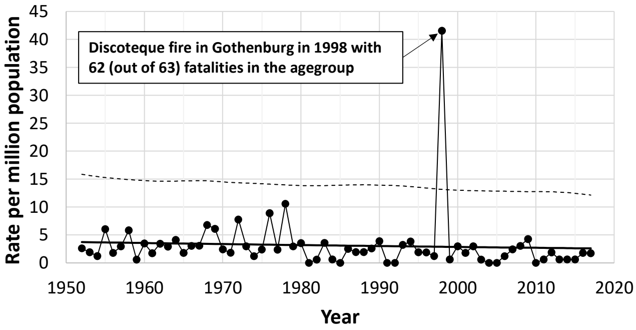

Figure 17.
Age-adjusted mortality rate for people aged 5 to 19 years. The solid line is the regression line and the dashed line show a 95% prediction interval.

For the total number of fire fatalities and for men/women, the peak is much less visible (see chapter 4.1). This indicates that the problem of fatal fires is much more related to small events with one or a few fatalities than to the major multi-fatality events that receive much more interest from newspapers, politics and research (see for example [97] for discussion of the latter).

To analyse the effect on the statistics presented in Paper I, the regression analysis was performed after omitting the individuals who died in the Gothenburg fire from the dataset. The result is presented in the table below. Note that in the regression analysis, years that have been made available since the publication of Paper I (2014-2017) have been included in the data set.

Table 9.
Age-adjusted mortality rate (per 1M) 1952-2017 based on Poisson regression, excluding the fatalities in the Gothenburg fire in 1998. Bold and parentheses show the difference in the results due to that the fire is excluded.

	Incident rate ratio		Incident rate	
	1952 to 2017	**Per year**	**1952**	**2017**
Total	0.34 (**-0.01**)	0.983 (**-0.001**)	22.0 (**+0.1**)	7.4 (**-0.1**)
Male	0.33	0.983	30.3 (**+0.1**)	9.9 (**-0.2**)
Female	0.36 (**-0.01**)	0.984 (**-0.001**)	14.0 (**+0.1**)	5.0 (**-0.2**)
0 to 4	0.07	0.959	22.0	1.6
5 to 19	0.35 (**-0.35**)	0.984 (**-0.011**)	4.0 (**+0.3**)	1.4 (**-1.2**)
20 to 44	0.24	0.978	13.2	3.2
45 to 64	0.41	0.986	21.7	8.9
65 to 79	0.42	0.987	37.8	16.0
80+	0.42	0.982	96.6	30.2

As can be seen in the table above, the exclusion had no or minor effects for most of the groups, including total and male/female, because the number of fatalities in the event is not extreme in relation to the average number of annual fire fatalities.

However, for one group, ages 5 to 19, the fire had a major effect on the results. This is not surprising, because the mortality rate for the group increased from 1.2 per million to 41.4 per million in 1998 due to the fire. With the fire excluded, the age group shows an improvement in line with the other groups.

Impact of first year in regression

Even if the Poisson regression provide a good fit to data, as can be seen in the results in section 4.1, not all groups have a very smooth, exponentially decaying, trend. For the youngest (0-4 yrs.) and oldest (80+) age groups, there appears to be a distinct kink in the trend in the late 1950s. This deviation from the behaviour in the regression model may make the results dependent on the first year included in the regression. Therefore, the first year included in the regression was increased in 10-year steps to assess the influence on the average yearly decline in mortality rate during the period.

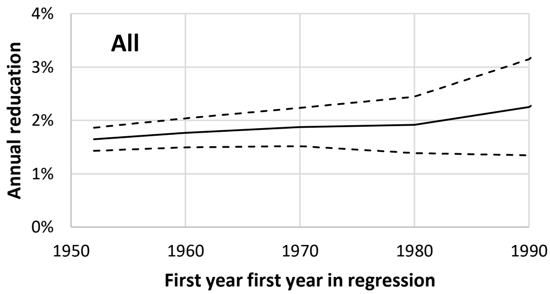

Figure 18.
Influence of the first year included in the regression on the annual reduction in mortality rate from the regression for all groups. Presented with 95 % confidence interval.

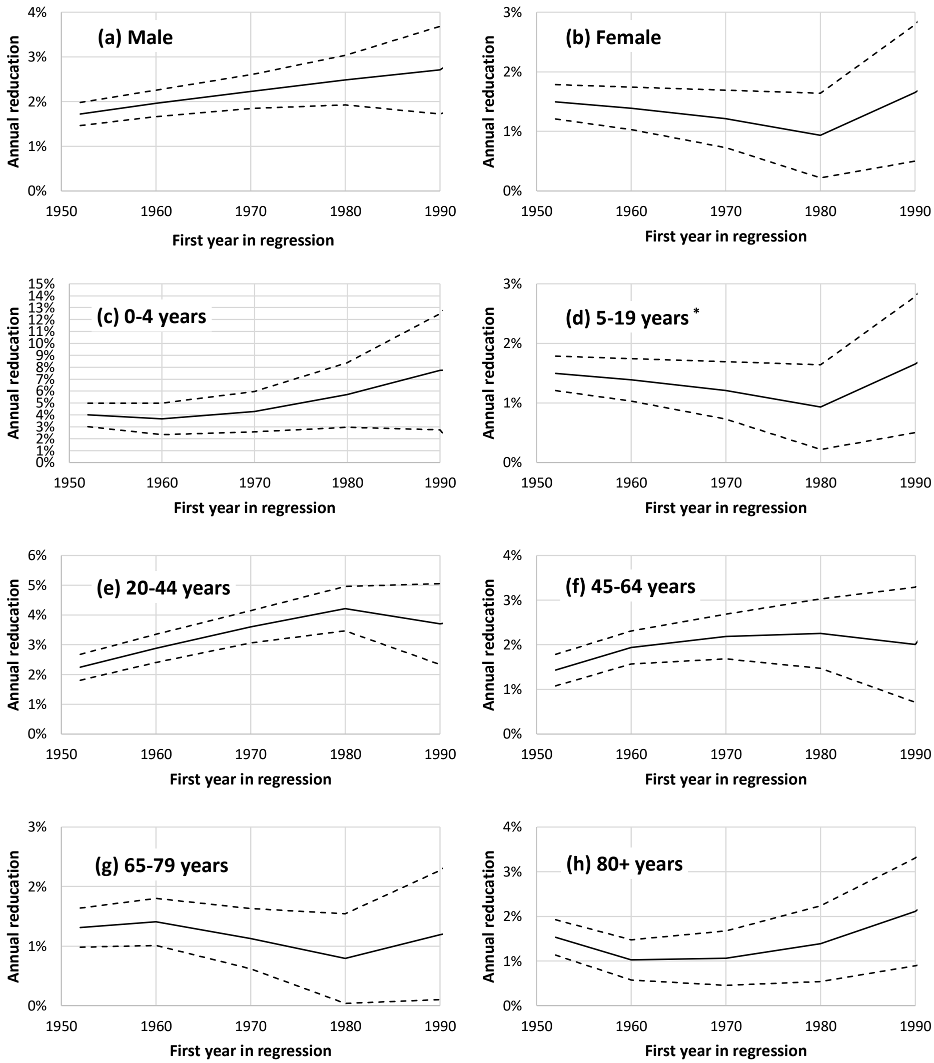

Figure 19.
Influence of the first year included in the regression on the annual reduction in mortality rate from the regression per group. Presented with 95 % confidence interval.
* excluding the Gothenburg discotheque fire

A regression that is sensitive to the first year included in the regression will show a distinct kink in the trend at a certain year. This is visible in Figure 19 for the oldest group (80+ yrs.), where the annual reduction decreases from 1.53% per year to 1.03% per year, if 1960 was the first year in the regression instead. However, this decrease is not statistically significant. The other group that was expected to be sensitive to the first year included, based on a visual examination, was the youngest group (0-4 yrs.). However, the results in Figure 19 indicate that it is not actually very sensitive, because the decrease in annual reduction was only from 4.00% to 3.67% if the first year in the regression was 1960 instead of 1952. Also, the reduction with 1970 as the first year in the regression resulted in an annual reduction of 4.29%, which is actually an increase from a regression starting in year 1952.

No other groups show a distinct kink in the trend, except during the later years which is due to having fewer data points in the regression because fewer years are included. This is visible through the widening confidence intervals.

The reason for including Figure 18 and Figure 19 was the sensitivity analysis presented in previous paragraphs, but it is also relevant as a result since a gradually increasing trend indicates that the rate of reduction is increasing with time. This is indeed what is found for some groups. Disregarding the results from the regression that starts at 1990 (due to limited data points) the following trends can be found.

Table 10.
Trend in annual mortality reduction based on visual examination.

Trend in the rate of mortality reduction		
Increasing	**Approximately constant**	**Decreasing**
All	45-64 yrs.	Women
Men		5-19 yrs.
0-4 yrs.		65-79 yrs.
20-44 yrs.		
80+ yrs.		

Conclusion on the sensitivity of the regression

A number of conclusions can be drawn from the analysis in the current section.

The first is that the data is highly overdispersed. This is partly due to the interdependence between events, because more than one individual can die in a fire. With the current distribution of the number of fatalities per fire, this leads to approximately 25% overdispersion (i.e. the variance is a factor of 1.25 larger than the mean), but this does not explain all the overdispersion. Another potential source of overdispersion is that the different scenarios and groups of victims are independently Poisson distributed events. Regardless of the source of overdispersion, this can be accounted for by using quasi-Poisson regression. This was not performed in the paper, but is performed for the results presented in section 4.1.

The second conclusion was that the Gothenburg discotheque fire in 1998, which killed 63 young adults aged from 12 to 20, was the reason for the limited reduction in mortality rate found for the age group of 5-19 yrs. If the event had occurred earlier in the time period, it would similarly have caused a large decrease in the trend. Time series is not a useful tool for investigating single large events, so the Gothenburg fire should be excluded from the analysis. This has been done for the results in section 4.1, but not in the paper. After removing this event, the improvement in the age group is on a par with the other groups.

The third, and final, conclusion from the sensitivity analysis was that the results were not very sensitive to the choice of first year for inclusion in the regression, except maybe for the oldest group (80+). The difference was not statistically significant and the rate of decrease appears to be increasing in later years, so therefore the results are not misleading.

5.2 Methods in Paper II

The most central method used in the paper is an interpretative approach, based on the full range of data available, to answer the question of whether a particular barrier could have prevented the fatality. One option could have been to use a formal method for text analysis such as content analysis [69]. This was judged not to be useful since, in the author's experience, investigation reports usually focus on the cause of the fire and less on fire spread and the victim. How the fatalities could have been prevented is usually only covered in a few sentences (if at all) and, usually, only a limited set of interventions are assessed. There are also frequent misconceptions about the effectiveness of different fabrics in preventing ignition, for example. There is also very valuable information in the photographs from the investigation reports that would have been missed when using a more formal method.

Because of this, a less structured method was chosen and which covered the full range of data available for the specific case (e.g. investigation report, autopsy report, etc.). The guiding question was: "would this fatality have occurred if [measure] had been in place and working?". It can be argued that the judgement is subjective, but in many cases it was very clear from the description of the scenario that there was little room for judgement. However, to assess the influence of subjective judgement, an inter-coder reliability test was performed by a co-worker who independently codes of a sample of five cases (3.5% of the total number of cases) based on a list of identified potential barriers. This entails 115 point-wise comparisons (5 cases times 23 barriers). The level of agreement was assessed using a multi-item within-group inter-coder reliability test, rWG_j [98], [99]. According to the method, the level of agreement on a single item can be calculated using the equation below.

$$r_{WG} = 1 - \frac{S_X^2}{\sigma_E^2}$$

The nominator, S_X^2, is the variance of the responses to item X between the raters. The denominator, σ_E^2, is the variance for the benchmark distribution that represents a situation with no agreement. The scale on which each barrier and each case was rated was a three-level Likert-type scale (not effective, unknown and effective). It was determined that a situation with no agreement was represented by a case where one rater judged a barrier to be "not effective" while the other one judged it to be "effective" and vice versa. This yields a bimodal distribution in the denominator.

To combine the agreement on the 115 items the Spearman-Brown prediction formula [100] was applied to the single item measure as suggested by [98]. This results in the following expression for the multi-item agreement.

$$r_{WG(J)} = \frac{J\left[1 - \frac{\overline{S_{XJ}^2}}{\sigma_E^2}\right]}{J\left[1 - \frac{\overline{S_{XJ}^2}}{\sigma_E^2}\right] + \frac{\overline{S_{XJ}^2}}{\sigma_E^2}}$$

In the equation, J is the number of items rated and $\overline{S_{XJ}^2}$ is the average variance of the different items.

The level of inter-rater agreement was found to be 0.84, which is considered strong agreement [101]. One researcher judged a barrier to be effective while the other judged it to be not effective in only 3% of 115 point-wise comparisons.

One commonly applied method that could potentially have been an option is the Cronbach alpha [102]. This method, however, only assesses the level of correlation between responses from judges and not the absolute agreement. Therefore, it would fail to discriminate between a case of agreement and a case of one judge constantly being a certain number of points above the other. Based on this, the interrater agreement measure presented above was judged to be more relevant.

One aspect of the paper that is not necessarily independent of the coder is the identification of potential preventive measures (called barriers in the paper). The paper identifies 23 different measures/barriers and it is possible that a different coder would have found additional measures. However, this was not regarded as a major limitation; it will not influence the presented effectiveness of the identified cases, but only influence the number of measures assessed. The evaluated measures also change over time due to innovations. The potential option of a systematic review of products was not pursued.

However, one quality measure for the identification of measures was performed in the form of an analysis of inductive saturation [103]. This was done with the diagram in Figure 20. It was found that saturation was achieved and it was therefore unlikely that many more measures would have been identified if more cases were analysed.

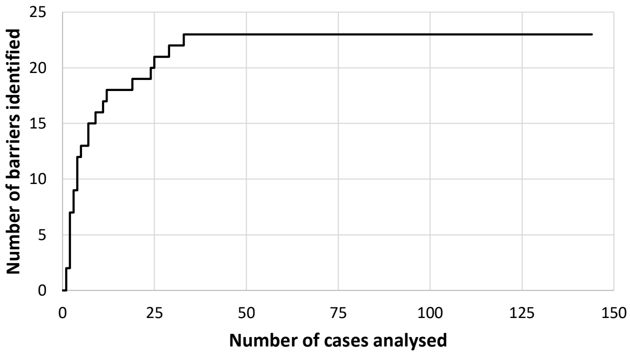

Figure 20.
Number of barriers identified after a certain number of cases are analysed

Few sophisticated statistical methods were employed in the paper. Percentages for the effectiveness of the different measures were calculated. For cases where the binomial distribution could be approximated with a normal distribution, these percentages were accompanied by a 95% confidence interval.

The criteria for where this approximation is appropriate differs between sources, but the criteria in Fleming and Nellis [78, p. 130] where both the number of events ($n\hat{p}$) and non-events ($n(1-\hat{p})$) need to be above 5 is employed in the paper. Barriers that did not satisfy this condition were presented without any confidence interval in the paper.

The 95% confidence interval, where appropriate, was calculated using the equation below for population proportion [78, p. 237].

$$P = \hat{p} \pm 1.96\sqrt{\frac{\hat{p}(1-\hat{p})}{n}}$$

The paper includes one more elaborate statistical method, which is to assess the influence of different background variables on missing values. Missing values, in relation to Paper II, occur when a fire is not investigated by either the fire service or the police. During the period studied, this was the case for 45% of the fatal fires.

The reasons for decisions not to investigate fire were assessed by contacting the fire service for a random sample of five cases where an investigation was not performed. The respondent referred to a number of different reasons, including a lack of employees with the necessary expertise, difficulties in investigating suicide cases and a lack of resources.

The statistical method chosen to investigate the effect of background variables on missing values was ANOVA. After publication, however, it was found that, even if ANOVA is insensitive to departures from normality [104] as stated in the paper, it might become underpowered for large deviations, which is obviously the case since the dependent variable is binary. There are few investigations of the use of binary variables in ANOVA and these indicate that it might still give good results, at least under some conditions [105].

However, a better method would have been to use logistic regression, which has been developed for binary dependent variables and quantitative, nominal and ordinal independent variables [81, p. 437]. Therefore, the missing value analysis is redone in Table 11 below and compared to the result in the paper.

Table 11.
Effect of background variables on the likelihood that a fatal fire is investigated with comparison between results for Paper I (using ANOVA) and using logistic regression.

		P-value	
Variable group	Background variable	… with ANOVA	… with Logistic regression
Fire related	Cause of fire	**0.021***	0.074
	Extent of fire	0.078	0.423
	Room of orgin	0.535	0.312
	Object of origin	0.415	0.333
Geographical	County	0.059	0.348
	Type of municipality (e.g. urban)	0.710	0.758
Temporal	Month	0.881	0.585
	Day of week	0.672	0.752

As can be seen in Table 11, the new missing data analysis did not generally result in higher-level significance, but could give both higher and lower P-values. The discussion in Paper II was that the one variable that turned out to be significant with the method used ("Cause of fire") did not have a large effect on the result in the paper. In the new analysis, this variable also turned out to be non-significant. Therefore, the use of logistic regression instead of ANOVA for the missing value analysis in Paper II would not have influenced the results.

5.3 Methods in Paper III

In Paper III, the findings for the 144 cases in Paper II was extrapolated to the 611 cases in the statistical fatal fires database, using a form of classification algorithm. Initially, one of the many formal statistical classification schemes based on cluster analysis was performed. However, it was found that those methods performed quite poorly and led to obvious misclassifications (e.g. stove guards as efficient for some smoking-related fires). Therefore, a novel methodology was developed and is presented in Figure 21.

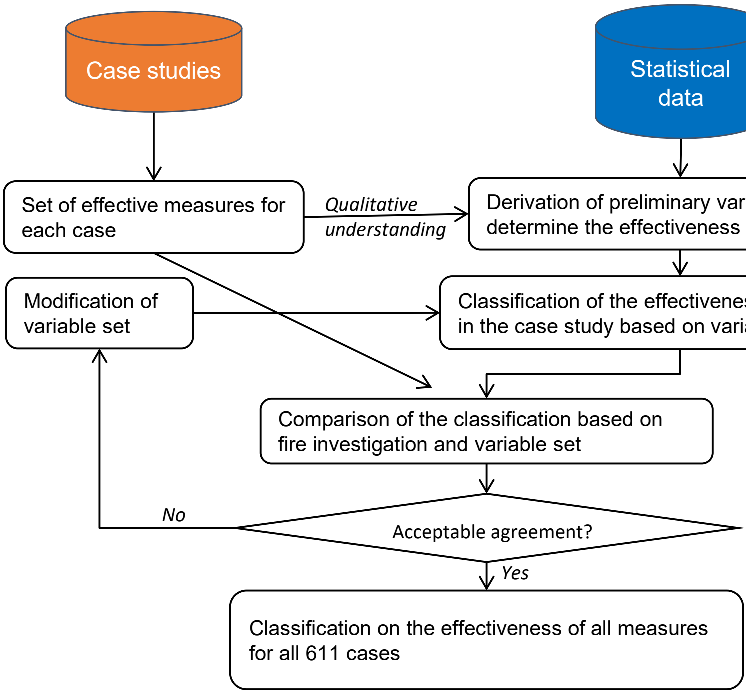

Figure 21.
Methodology for extrapolation from 144 case studies of fatal fires to 611 cases in the statistical database.

In the methodology, the results from the analysis of fire investigation reports in Paper II are used in two ways. First, a general qualitative understanding of the effectiveness indicators was used to develop a series of Boolean statements based on the variables available in the statistical database. These statements were then used to classify the same set of 144 cases. The result of that classification was then compared to the classification from the analysis of the fire investigation reports. A high level of agreement between the two was seen as a quality measurement for the set of statements, and the misclassified cases were examined more closely to investigate the reason for the misclassification and whether added or modified Boolean statements could lead to the correct classification. This was iterated until a sufficiently high level of agreement was found. The set of Boolean statements was then used to classify all 611 cases in the statistical database.

The method has some similarities with Artificial Neural Networks (ANN) where a network that predicts the dependent variables from the independent variables are first initialized and then improved using a learning set by updating variable weights. When the developed network is good enough, it is used to classify similar cases outside the learning set. This method could have been used as an alternative to the one employed in the paper and will be attempted in an ongoing research project funded by Brandforsk with a focus on older adults.

Using the method in the paper, Table 12 shows the fraction of correctly classified cases. The Boolean statements for most measures performed quite well even in the first iteration, while the statement for smoke alarms needed improvement. The final set performed quite well, with over 90% correct classifications for all measures except thermally activated suppression, which was slightly below.

Table 12.
Fraction of correctly classified cases in the first and last iterations of the method in Figure 21

Measure	Fraction of correct classified cases in the learning set in…	
	… first iteration	… last iteration
Well maintained electrical system	93%	94%
Fire resistant beds	95%	96%
… sofas	95%	98%
… clothes	89%	90%
Stove guard	98%	98%
Ignition-proof cigarettes	99%	99%
Themally activated suppression	84%	88%
Detector activated suppression in bedroom and livingroom	93%	95%
Smoke alarm (according to law)	75%	91%

After the set of statements was applied to the entire statistical dataset, including all non-intentional fatal fires in residential occupancies (611 cases), a bigger dataset was available and could be divided into different subgroups.

One of the divisions that was judged to be useful was the division based on age, because that is an important precursor for the types of scenarios faced by individuals [12]. One possibility would have been to use one of the commonly used divisions in the literature, which are often based on different stages in life (e.g. becoming adult, retiring, etc.) similar to what was done in Papers I and IV. However, it was judged to more useful to let the data dictate the division. The division into groups was made so that the differences between groups was as large as possible. Difference was measured as the mean Euclidean distance between all groups in the nine-dimensional space defined by the included measures. In this way, placing an individual into one of those groups would give as much information as possible about the effectiveness of the different measures.

The method for finding the optimum division was a brute force approach, where all possible divisions into age groups was performed and compared. A restraint on them containing no fewer than 10% of the cases (i.e. 61 cases) was also included, so that meaningful statistics could be calculated for each cluster. The number of age groups varied between three and seven. Also, to assess the stability of the clusters, a half-sample resampling (also known as Jackknife) was performed 100 times and a confidence interval was calculated. Jackknife is performed by deleting a number of cases (in this case half the observations) and redoing the cluster analysis. Jackknife was used since it has been found to be superior to Bootstrap when comparing the results of cluster analysis [106]. The results can be found in Table 13.

Table 13.
Division into age groups that best explain the effectiveness of different measures, 95% confidence interval of 50% of sample resampled 100 times: **<5 years, *<10 years and ^{0}>10 years

#	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	Group 7
3	0 - 31^0	32^0 - 84^0	85^0+				
__4__	__0 - 31*__	__32* - 48^0__	__49^0 - 84*__	__85*+__			
5	0 - 31*	32* - 48*	49* - 78^0	79^0 - 85*	86*+		
6	0 - 31*	32* - 49*	50* - 59*	60* - 78^0	79^0 - 85**	86**+	
7	0 - 31*	32* - 48*	49* - 63*	64* - 67*	68* - 78*	79* - 85**	86**+

As can be seen in the table, the division is quite stable, as the number of clusters increases when the different age groups are further divided as the number of clusters increases. For practical reasons, the number of clusters should not be too large and the number of years in each group should not be too small. The last reason is both so that the number of cases is adequate in each group, but also because, from a theoretical standpoint, it is not plausible that only a few years' increase would drastically alter the effectiveness of the measures.

Based on those reasons, four clusters were chosen. As can be seen, the dividing age between group 2 and 3 is quite sensitive to the resampling. However, the dividing age recurs for all numbers of groups (except three groups) and, for those divisions, the age is more robust. This indicate that this age indeed indicates a difference in the set of effective measures. Since group 3 had a large number of cases (396 cases), it was further divided into men and women.

5.4 Methods in Paper IV

Both the major statistical method (quasi-Poisson regression) and most of the data is identical to Paper I, so the reader is referred to the section on that paper (section 5.1) for a discussion of those topics. One additional statistical method was used to combine historical effectiveness, based on the quasi-Poisson regression, and the current effectiveness derived in Paper III, and that was the Monte Carlo-simulation which is described later in this section.

The quasi-Poisson regression was performed with one additional independent variable compared to Paper I, and that is smoke alarm prevalence over time. Unfortunately, data on smoke alarm prevalence was not available per age group until 1996, which was detrimental to the analysis and therefore required substantial sensitivity analysis of the results. This was performed by translating the measurements prior to that date five years forward in time, which represents both a later adoption and/or a lower prevalence in the group than for the grand mean. For the two youngest age groups (20-44 yrs. and 45-64 yrs.) the result was very robust with regard to this test, leading to less than 2% difference in the estimate (from 84.5% to 86.2% and from 74.4% to 72.3% respectively). However, for the oldest group, 65-79 yrs., the sensitivity was substantially larger, leading to a decrease in effectiveness from 47.3% to 27.4%. This decrease reflects the less apparent decrease in the visual trend and therefore the wider confidence interval and less significant result. The result for this age group should therefore be interpreted with some caution, but it is apparent that it is substantially lower than for the two other age groups in the analysis.

The regression was performed according to the model below, which is identical to that of Paper I apart from the inclusion of one additional independent variable, which is the smoke alarm prevalence over time, X(t).

$$ln\left(\sum_{\forall A \in G} F_{A,t}^{adj}\right) = ln(N_{2013}) + \beta_0 + \beta_1 \cdot t + \beta_2 \cdot X(t)$$

$$M_t^{adj}(t, X(t)) = \frac{\sum_{\forall A \in G} F_{A,t}^{adj}}{N_{2013}} = e^{\beta_0 + \beta_1 \cdot t + \beta_2 \cdot X(t)}$$

The expected age-adjusted mortality rate for year *t* without smoke alarms (i.e. *X(t)*=0) is accordingly:

$$M_t^{adj}(t, 0) = e^{\beta_0 + \beta_1 \cdot t + \beta_2 \cdot 0} = e^{\beta_0} e^{\beta_1 \cdot t}$$

The effectiveness (i.e. the fraction in decrease in mortality due to smoke alarms) is therefore given by the equation below. The calculation is performed for 2014, since this was a year that had a survey of smoke alarm presence that is in the range of the assessment of fire fatalities used later in the derivation.

$$\frac{M_t^{adj}(t, X(2014))}{M_t^{adj}(t, 0)} = \frac{e^{\beta_0} e^{\beta_1 \cdot t} e^{\beta_2 \cdot X(2013)}}{e^{\beta_0} e^{\beta_1 \cdot t}} = e^{\beta_2 \cdot X(2014)}$$

After the reduction in mortality rate due to the historical increase in smoke alarm prevalence from 0% to *X(2014)* the potential increase from *X(2014)* to 100% was assessed. This was based on the results in Paper III that assess the fraction of current cases that could have been prevented if everyone has a smoke alarm installed. This fraction is included as a variable called, E_{fatal}. The mortality rate if everyone has a smoke alarm installed (i.e. $M_t^{adj}(t, 100)$) can then be calculated by multiplying the current mortality rate by one minus the fraction that could have been prevented, as shown below:

$$M_t^{adj}(t, 100) = \left(1 - E_{fatal}\right) \cdot M_t^{adj}(t, X(2014))$$

Combining this equation with the equation for mortality rate for the case without any smoke alarms yields the following equation:

$$M_t^{adj}(t, 100) = \left(1 - E_{fatal}\right) \cdot e^{\beta_2 \cdot X(2014)} \cdot M_t^{adj}(t, 0)$$

$$\frac{M_t^{adj}(t, 100)}{M_t^{adj}(t, 0)} = \left(1 - E_{fatal}\right) \cdot e^{\beta_2 \cdot X(2014)}$$

Given this quota of mortality with 100% smoke alarms and no smoke alarms, the fraction of decrease between these extremes, E_{total}, can be calculated according to the below equation:

$$E_{total} = 1 - \frac{M_t^{adj}(t, 100)}{M_t^{adj}(t, 0)} =$$

$$E_{total} = 1 - \left(1 - E_{fatal}\right) \cdot e^{\beta_2 \cdot X(2014)}$$

In this equation, all the variables are random variables, so to derive the distribution of E_{total}, the Monte Carlo-simulation was therefore applied. This is performed by drawing a random number from the distribution of each of the random variables and calculating the dependent variable. In this case, all independent variables was assumed to be normally distributed. This procedure was iterated 100,000 times to derive a reliable empirical distribution of E_{total}. The 95% confidence interval was calculated from the 2.5%- and 97.5%-percentile of the empirical distribution.

5.5 Methods in Paper V

Paper V investigated the frequency of fire service rescues and the capability needed to successfully perform each rescue. A rescue was defined as;

> *At least one individual would be severely injured or killed if the fire department would have arrived 30 min later at scene.*

The timeframe of 30 minutes was added after a pilot study, where the reference case was instead "[…] *if the fire department had not arrived.*". The reason was that some informants had difficulties relating to a hypothetical case without any response, because they reasoned that they would always arrive eventually. The choice of 30 minutes as a timeframe was to provide a sufficiently long time for the fire to develop substantially. However, the timeframe must also be short enough not to approach 60 minutes, which is the fire resistance requirement between residential units in Sweden. Some people in the fire services confuse this with actual time rather than a standardized thermal load.

To generate data for the analysis, interviews were conducted with the commander who was first on the scene. The aim of the interviews was to answer the following two questions for each case:

1. Was it an actual rescue, as defined in the paper?
2. What tasks could have been used to perform the rescue?

The interview was performed as a semi-structured interview and the interview guide is available in appendix B. The questions was designed to follow the "funnel model" developed by [107]. According to this model, the interview should start with general information about the individual performing the interview and the purpose of the interview. The next step is a free narrative by the respondent which, in this case, was initiated by the question "Can you tell me a bit about the event?". After that, a number of more precise questions were asked to get all the data needed for the analysis, and clarifications were requested. The interview was finalized by informing the respondent about the conclusions regarding the two overarching questions behind the interview described above and a thank for their time.

The interviews were typically about 30-45 min long and performed over the phone or, in one case, in person, within a week or two of the event. All the interviews (except one) were recorded, but were not transcribed. Additional data in the form of pictures and/or film was asked for during the interview and, in most cases, was provided after the interview.

An alternative to using semi-structured interviews could have been structured interviews, in which all the questions would be exactly formulated before the interview [108]. The reason the semi-structured form was chosen, was to allow the possibility of formulating more open questions with a lower risk of influencing the reply [108]. For example, a great deal of each interview concentrated on the first question, where the interviewees had the opportunity to freely describe the event. In many cases, it was very clear from this description whether the victim was really in danger or not. If the questions had been more specific, for example "was the victim at risk when you evacuated him/her", the question could induce bias into the reply. A fully unstructured interview, where the respondent essentially choose the discussion within a broad theme [108], was also regarded as having limited value because it might not answer all the underlying questions that were needed for the analysis (e.g. the set of tasks that could have been used to perform the rescue).

An alternative method would have been to use a questionnaire and send it to the fire services. This could have been very positive for the study's time consumption, because trying to contact people who work shifts was very time consuming and, on a number of occasions, the interview had to be interrupted because the respondent had to respond to a call-out. There are, however, main two limitations that were judged to be very detrimental to the analysis. One was that questionnaires often have a very limited response rate [109] and this would entail a number of unknowns in the data set. Since the number of observations in the data were already quite low, missing data was seen as a major threat to the validity of the results because only a few cases could have a major influence on the results. The second important limitation was that it would remove the section in which the respondent had to prove that it was actually a rescue. The commander can be expected to have had an underlying wish that it would have been a rescue and might therefore be biased to label it as a rescue [110]. This bias is, of course, also present during the interviews, but since actual arguments and proof of the rescue needed to be presented, its influence was expected to be more limited.

After the interviews were performed to determine whether the case should be included in the analysis (i.e. is a rescue according to the definition in the paper) and the set of available tasks to perform the rescue had been defined, the results were coded into a statistical database. The statistical database was then combined with data on fatalities. Univariate odds ratios were calculated to investigate similarities and differences between fatalities and rescues; the results were presented in a diagram that is figure 3 in the paper, which only presents variables with a significant effect of the odds. When performing significance tests on a number of variables a significance level of 95% is normally used, so even for random data one variable in twenty can be expected to generate significant results. To counter this effect, a correction of the significance level, called Bonferroni correction [111], is often employed where the alfa-value (which is 0.05 for 95% confidence) is divided by the number of tests. However, since the number of individual tests was rather high (33 variables for scenarios and 14 for victims) the alfa-value would be very low and therefore the statistical power of the test very low. This would result in (artificially) very few variables giving significant effect on the probability of rescue. This is also known as a type II-error.

To prevent this effect, a different method to account for multiple comparisons was sought and a method developed by Benjamin and Hochberg [112] was chosen as being suitable. In this method, a False Discovery Rate (FDR) is defined as an alternative to an alfa-value were the FDR is the fraction of discoveries that are false. The method is very popular; the paper introducing the method, cited above, was identified as one of the 25 most-cited statistical papers in 2005 [113].

The method dictates that the P-values of the different comparisons should first be ordered from lowest to highest and given a rank, i. For a variable to be classified as having a significant effect, the P-value should be below (i/m)*FDR where m is the total number of tests.

The main difference from the Bonferroni correction is that it accounts for the number of discoveries. An alfa-value of 0.05 gives a 5% probability of rejecting the null hypothesis when it is actually true, regardless of the results for the other tests. The method developed by Benjamin and Hochberg judges that the number of discoveries is important. The rationale behind this is that if we have, say, 5 discoveries out of which 3 are false discoveries, this is a very bad result, while if we have 50 discoveries and 3 are false discoveries, the results are more reasonable.

The choice of false discovery rate (FDR) is just as important as the choice of alpha value for traditional hypothesis testing. The suggested level is 10% or 20% [114] and both those levels were tested for their influence on the results, but the more restrictive level of 10% was finally chosen for the diagram. However, both levels were used for the regression presented below, in which the variables that satisfy the more restrictive requirement are included in model 2 and the less restrictive in model 3.

After the similarities and differences between fatal fires and rescues were assessed, the results were used to derive an equation for the probability of rescue using logistic regression. The three different models used were “model 1”, which only accounted for response time, “model 2” which also included the variables with FDR<0.10 (k=7), and “model 3” which had all variables with FDR<0.20 (k=9). The significance of the influence of the different independent variables was assessed using bootstrap methodology [115] with 30,000 samples. The results of this analysis were also used to derive a confidence interval for the dependent variable. Bootstrap was used instead of the Jackknife technique used in Paper III, despite them addressing the same questions, because Bootstrap has been found to be superior for assessing confidence intervals for methods based on Expectation Maximization (EM) [116] such as logistic regression (see section 3.3.2).

The results showed that for all three models, the response time was highly significant ($P<0.01$). However, the effect of response time was reduced from $\beta_1=-0.210$ to -0.139 and -0.150 for models 2 and 3 respectively. The fit of the model to the data was measured using two pseudo-R^2 measures. The two measures were Cox-and-Snell-R^2 and Nagelkerke-R^2, which both increased by approximately a factor of 4 from model 1 to the other models, while being similar for models 2 and 3. This indicates that either model 2 or model 3 could be used to describe the data. In the paper, it was decided to use model 3.

The bootstrap methodology was also employed to derive a confidence interval for the probability of rescue. The probability distribution of this measure showed a clear bimodal pattern, which resulted in the upper bound for the confidence interval being very large for a 95% confidence interval. A reduction in the confidence interval to 80% led to one of the modes of the distributions being excluded from the confidence interval and therefore a much narrower span was achieved. Even if the confidence level of 95% is extremely common in science, there is no fundamental reason for this choice [117]. However, it would be desirable to be able to present a standard 95% interval. This might be achieved with a larger data set, but since the distribution is based on a sum of normal distributions, where bimodal distributions are not uncommon, this behaviour might remain even if more data is gathered.

5.6 Methods in Paper VI

Similarly to Paper V, odds ratios (OR) with confidence bounds were also calculated in Paper VI. However, while the odds ratios in Paper V were univariate, the odds ratios in Paper VI were the multivariate odds ratio.

Consequently, that the odds ratios in Paper VI account for the correlation between independent variables, while this was ignored in Paper V. The reason for this difference was that the small sample of cases in Paper V was not enough to perform multivariate tests, because the number of variables (33 for scenarios and 14 for victims) was approximately the same number as the number of cases (42 rescues with 51 individuals). Generally, unless a deeper analysis and control of confounders is performed, ten events (and non-events) per variable is often recommended [118]. In Paper VI, the number of events (i.e. non-fatally injured) was 345 and the number of non-events (i.e. fatalities) was 269. This indicates that the number of variables should not be much over 27.

The number of variables that was judged to be relevant (and available in the incident reports or municipal databases) were in total 46, so a stepwise approach was chosen. First, all the variables were coded into dummy variables (i.e. having only the value 1 and 0) and the variables were classified into "fire related", "location and temporal" and "macro-level". The variables included at each level are presented in the appendix to the paper. The following procedure was followed:

1. All fire-related (dummy) variable-value-pairs were included except a reference category (to avoid collinearity).
2. Logistic regression was performed and all highly non-significant (P>0.10) pairs were excluded.
3. The reference category was reintroduced and, again, all highly non-significant (P>0.10) pairs were removed.
4. Steps 1-3 were reiterated with the addition of "location and temporal variables" and then "macro-level" variables
5. A final step of logistic regression was performed with a lover significance threshold (P<0.05) to derive the final model.

The reason for choosing a higher significance threshold for the initial variable selection is to not exclude potentially multivariate significant variables. This procedure has been suggested in the literature [119].

Steps 2 and 3 were iterated to confirm that all variables were significant given the defined threshold.

Given this approach, the number of variables in each round of logistic regression is presented in Table 14. As can be seen, the highest number of variables in any logistic regression was 27. This was acceptable for the "All survivors" case, but above the suggested 10:1 ratio described above for the different evacuation modes. However, since the final iteration at each level was in the same order as the suggested 10:1 ratio, it was judged not to affect the results except a potentially reduced statistical power. Therefore, for the different evacuation modes, a lack of significance should be interpreted with caution, especially for those evacuation modes with a small number of events. First responder refers to the fire service, police and ambulance, even if the fire service in practice performed most of those evacuations (94%).

Table 14.
Number of events/non-events and number of variables in the first and final logistical regression at each level. Presented for both all survivors and for the different evacuation modes analysed.

Level	Number of events/ non-events	Fire level		Individual and temporal level		Macro level	
Iteration		First	Final	First	Final	First	Final
All survivors	345/269	27	14	14+8=22	16	16+11=27	11
Self-evacuation	136/453	27	7	7+7=14	8	8+11=22	8
Neighbor-evacuation	61/392	27	5	5+7=12	6	6+11=17	7
Homecare-evacuation	29/363	27	4	4+7=11	5	5+11=16	4
First-responder-evacuation	94/269	27	6	6+8=14	8	8+11=19	8

Classifying the cases into different modes of rescue was performed by an analysis of the free text fields in the incident reports. Similarly to Paper II, the value of a formal method for text analysis was judged to be limited and an assessment of the interrater agreement was seen as more appropriate.

In Paper II, the interrater agreement was measured using the measure developed by James et al (see section 5.2). This was due to the data being on a Likert-type scale and rated on several variables. In Paper VI, the data are in the form of a single a categorical variable instead. One measure of interrater agreement suitable for this type of variable is Cohen's kappa [120], which provides a measure of absolute agreement corrected for chance agreement. The measure is calculated using the equation below:

$$\kappa = \frac{p_0 - p_e}{1 - p_e}$$

In the equation, p_0, is the fraction of agreement and p_e is the agreement by chance. Cases classified as unknown mode of evacuation (N=25, 7% of the sample) were excluded from the analysis: Since they were not included in the analysis there were four categories in the variable and, therefore, p_e is equal to 25%. The number of cases assessed by the second rater was 30. The result was that Cohen's kappa became 0.849±0.137, which is classified as "almost perfect agreement" [120].

5.7 Concluding remarks on the methods used

As is evident from the current chapter, a rather wide range of methods has been employed in the different studies, ranging from qualitative analysis to different kinds of statistical analysis. The reason for this was always to take the research question as a point of departure, and then look for the best method to answer that question.

Also, on several occasions, different methods were used to measure the same quantity to provide a triangulation of the results to assess their validity (see section 7.1). For example, out of the 23 identified barriers/measures in Paper II, nine were assessed with a different method in Paper III and, out of those nine, one (smoke alarms) was also assessed in Paper IV.

The combination of qualitative analyses of single cases and statistical analyses of many cases was found to be very beneficial. It gave the researcher a dense contextual understanding of the cases, so that the findings from the statistical analyses could be interpreted on a foundation of actual cases and their causal patterns. At the same time, the statistical overview provided an overarching pattern for understanding each case in a wider context.

6 Research results

In this chapter, the results from the individual papers are used to attempt to answer the research questions formulated in section 2.2. The chapter is finalized by addressing the research objective in section 2.1.

6.1 Addressing the research questions

The following section addresses each of the research questions. The reader is referred to the indicated papers for detailed results.

6.1.1 RQ1: What is the long-term trend in the risk of dying in unintentional fires and can any shifts be identified? (*Paper I*)

The long-term trend in the risk of dying in fires (expressed as age-adjusted mortality rate) is very positive. For the entire population, the risk has decreased by 66% (95 % CI; 49-83%) between 1952 and 2017. This decrease can be found in all age groups, over the age of 5, and for both genders, where the decrease is between 58% and 77%. For children below 5 years of age, the decrease is even bigger, 93% (95% CI; 72-100%)[6]. The trend is very similar for men and women, with a decrease of 68% and 62% respectively.

As noted in section 4.1, a shift in the mortality trend can be identified during the 80-ties which is, as previously discussed, concurrent with the introduction of smoke alarms in Sweden. This can be further analysed by a piece-wise regression where separate Poisson regressions is performed for the period prior to smoke alarm introduction (pre-period, 1952-1980), during the rapid increase in smoke alarm prevalence (mid-period, 1980-1996) and for the period with a less rapid increase in prevalence (post-period, 1996-2017). The result can be found in Figure 22.

[6] As discussed in section 4.1, much of the decrease was in the late 1950s, which might be due to changes in childcare during the studied period. Historically, young children were often left alone, or with older siblings, when the parents left for work, whereas they are now usually put in organized childcare. [82]

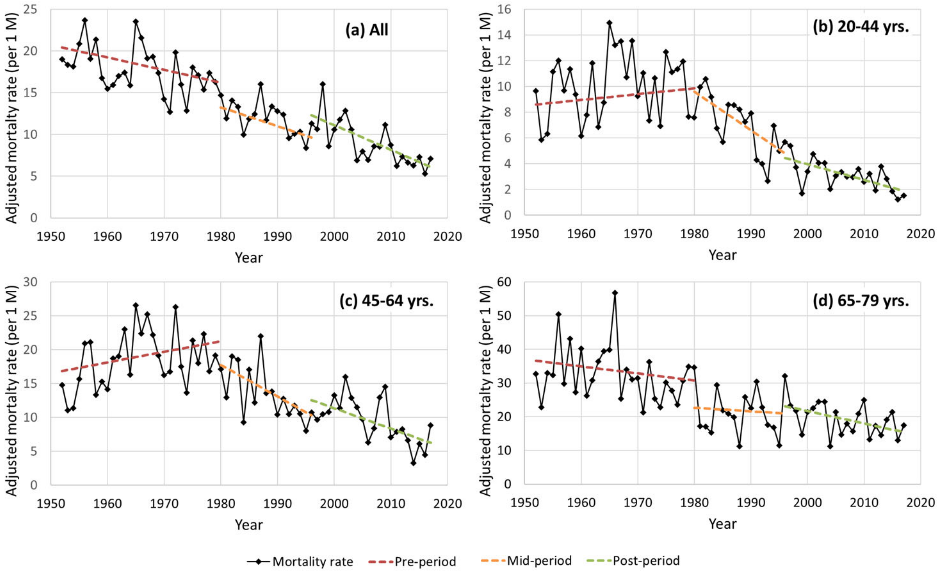

Figure 22.
Age-adjusted mortality rate for fire related mortality 1952-2017 per age group and Poisson regression of before smoke alarm introduction (pre-period, 1952-1980), during the rapid increase in prevalence (mid-period, 1980-1996) and the period with less rapid increase (post-period, 1996-2017).

The result indicate that the shift is clear for two of the age groups (20-44 and 45-64 years) and, to a lower extent, also for the older group (65-79 years). While the shift for the entire population (0-100+ years) is less clear. This motivates a quantification of the effect which is the topic of RQ3.

It was also found that burn-related injury diagnoses decreased more than carbon monoxide related diagnoses. This can probably be largely explained by improved burn care, but may also be due to the increased prevalence of synthetic fibres in clothes. Clothes are one of the most prevalent ignition objects for fires that cause severe burns, and therefore the decreased ignitability and decreased degree of burn injury from clothes made from synthetic materials is likely to partly explain the higher decrease in burn-related injuries. Also, an increase in synthetic stuffing in furniture, which entails a faster rate of fire growth, might have counteracted some of the decrease in carbon monoxide poisoning.

6.1.2 RQ2: Which measures are effective in reducing fire related mortality? (*Paper II & III*)

For the general population, thermally activated sprinkler systems were found to be the most effective measure, with a reduction in mortality of 75%, followed by smoke alarms at 42%, and ignition-proof cigarettes (such as e-cigarettes) at 39%. One of the main conclusions of the initial studies was, however, that population average effectiveness is not a very useful quantity in most situations, because it varies so much between groups. Therefore, there is an apparent risk that the average value will not be representative of the effectiveness for any of the groups and should therefore be derived for specific groups.

For the two youngest age groups (0-34 and 35-49 yrs.), thermally activated sprinkler systems are incredibly effective, with 95% and 94% effectiveness respectively. Also, smoke alarms are very effective, with 66% and 69% effectiveness respectively. For the older age groups, the effectiveness for both those measures decreased substantially, down to 63% and 13% respectively for the oldest group (85+ yrs.).

Also, for these older age groups, age was found to be an insufficient division given the fundamental difference in many of the smoking-related scenarios compared to the non-smoking related scenarios. Therefore, to be able to give a more precise answer to the research question, the population in the two older age groups (50-84 and 85+ yrs.) needs to be divided into smokers and non-smokers. The effectiveness data for smoking and non-smoking related fires is available in Paper III. However, to calculate the effectiveness for smokers (regardless of cause of fire), it was assumed that smokers are as exposed to non-smoking related fires as non-smokers[7]. This was not presented in Paper II, but can be found in section 4.3.

The results show that smoke alarms remain somewhat effective for the younger of these two age groups (50-84 yrs.), regardless of the victim being a smoker or not, with 39% and 47% respectively. However, for the oldest age group (85+) the effectiveness is decreased substantially to 1% and 18% respectively.

Also, thermally activated sprinkler systems are very effective for the non-smokers in both the second oldest and the oldest age group, with an effectiveness of 88% and 80% respectively. However, if the individual is a smoker, the effectiveness is 49% and 25% respectively for the two age groups.

For the older smokers, other measures turned out to be more effective. One of these is ignition protection in materials. Interestingly, the most efficient object to which to apply some kind of fire resistance was different between the two groups. This is probably due to different smoking routines in the different groups. While bedding

[7] In theory, non-smokers can also be killed by smoking if someone else is smoking and cause a fire. However, data from the fatal fire database (se section 3.2.2) indicate that this is a rare event with only a single case identified in residential occupancies between year 2009 and 2018.

and sofas were very effective for the younger of the two groups (50-84 yrs.), at 37% and 34% respectively, they were much less effective for the oldest group (85+ yrs.) at 20% and 7%. At the same time, ignition protection in clothes was highly effective for the oldest group, with 61% effectiveness compared to only 9% for the younger group.

How the fire resistance is achieved in practice might in some cases be dependent on whether the heat source is flaming or smouldering. Therefore, the type of ignition source can be found in Table 15.

Table 15.
Type of ignition source for different objects in Paper II and III.

	Object	N	Smouldering	Hot object	Flaming	Unknown
Paper II	Clothes	13	62% (*n=8*)	0% (*n=0*)	38% (*n=5*)	0% (*n=0*)
	Sofa	18	33% (*n=6*)	11% (*n=2*)	6% (*n=1*)	50% (*n=9*)
	Bed	26	62% (*n=16*)	8% (*n=2*)	0% (*n=0*)	31% (*n=8*)
Paper III	Clothes	39	59% (*n=23*)	3% (*n=1*)	23% (*n=9*)	15% (*n=6*)
	Sofa	54	56% (*n=30*)	4% (*n=2*)	0% (*n=0*)	41% (*n=22*)
	Bed	76	74% (*n=56*)	3% (*n=2*)	0% (*n=0*)	24% (*n=18*)

In section 1.4 some discussion in how different sources of ignition affects the type of fire resistance, but more details are provided in, for example, [42].

For older non-smokers, a common impression is that stove guards are very effective due to the higher prevalence of dementia. However, the data indicate that this is not actually the case, because stove guards could only prevent 8% of the fatalities among non-smokers. Much higher effectiveness would be achieved by remedying deficiencies in electrical systems, which could prevent 29% of the fatalities in the oldest group. A sample of those cases was assessed to gain a deeper understanding about the nature of these scenarios. The conclusion was that a range of different products (e.g. fridge, washing machine) and fixed installations caused the fires. The increased prevalence of scenarios with this origin was deemed to be due to reduced mobility in this group.

6.1.3 RQ3: How effective are smoke alarms in preventing fatal fires? (*Paper IV*)

The effectiveness of the increased prevalence of smoke alarms in preventing current fatalities was assessed in RQ2, but in some situations it is also valuable to assess the currently avoided fatalities due to that a large majority of households having a smoke alarm installed (96% in Sweden 2018 [24]).

Based on the clearly visually apparent kinks in mortality trends around the introduction of the smoke alarm, a quantification of the historical effect was motivated. The results show that, in a hypothetical scenario with 100% smoke alarm coverage (with 90% reliability) the mortality rate would be 45% (95% CI; 28-60%) lower than in a scenario with no smoke alarms installed.

For the age group from 20 to 44 years old, the mortality rate would be 84% (95% CI; 74-92%) lower. For the group aged 45 to 64, the mortality rate would be 74% (95% CI; 60-84%) lower and, finally, for the age group aged 65 to 79, the mortality rate would be 47% (95% CI; 19-68%) lower. It should, however, be noted that the effectiveness for the oldest included group (65-79 yrs.) was quite uncertain.

People below 20 and above 80 years of age were omitted from the group-wise analysis, since data on smoke alarm availability is not available for these specific groups, and is only included in the population average effectiveness. As seen in section 4.1, the mortality rate below 20 years of age is very low compared to the other age groups, so therefore probably has a limited effect on the population average effectiveness. However, people above 80 years of age have a much larger risk (over 20 times that of people below 20 years of age) and will therefore have a greater influence on the average effect. Therefore, it is most likely that effectiveness for that group is substantially below the population average effectiveness of 45%. This is because all the age groups investigated individually have an effectiveness above the population average, so one of the age groups not individually studied must have an effectiveness below the population average. This is also coherent with the findings from the current fatalities presented in relation to RQ2.

6.1.4 RQ4: How many people are rescued from fires by the fire service and what response capabilities are needed? (*Paper V*)

The study found that a total of 51 individuals were saved by the fire service during the year included in the study (2017), which represents 5.1 individuals per million population. This is similar to what was found in a previous study from the Netherlands (5.6 individuals per million)[8] [88]. However, a larger data set should be developed to arrive at a more precise result.

As previously discussed, capability can be divided into time, task and persistence, where only the first two are relevant to rescuing individuals from residential fires.

[8] The response time in the cases with rescues in the Netherlands was generally lower with 35% within 5 minutes and 88% within 8 minutes to be compared with 10% and 62% respectively for Sweden which might explain part of the difference in results

The results in Paper V show that response time has a very significant ($p<0.01$) influence on the possibility of performing a rescue, even when considering the differences between fatal fires and rescues. The data set is somewhat small for investigating differences in the trend for different response times, but the empirical distribution indicates that the probability decreases very rapidly over 10 minutes and is almost negligible above 20 minutes. The overall trend is shared with previous research (see section 1.4), but the dependence for different response times is different between studies.

For the second dimension of the used capability concept, tasks, the results show that interior rescue with breathing apparatus is very important in performing rescues because it is the only task that can be used in 40% of cases, and can be used in 98% of cases. Outside rescue by manual ladder or aerial apparatus appeared to be less effective, since it was the only effective task in just 2% of cases and could meet the need in 28% of the cases. Interior attack without breathing apparatus was possible in 36% of the cases.

Given the Swedish legislation, this results in the standard engine/rescue unit having an effectiveness of over 98%, which increases to 100% when combined with aerial apparatus. Smaller units (with a single firefighter), which are common in some rural areas, have an effectiveness of 36% because they only allow interior attack without breathing apparatus. The cost of the second unit is, however, much lower and therefore more units, and therefore shorter response times, might be achieved. Which strategy is most beneficial (few large units or many smaller units) depends on the local context, but the method developed in Paper V provides the equations needed to perform the comparison.

6.1.5 RQ5: Who evacuates older adults at risk from fires and what are the characteristics of these scenarios? (*Paper VI*)

For the individuals that survived, with injuries, the mode of evacuation was analysed based on the free text fields in the incident reports. The results are shown in Figure 23.

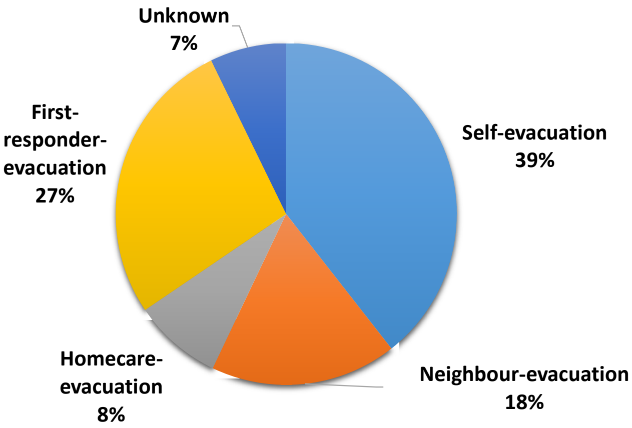

Figure 23.
Distribution of different modes of evacuation for the cases with injured older adults (65+ years) (N=345)

The results show that at least 53% of the victims depended on others for their evacuation and that first responders, neighbours and home care are all important for successful evacuation. Homecare accounts for fewer cases, but since only about 10% of the population aged over 65 have homecare, it is judged to be very important for that group.

The factors that increase or decrease the probability of each mode of evacuation are quite similar. Generally, causes of fire that ignite objects in direct proximity to the victims decrease the probability of rescue. Small fires, and fires in rooms where the victim is less likely to be, increase the probability of all modes of evacuation. Also, close proximity to neighbours and the fire service tends to increase the probability for being evacuated by others. Only two factors have opposite effects of different kinds of evacuation. The first is age, where high age increases the probability of homecare rescue, while decreasing all other modes. The second is living in a house (in contrast to an apartment), which increases the probability of self-evacuation, but decreases the probability of first-responder evacuation.

The results for who evacuates older adults were found to be interesting and relevant for intervention. However, due to the limited information about the cases and victims available in the incident reports, the results for the factors were found to be less useful. Therefore, collecting more, and more intervention-focused, data in the incident reports in the future is important.

6.2 Addressing the research objective

The topic of this thesis is exploring cases of fire fatalities, and close calls, to assess how fatalities can be prevented through a combination of prevention and response measures.

Paper I provided a general overview of fire mortality trends and, an explorative search for kinks in the trend that might point to important shifts in society, intentionally or unintentionally.

After that, the possibilities for prevention of fatalities were assessed in Papers II-IV and a number of suggestions for improved effectiveness of preventive measures will be given in chapter 8.

The role of various actors' responses in case of fire, such as neighbours, homecare and, not least, fire services, was explored in Papers V-VI. These studies are exploratory in nature since, in contrast to preventive measures, literature on this topic is very scarce. The results demonstrate the importance of response in the prevention of fire fatalities and more studies in this area are strongly motivated.

7 Discussion

This chapter does not aim to discuss the research results as such, this is done in other chapters (particularly section 4 and 6.1). Instead, the focus is on the quality of the research, which is often performed in relation to the concepts of validity and reliability of the research. Validity relates to the accuracy of the research (i.e. if the study measures what is intended), whereas reliability relates to its reproducibility [108, p. 77]. The generalization of the results (sometime called external validity) is also discussed.

7.1 Validity of the results

The validity of Paper I is primarily dependent on the cause of death being coherently coded by the forensic physician who performs the autopsy during the period. Discussions between the main author of that study (Dr. Anders Jonsson) and physicians active in the field have, however, indicated that the method and indicators of fire-related causes of death have remained essentially unchanged during the period. There is therefore no reason to doubt the validity of this study.

The main approach for assessing the validity of the studies on preventive measures (Papers II-IV) is to use several different data sources and methods to measure the same quantity. This is called triangulation [108, p. 158] and was possible for nine of the 24 barriers identified in Paper II. It is presented in Paper III.

In Paper II, the data used were fire investigations by the fire service and police, and, to some extent, autopsy reports and additional pictures submitted by the local fire service. The method was qualitative analysis of the reports. In Paper III, the data were fire fatality statistics from the fatal fires database maintained by MSB and the method was an iterative method for using variable values to discriminate between cases in which the measure would have been effective or not. In Figure 24, the results for the entire population for the two different approaches can be found. However, it should be acknowledged that the two studies are not fully independent of each other, because the learning set in Paper III comprises the cases in Paper II (representing 25% of the entire data set). The level of agreement is still very large for the majority of the barriers. The highest level of disagreement is found for smoking and detector-activated suppression. This is not unexpected, because smoking-related fires were less frequently investigated by the fire service and police, causing them to lack data in the analysis, than were other causes of fire (see section 5.3). Discussions with fire investigators about the reason for this resulted in the conclusion that these fires were often small (and often confined to the individual's clothes) and that there was thus a perception that there was less to be learned from such a fire.

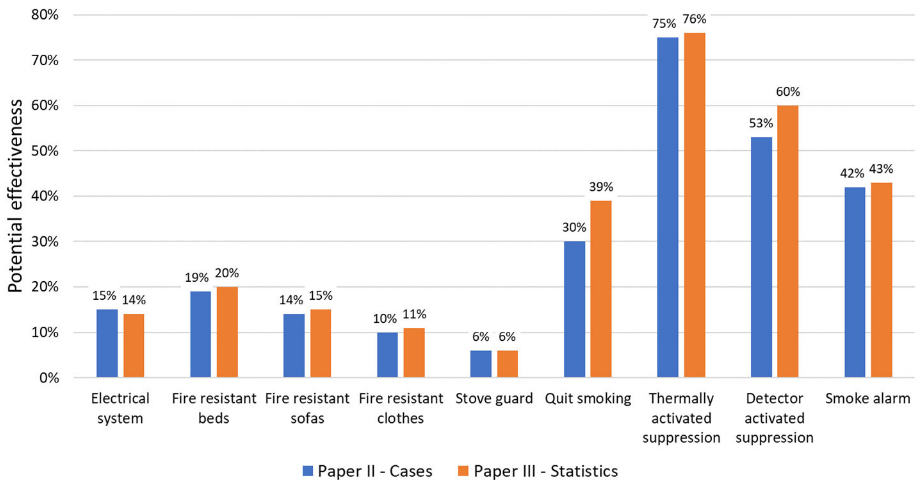

Figure 24.
Comparison between the results from the analysis of the investigation reports (Paper II) and the statistical analysis (Paper III)

Beside the agreement in the results of Paper II and Paper III, the agreement with previous studies (see section 1.4) also, to some extent, indicates the validity of the current studies.

Unfortunately, effectiveness for different subgroups (particularly based on age and sex) is very scarce in the literature and, because Paper II only included measures for the entire population, it is not possible to assess validity for the different groups in the same way as for the entire population. However, given that the assessment for the entire population, through comparing Papers II and III, along with previous studies, indicates adequate agreement, there is no reason to believe that this should not be the case for the different subgroups.

A limited assessment for smoke alarms can be performed by a comparison of historical effectiveness (Paper IV) and effectiveness for current fatalities (Paper III). It should be acknowledged that the populations are different in the two papers, as Paper IV includes those who now survive due to smoke alarms while Paper III includes those who now die from fires. Given the distribution of scenarios that affect different groups (see [11], [12]) it is not a surprise that the absolute magnitude is different for the fatalities that are now being prevented and those that still occur. The comparison can be found in Figure 25.

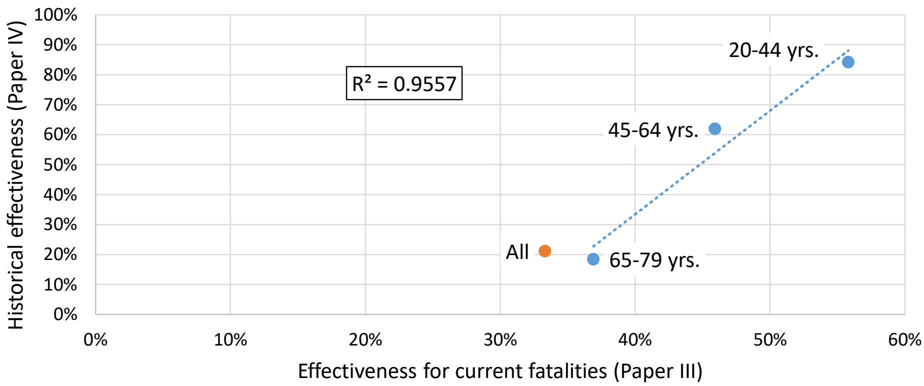

Figure 25.
Comparison between the effectiveness for current fatalities (Paper III – recalculated to the same age groups) and historical effectiveness (Paper IV). The current effectiveness has been corrected for 90% reliability according to Paper IV.

Even if three data points are very low for regression, the trend of decreasing effectiveness with higher age is clear in both studies. It is also clear that the historical effectiveness for the oldest age group (80+ yrs.) must be lower than the effectiveness for the entire population ("All") since it is impossible for all groups to be above the average effectiveness. This is also coherent with the data used in Paper III, where the effectiveness for that group was 21%. Even if this does not prove the validity of the absolute number, it does reinforce that the trend between age groups found in the studies was correct.

The validity of the fire service response paper, Paper V, is dependent on the ability of the first commander at the scene, along with the author, to assess the contra-factual scenario of a much later fire service arrival. The level of validity of this assessment is not obvious. To some extent it can be expected to have a decent level of validity given the experience of the fire commander and the author's knowledge of fire dynamics. Also, in many cases, the condition of the victim provided a strong indication of the likely outcome in the absence of fire service intervention. However, this is subjective and validity could have been assessed by an independent rater, similarly to what was done in Paper II and VI. However, the data for such an assessment would be the recorded phone interviews and, in those, the judgement of the commander and author would normally be apparent through the dialogue, so the assessment would not actually be independent. The conclusion is therefore that the paper's validity is not decisively proven, but it likely to be superior to most other methods (e.g. questionnaires where the judgement is made by a single rater and the rater varies between cases).

For the last paper, Paper VI, which compares fatal and non-fatal fires with injuries to older adults (65+), validity is expected to be lower because acknowledging the presence of victims with injuries is solely dependent on the assessment of the commander. It is likely that different commanders have different thresholds for what they classify as an injury worthy of inclusion in the report. However, the fact that a large proportion (at least 54%) of the non-fatal cases could not evacuate without help, indicates that the data on non-fatal cases still represent potentially very dangerous situations. This was the main reason for not including all non-fatal fires. The data on the fatal fires is based on the fatal fires database maintained by MSB, which is expected to be of very high quality (see section 3.2.2). Therefore, the general validity of the study is judged to be adequate, but probably lower than the other studies included in this thesis.

To summarize, the general conclusion is therefore that the validities of the trend paper (Paper I) and prevention-related papers (Paper II-IV) are rather good. The validity of the fire service response paper (Paper V) is probably slightly less so, because its findings have not been assessed through different data and methods and are also dependent on subjective judgements. The final paper, Paper IV, which compares fatal and non-fatal fires with injuries, is believed to have lower validity than the other studies, but enough validity to develop hypotheses about the main differences between the cases.

7.2 Reliability of the results

The reliability is, as stated above, the extent to which the study can be reproduced with the same results. For the papers using statistical analysis on externally generated data (Paper I, IV & VI), the expected level of variation in a test-retest scenario is captured in the confidence interval. Therefore, the level of reliability can be expected to be high. In Paper IV the results are, however, also dependent on the choice of regression model for smoke alarm prevalence over time. The chosen functional form of the regression, logistic, is judged as being fairly obvious since it gave a very good fit to the data (R^2=0.98) and it is therefore likely that the same functional form would be chosen by an independent researcher. The reliability of those papers is therefore expected to be high.

In Paper II the results are more dependent on judgement and the results can thus be expected to be less reliable. However, this is partly remedied by the interrater assessment (see section 5.2) that shows that a good level of interrater agreement. However, it should be acknowledged that the two raters have a similar background (both fire protection engineers employed in an academic institution) and that a rater with a different background (e.g. fire investigator, fire fighter) might make a different assessment.

In Paper III, the identification of the set of variables discriminating between cases in which a measure would have been effective or not was performed based on the qualitative understanding of the researcher and validated against a learning set (see section 5.3). This might lead to a reduction in the reliability of the results. More formal statistical methods for discrimination were attempted in the early parts of the analysis. The results were, to some extent, not theoretically plausible because a part of the smoking related fires was classified as could have been prevented by a stove guard, for example. Given this obvious misclassification, a higher level of correct classification was found using the more subjective method. The situation therefore required a trade-off between reliability and validity and, given the lower level of correct classification for the formal statistical method, the more subjective method was ultimately chosen.

The reliability of the fire service response paper, Paper V, is, along with the non-independent rater issue discussed in section 7.1, limited by the small data set that has only 42 cases and 51 individuals. However, this is explicit through the inclusion of a confidence interval similar to that in the papers discussed in the first paragraph of this section. The bimodal nature of the distribution does, however, result in the usually employed 95% limit yielding very large confidence bounds, so an 80% limit was used. This is not common in statistical analysis and not optimal, so a larger data set (i.e. more years of data) is very important. For more discussion on this topic, please refer to Paper V.

The reliability of the free-text coding in Paper IV was, similarly to Paper II, assessed using a test of inter-rater agreement with very good results (see section 5.6). In contrast to Paper II, the second rater had a different background to the main author, being a public health researcher in an epidemiology department.

7.3 Generalization of the results

Two main concerns have been identified regarding the generalization of the results. One is the generalization to other years. Random fluctuations between years are not an issue, since this can be accounted for using statistical methods (which are generally presented in each paper). A more challenging issue is the possibility that the risks have changed since this data was collected. There are probably some changes, but looking at trends in causes of fire and victims' ages, for example, in newer data indicates that changes are rather slow and gradual. However, there is always a need to reassess findings at a certain interval, because all analysis is situated in a specific point in time.

The second concern for generalization is generalization to other countries. All the studies in the current thesis have been performed in a Swedish context. To some extent, this is beneficial since it makes them comparable and complementary, although it does raise the question of whether the results can be generalized to other countries.

Generalizability to other countries is difficult to prove decisively, but the high level of agreement in risk factors (see section 1.2) and the effectiveness of different measures (see section 1.4) between countries indicate that this is likely to be the case, at least for most Western countries where the bulk of the studies have been performed.

However, given that the age structure was found to be of such high importance, a similarity in age structure between Sweden and the country in which the results are applied was seen as a necessary, but not sufficient, condition for generalizing the results. This motivated the factor analysis of different countries' age and sex structure for fire fatalities, as presented in appendix C. The variation between the 63 countries included in the analysis was found to be adequately explained by two factors, together explaining 91% of the variation. The first factor relates to the absolute magnitude of (unintentional) fire mortality, while the second factor relates to an increase in middle age mortality (see appendix C for dependence on different ages). The factor score of the different countries can be found in Figure 26 and Figure 27, where Figure 27 shows a part of the diagram in Figure 26 for increased readability.

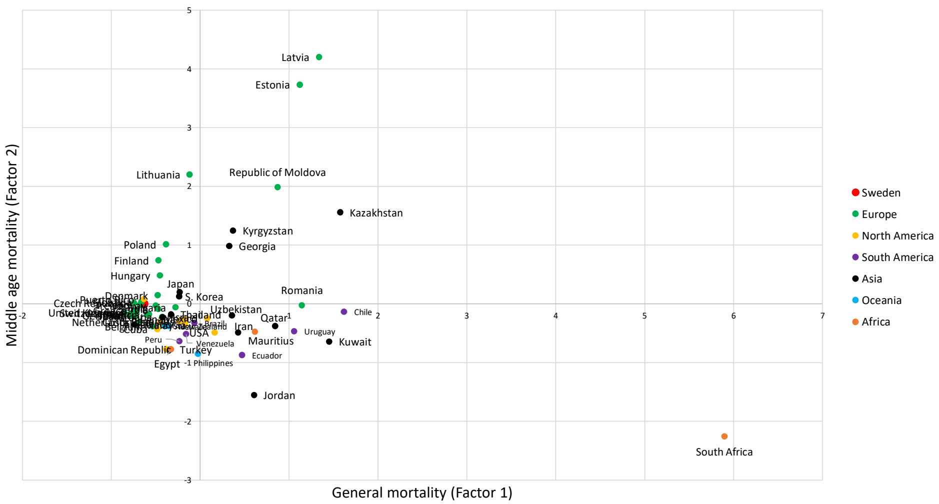

Figure 26.
Similarity of sex and age structure between countries

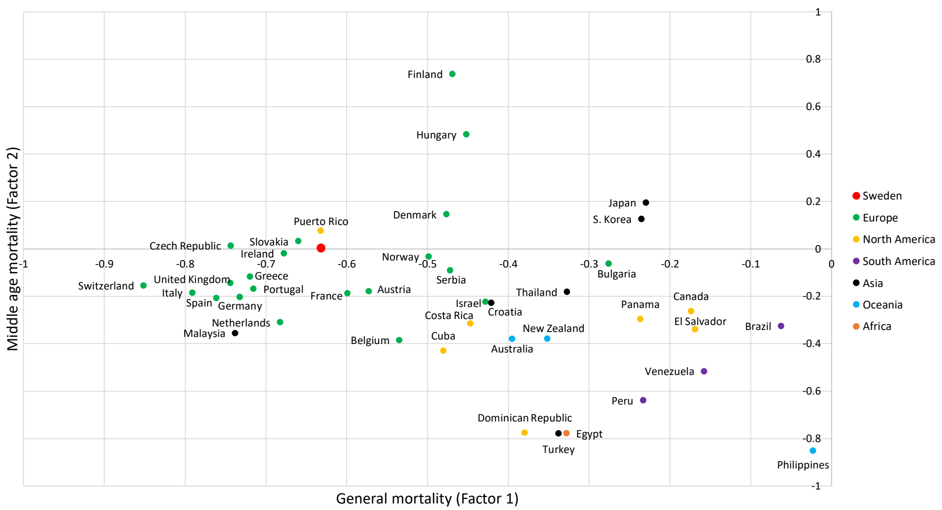

Figure 27.
Similarity of sex and age structure between some countries (part of Figure 26)

The conclusion is that the results in the current thesis could potentially be generalized to most other Western European countries and North America. However, it is less likely for the results to be generalizable to Eastern European and Middle Eastern countries. Many Asian and Oceanian countries were quite similar to Sweden (at least in regard to age/sex-structure), which might be interpreted having potential for generalization to these countries. However, this should be done with great caution, because lifestyles can be expected to be more different from Sweden than those in Western European and North American countries.

It is interesting to note that the results might even be difficult to generalize to a neighbouring country, such as Finland. However, this was not unexpected since the difference in fire-related mortality between Finland and Sweden was the subject of a master's thesis supervised by the author [121]. The conclusion of that study was that one of the most likely reasons for the difference is the level of alcohol consumption. For example, the mortality rate for alcohol-induced illness (which can be expected to be one of the most robust measures of excessive alcohol consumption) in Finland is almost five times that of Sweden. It is possible that excessive alcohol consumption can explain variations in the y-axis for other countries; this should be a topic for future research (see chapter 9).

Regardless of the underlying causes for the variation between countries, the results can be used to give some guidance on the limits for generalizing the results. Additional guidance can be found in the results from previous studies in section 1.4, since most of the results agree with those of these studies. Therefore, it can be expected that most of the results in this thesis could potentially be generalized to the countries investigated in those studies (particularly the US which was the setting of most studies), even if this cannot be decisively proven.

8 Conclusions and Recommendations

The first section of this chapter, formulates scientific conclusions based on the research conducted within the scope of this thesis. After that, the conclusions are used as a point of departure to provide more specific recommendations for practitioners working in the field. To improve readability for the Swedish audience, that section has been translated into Swedish and is available in appendix D.

8.1 Scientific conclusions

Based on the studies conducted within the current thesis, a number of conclusions can be drawn. These are divided into general, prevention and response-related conclusions below.

General conclusions

i. The general trend in unintentional fire mortality is very positive for the period between 1952 and 2017, with a decrease of around 60% for all age groups and both genders.

ii. The risk of dying from fires increases with age, but in the absence of smoking, the relative risk remains less than three times that of the general population even for the oldest group (85+). However, if an individual in this group is a smoker, their risk of dying in a fire increases drastically, to 45 times the risk of the general population. This indicates a strong synergy between the two risk factors (smoking and age).

Prevention-related conclusions

i. The effectiveness of different prevention measures is very different between population groups. Therefore, population average effectiveness might not be very useful in many situations.

ii. At least for older adults, smoking has a fundamental impact on the prevention of fire fatalities. If a person aged 85 years or above smokes and dies in a fire, the probability that it is caused by smoking is 94%. For people aged 50-84, the probability is 88% and 85% for women and men respectively.

iii. Probably due to differences in smoking routines, the primary object of ignition is different between groups. This influences the most effective target for fire resistance, where clothes were highly effective for the oldest group (85+), while sofas were effective for men in the younger group (50-84). Bedding was effective for both men and women in the younger group (50-84), but less effective for the older group (85+).

iv. For smoke alarms, the highest benefit per installation was found for male smokers aged 50 to 84. For the oldest group, the benefit was quite low despite the very high risk in the group, due to low effectiveness for the group.

v. Sprinkler systems have decreased effectiveness with age and with the presence of smoking. However, due to the sharply increasing risk, the benefit per installation still increases with age and the presence of smoking. For the youngest groups (0-34 and 35-49) the effectiveness of sprinkler systems was very high.

vi. Detector-activated sprinkler systems (installed in bedrooms and living rooms) are very effective in preventing fire fatalities, especially among smokers. The benefit per installation among smokers aged 85 or above was the highest for all measures (except for safe cigarettes) and had a factor of 2.6 over traditional sprinklers for that group.

vii. Around 20% of the victims of fatal fires had the opportunity to evacuate but chose not to, primarily to try to extinguish the fire

Response-related conclusions

i. During 2017, a total of 51 individuals would have died without (or with significantly delayed) fire service response. This is equal to 5.1 persons per 1M and is equal to an increase in the number of fatalities in residential occupancies by 58% for that year.

ii. For the fire service, response time is very important ($p<0.01$) to the probability of performing a successful rescue, but the tasks that the unit can perform are also important, because breathing apparatus is needed in many of the rescues.

iii. The model for predicting the probability of a successful rescue, based on response time and the set of tasks that the responding crew can perform, is promising, but more data are needed to improve the model's predictive capabilities.

iv. For all types of rescues (i.e. not only by the fire service) proximity to neighbours seems to be very important since, for the case of fire-service rescue, neighbours alert the fire service 50% of the time and also, independently, perform 18% of the evacuations of injured older adults (65+).

8.2 Recommendations for practice

This section uses the results from the various studies conducted within the scope of this thesis as a point of departure for formulating recommendations for practice. The recommendations are based on the results, but mixed with the author's personal opinion in order to make more normative statements. For increased readability, the current chapter is also translated into Swedish in appendix D.

First of all, it is very clear that fires with a fatal outcome are very different, both in term of scenario and risk groups, from fires which cause primarily property damage. Therefore, a fire prevention strategy needs to clearly differentiate between the two.

Also, prevention of fatal fires needs to differentiate between different groups. The cluster analysis introduced in section 1.2 identified six clusters but, looking more closely at the groups, three distinct groups can be identified for unintentional fires.

i. Older adults with reduced mobility

ii. People with alcohol addiction

iii. The general public

For people in the older adult group who are smoking, smoking is almost the only concern in relation to fire safety as it is quite unlikely that a fatal fire will be caused by any other ignition source. The most common object of ignition is the person's clothing and, to a lesser extent, upholstered furniture. The recommended measure is that the individual has synthetic clothes, detector activated sprinklers or, in some cases, institutionalized care. In many of the fatal fires that affect this group, the outcome can be well predicted by the identification of many burns on the floor, clothes and furniture. A great majority of these individuals have regular visits from home care, so it should be rather straightforward to identify many potential victims before a lethal fire occurs. Therefore, training and increased reporting responsibility for home care regarding hazardous conditions could be effective.

Older adults who do not smoke also have an increased risk of dying in fires, although less than a tenth of the risk for smokers in the same group. A common misconception, heard by the author on many occasions, is that the stove is a major threat to this group due to a higher prevalence of dementia. The data, however, suggests otherwise. The reason for this is not known, but it might be due to many people getting their food delivered by home care or that they might, generally, use less butter and oil on the stove[9]. More common were fires related to electrical faults, often from appliances such as fridges or washing machines.

At least 43% of fire fatalities in residential fires have at least 0.2‰ alcohol in their blood (the limit for driving with alcohol in Sweden), but generally the levels are much higher in this group, with a median of 2.2‰ and 95% of the cases between 0.32‰ and 3.94‰ (based on raw data from 385 cases obtained from [12]). Most people will not be able to sustain this level of blood alcohol level, which indicates that these victims are not the typical casual drinker, but rather people who drink throughout the week.

People with an alcohol addiction and who smoke are also very often killed in a fire caused by smoking [12] but, in contrast to the older adults above, the first object of ignition is more often upholstered furniture (particularly sofas). A potential intervention could be distributing e-cigarettes (or Heat-Not-Burn cigarettes) free of charge to these individuals, since their income level is often quite low. Apart from smoking, the stove is also a major threat and so the introduction of stove guards could probably be motivated. Alternatively, the traditional stoves could be replaced with induction stoves since they achieve lower temperatures and therefore reduce the probability of ignition. Also, smoke alarms could be introduced since these people often have the physical ability to evacuate if they wake up (unfortunately research has shown that it is more difficult to wake people who are intoxicated). An alternative approach is, of course, also to help the individual limit their alcohol intake, which will have many other positive effects on their life.

For the general public, the risk is much lower than for the two groups above so, for a strategy against fatal fires to be effective, a clear and explicit focus on one or both of groups should be stated. From a utility-based standpoint, the substantially lower risk for what is called the general public warrants less money available for interventions for this group. However, smoke alarms are a very small investment

[9] Butter and oil were found to be involved in 98% of the cases with open flames in a master's thesis supervised by the author [124]. Other foodstuffs are very difficult to ignite with the temperatures that can be achieved on a stove.

and have a very good effectiveness for this group. This will also, as a side effect, reduce property damage by fire for this group; research has shown that the cost/benefit ratio for smoke alarms is well above unity. The current requirements that often lead to that bedrooms are not fitted with smoke alarm should be changed so that smoke alarms should also be required in bedrooms. Even if stove guard is difficult to motivate for this group, choosing an induction stove will reduce the probability of ignition or even the new “smart stoves” that have sensors to prevent fried food stuff from being burnt on the stove and therefore, naturally, also ignition.

Another factor that is of great importance for this group is to only extinguish the fire if they have a safe route out of the building, because approximately 20% of fire fatalities had the opportunity to evacuate but chose not to do so, usually to try to extinguish the fire instead. In practice, this can be introduced in fire prevention courses, which are often available through workplaces, on which the participant can be taught to “think like a security guard”. A security guard is taught to always stay between the felon (i.e. the danger) and the door, so always has a safe exit. Many lives can probably be saved if the same mind-set can be introduced to the general public in relation to fire.

Turning from prevention to response, the results clearly show the importance of both professional and non-professional actors (e.g. neighbours) in saving lives in fires. Response is often dependent on neighbours’ actions, either through direct intervention or through calling the fire service. It could therefore be important to contemplate how to improve willingness to respond in these situations. In some cases in the study of fire service rescues, the door to the apartment was unlocked and the fire small, which would have allowed a neighbour to perform the rescue if they were willing to. Unfortunately, in those cases they were not willing, which might be dependent on the level of trust between neighbours. It is also important to acknowledge that the availability of the cues for a progressing fire to the neighbours is important. In detached houses, awareness of a fire by neighbours might be difficult, as well as in modern apartment buildings, with air tight doors (which prevent the smell of smoke) and a high level of acoustic requirements (which limit hearing smoke alarms). It is important to investigate whether there is another way of letting potential rescuers become aware of a fire, and for the older adult groups a security alarm is one of those measures. Many in this group press now the alarm if there is a fire (since they are often awake), but this could be further increased by connecting a smoke alarm to the security alarm, as is done in some municipalities. Also, technical means can be used to alert a trusted neighbour to the fire and allow them to intervene.

For the fire service, it is clear that response time is of great importance, as are the tasks that the unit responding is able to perform. Interior attack with breathing apparatus is needed in many cases, but can be supplemented by smaller units with a more limited repertoire. The research within the scope of the current thesis is still considered exploratory and a major recommendation is for governmental agencies (e.g. MSB in Sweden) to start systematic collection of high quality data on rescues to allow further research and development within the field. Also, application of the methodology should be tested, both through implementing the equation into a GIS environment, but also by performing local analyses such as the cost/benefit analysis of the replacement of an aerial apparatus in Grums by the local fire service [122]. Implementation into a GIS environment will be of value, both in assessing capabilities during normal operations and during large events that may make units unavailable for prolonged periods. It will also facilitate a joint assessment of the geographical distribution of capability and risk levels.

For the results and recommendations in this thesis to be put into practice, it is of vital importance that the main actors are willing to critically examine current practices and develop an evidence-based strategy for fire prevention. It is therefore promising that such process is already underway at both MSB and the Swedish FPA.

It is also of great importance that the responsibility for the prevention of fatal fires within the legal framework, particularly in relation to the two high risk groups, are clarified. This is unfortunately not the case in Sweden today. This is not a research problem, but rather an administrative and/or regulatory problem. However, for the research to matter it must be put into practice and today, with limited government funding, the question of responsibility must be very clear if actors are to prioritize their funding for fire prevention

9 Future research

Based on the results in this thesis, this chapter provides some suggestions for future research.

Implementation

The current thesis, along with previous studies, provides a relatively comprehensive description of the effectiveness of different measures. However, they can only be of value if they are put into practice. Therefore, it is of vital importance to perform research on implementation success factors and problems for different actors. This can be analysed using various kinds of action-research methodologies. The research should be focused on the main risk groups, which are older adults with reduced mobility and people with substance abuse.

Novel technologies for the prevention of smoking-related fires.

It is clear that smoking is a prime concern in the prevention of fatal fires and that many of the common preventive measures (e.g. smoke alarms) are not enough. Therefore, additional technologies must be developed. One potential technology is the introduction of spandex into fabrics made using natural fibres, since it appears that natural fibres with at least 5% spandex are very difficult to ignite with a cigarette. This is a treatment that is stable over time, environmentally friendly and generally increases comfort (which is very important for many older adults). This behaviour should be verified through a more comprehensive study. It is also important to develop environmentally friendly and cheap methods for reducing the ignitability of furniture.

Also, different kinds of safer smoking equipment, such as electronic cigarettes should be tested for acceptance among the risk groups. If accepted, this could lead to a substantial decrease in risk for those individuals.

Fire service response

The study on fire service response included in this thesis is explorative in nature and a larger data set should be developed to increase the predictive capabilities of the model. Also, the model should be implemented in a GIS environment to facilitate planning, both during normal operations and dynamically when units are occupied or displaced during events. Implementation would also facilitate the combination of capabilities and risk levels at different geographical locations.

The current model is also limited to only saving lives in fires. To increase the usefulness of the model, other needs should also be analysed and models for those needs should be developed. This could be performed using a similar approach, at least for rather frequent events. A different and more analytical method might be required for rarer events.

Prevention of fatal fires in other countries

As previously discussed, this thesis is situated in a Swedish context and most published studies are also from a few Western countries. Therefore, a deeper investigation into cases of fatal fires should be performed in other countries to analyse how they are similar to and different from fatal fires the studied countries and what measures could be effective in preventing fatalities in those countries. This could be performed, for example, by employing the method developed in Paper II.

Also, an extension of the analysis of differences between countries in appendix C should be performed to investigate whether the hypothesis that factor 2 (labelled “middle age mortality”) is correlated with alcohol-related mortality in these countries is valid.

Property damage from residential fires

Residential fires do not only cause fatalities and injuries, but also substantial property damage. This is, however, rarely investigated in the literature and therefore more knowledge is needed. The causes and extent of property damage in residential fires are relevant reducing costs, but is also very relevant in relation to fatal fires, because this is part of cost-benefit analyses and therefore affects which measures that are motivated.

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Appendix A – Major fatal fires in Sweden 1950-2018

The cases below are gathered from the large accident database maintained by the Swedish Civil Contingencies Agency (MSB).

Table A.1
Major fatal fires in Sweden 1952-2018 defined as a having at least 5 casualties (regardless of place of residence).

Year	No of fire fatalities	Municipality	Occupancy	Short description
1952	10	Eslöv	Nursing home	Arson fire to conceal the murder of mother, father, fiancée and one staff. The six fire fatalities were collateral
1954	5	Eksjö	Nursing home	The victims was on second floor. The fire service evacuated remaning residents.
1954	5	Perstorp	Industry	Dust explosion in wood dust
1956	7	Storuman	Industry	Dynamite exploded prematurely during the construction of water power plant
1956	6	Lycksele	Nursing home	Iron caused a fire in a nursing home
1958	5	Stockholm	Industry	Overfilling of a fixed gasoline tank caused an explosion
1960	5	Stockholm	Residential	Fire spread through a light shaft in a five-storey building
1962	9	Östersund	Nursing home	Fire likely caused by a malfunction in ventilation system
1964	8	Nora	Industry	Production of dynamite caused explosion that destroyed all windows within a 5 km radius
1965	5	Ronneby	Residential	Two adults and three children killed. Cause of fire was likely to be cigarette igniting an armchair
1967	5	Enköping	Assembly	The fire started in the teachers' cloakroom
1968	5	Trollhättan	Residential	Kerosene heater was knocked over during a fight
1969	5	Sundsvall	Residential	Three-storey wood frame building with fire spreading through stairwell
1970	9	Kungsbacka	Industry	Pyrotechnic factory ignited by friction in a machine.
1971	11	Göteborg	Industry	The machine room in a tanker located in a dry dock ignited. Likely cause was welding.
1971	5	Flen	Nursing home	Fire in nursing home in Malmköping
1975	7	Stockholm	Hospital	The fire was caused by a bedridden patient igniting a match. The fire caused an oxygen pipe to break which contributed to rapid fire growth.
1976	15	Jönköping	Bus	An overheated tyre caused the bus to ignite
1976	8	Kungsbacka	Care home for children with special needs	The cause was probably arson and the wooden building quickly became fully involved in the fire. Smoke alarm was lacking and the fire service was unaware of the new building's use.

1978	20	Borås	Hotel	A cigarette caused a fire in a waste basket under a roulette table. The smoke spread rapidly in the building.
1982	6	Borås	Residential	Six people, including four children, died in the fire that was likely caused by smoking in bed
1982	5	Sundsvall	Care home	Five people died in the fire
1987	6	Norrtälje	Residential	A family of six died in the fire that had probably been smouldering for a substantial time. The cause was unknown.
1989	6	Malmö	Care home	The fire started in a smoking room and eight people managed to evacuate.
1990	158	Skagerrak (sea)	Ship	The fire on the ferry *Scandinavian Star* was intentionally set and most people died in their cabins from smoke poisoning.
1993	5	Eskiltuma	Residential	Four children were among theh victims. Two individuals managed to safely evacuate.
1998	63	Göteborg	Assembly	The fire was deliberately set in a stairwell and the victims were all between 12 and 20 years old.
2009	7	Stockholm	Residential	A mother and six children attempted to evacuate through a smoke filled stairwell, but died on the way out.
2009	5	Staffanstorp	Residential	A computer ignited a sofa.
2012	6	Tidaholm	Residential	A Danish family with two children died in their holiday cottage

Appendix B – Interview guide for Paper V

The interviews with the first commander at scene were performed in Swedish, but are translated into English below. The exact formulation and order of questions were varied to increase the natural flow in the conversation.

Introduction

My name is Marcus Runefors and I'm calling from the Division of Fire Safety Engineering at Lund University. I'm involved in a research project about residential fires funded by the Swedish Civil Contingencies Agency and I'm currently looking at cases where the fire service has performed a rescue.

A few days ago, you filled out an incident report and stated that you had performed a rescue, so I wonder if I could ask you some questions about that. Is that okay?

I would like to record the interview to facilitate the analysis. Is that okay? The recording will be treated confidentially and will be deleted after the study has been completed.

I will start the recording.

Free narrative

i. *Can you tell me a bit about the event and what happened from call-out to when you evacuated the individual?*

ii. *What would have happened to the individual if you had been occupied on another call and arrived at the scene 30 minutes later?*

[If it was found not to be a rescue, the interview was terminated and the respondent thanked for their time]

Specific questions

[Questions that were redundant due to the free narrative was excluded]

iii. *You evacuated the individual using XXX. Were there any other ways to evacuate the individual or prevent them from being injured?*

iv. *Why couldn't the individual evacuate themself?*

v. *Was the door locked?*

vi. *Where was the victim in relation to the fire at the time of ignition?*

vii. *… at rescue?*

viii. *Did the victim have impaired mobility?*

ix. *Was the victim asleep?*

x. *Who called the fire service?*

xi. *Do you have any pictures or film from the incident that you can send me?*

Appendix C – Similarities and differences in fire mortality between Sweden and other countries

As stated in section 7.3 , similarities in mortality as regards age and sex structure was seen as a necessary, but not sufficient, condition for generalizability of the results to other countries. Therefore, a comparison between countries was performed using WHO data on the number of fire fatalities in different age groups and population data from UN data for the same groups.

Only countries that had reported at least 100 fire fatalities during the ten newest available years in the database (2007-2016) were included in the analysis. This was because a reasonable sample size is needed to get reliable data on the individual age groups. Not all countries have reported all years, so the expected number of fire fatalities per year reported per year-group was calculated. This resulted in a total of 70 countries.

Population data was primarily based on 2012, because it was in the middle of the studied period and not expected to change significantly during the period. Population figures for this year were available for 46 of the 70 countries. For 18 additional countries, population data was found reasonably close to this year (7 for 2011, 6 for 2010, 2 for 2015 and one for each of 2006 and 2007). For the remaining seven countries, no population data was found and they were therefore omitted from the analysis.

Fatalities of unknown age (0.6% of the cases) were distributed over the other age groups according to their original proportion of the total. Fatalities with unknown gender (0.2% of the cases) was evenly distributed between men and women.

After the average mortality rate for the included years had been calculated, a factor analysis was performed on the six age groups (0-4, 5-19, 20-44, 45-64, 65-79 and 80+ years) and two genders, where all 12 combinations of age group and gender were seen as a variable. The factor analysis was performed using principal component analysis with quartimax rotation. The results can be seen in the screenplot in figure C.1

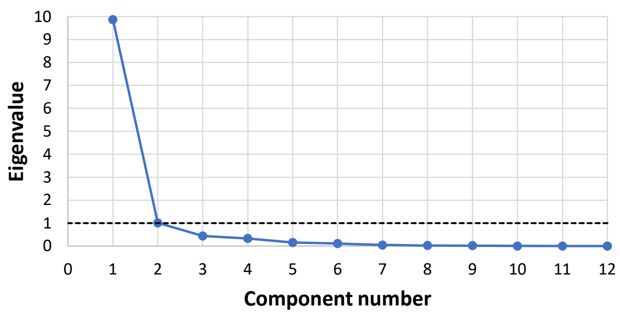

Figure C.1
Screeplot of the factor analysis of the age-sex-structure of fire mortality

A clear elbow can be found after two factors, where the addition of other factors adds very little to the explanation of variance. These two factors, together, explain 91% of the variance. These are also the factors which have an eigenvalue above unity (i.e. explaining a larger fraction of the variance than the mean of all factors), which is an alternative criterion for selecting the number of factors to include. However, the graphical method is often recommended [123].

Figure C.2 presents the loading of the rotated factor solution on the different age groups and genders. The first factor explains 82% of the variance and the second 9%.

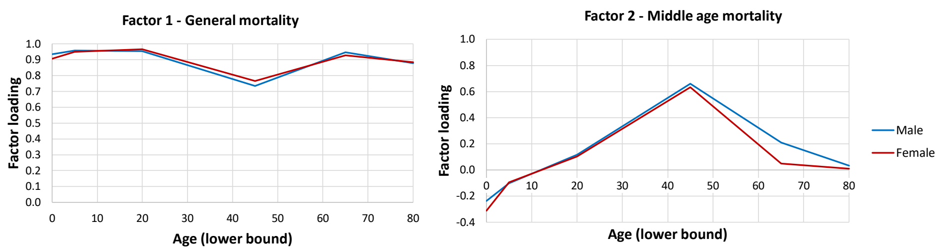

Figure C.2
Factor loadings on the different age-groups and genders.

As can be seen, the first factor is primarily a description of general mortality while the second factor primarily describes middle-age mortality.

Figure C.3 present a plot of the different countries on these two factors.

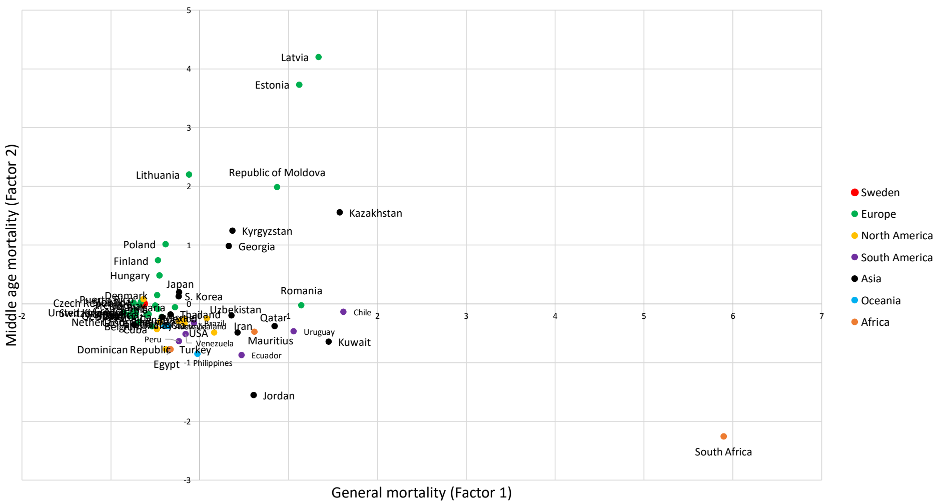

Figure C.3
Factor scores by country.

As can be seen in figure C.3, South Africa has a much higher mortality rate than other included countries. Several of the former Soviet European states have a much higher mortality rate among the middle-aged. The difference between Finland and Sweden has been investigated [121] and much indicates that the cause of the increased mortality among the middle-aged is the higher alcohol consumption in these countries.

Most of the Western European and North American countries can be found in the general mortality scale between -1 and 0 and in the middle-age mortality rate between -1 and 1. Therefore, the figure in figure B.3 zooms in on this region to better be able to assess similarities and differences in that range.

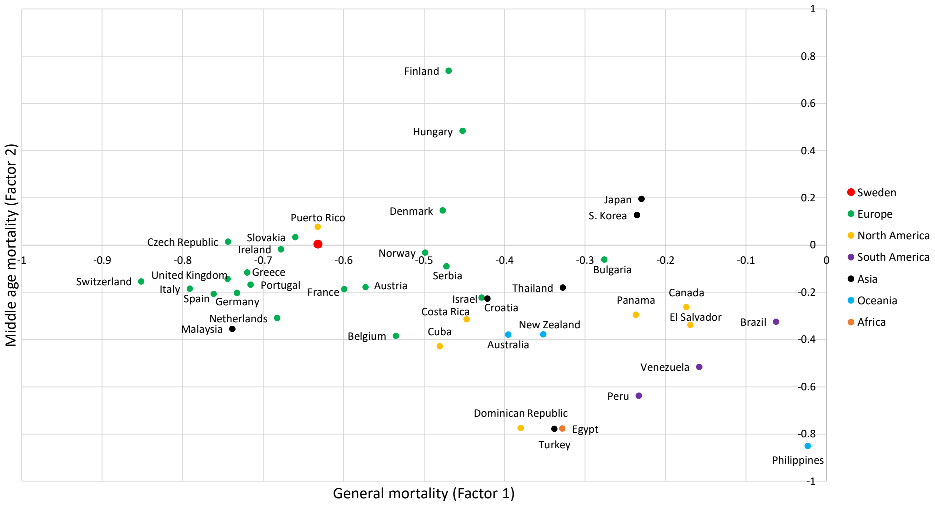

Figure C.4
Factor scores by countiry for a part of figure C.3

Table C.1 shows a ranking of countries based on squared Euclidian distance from Sweden and the distance based on each factor.

Table C.1
Rank of similarity of age and gender structure between Sweden and other countriesas measured by the squared Euclidian distance and distance for each individual factor

Rank from similar to dissimilar mortality rate	Rank from similar to dissimilar based on factor score on general mortality (factor 1)	Rank from similar to dissimilar based on factor score on middle-age mortality (factor 2)
Slovakia (0.002)	Puerto Rico (0.00)	Czech Republic (0.01)
Ireland (0.003)	France (0.03)	Ireland (0.02)
Puerto Rico (0.005)	Slovakia (0.03)	Slovakia (0.03)
Czech Republic (0.013)	Ireland (0.05)	Romania (0.03)
Norway (0.019)	Netherlands (0.05)	Norway (0.04)
Greece (0.022)	Austria (0.06)	Puerto Rico (0.07)
Serbia (0.035)	Portugal (0.08)	Bulgaria (0.07)
United Kingdom (0.035)	Greece (0.09)	Serbia (0.09)
Portugal (0.037)	Belgium (0.10)	Republic of Korea (0.12)
Austria (0.037)	Germany (0.10)	Greece (0.12)
France (0.038)	Malaysia (0.11)	Denmark (0.14)
Denmark (0.044)	Czech Republic (0.11)	Chile (0.14)
Germany (0.053)	United Kingdom (0.11)	United Kingdom (0.15)
Italy (0.061)	Norway (0.13)	Switzerland (0.16)
Spain (0.061)	Spain (0.13)	Portugal (0.17)
Switzerland (0.073)	Cuba (0.15)	Austria (0.18)
Croatia (0.093)	Finland (0.16)	Japan (0.19)
Israel (0.098)	Serbia (0.16)	Thailand (0.19)

Netherlands (0.101)	Denmark (0.16)	Italy (0.19)
Thailand (0.127)	Italy (0.16)	France (0.19)
Bulgaria (0.131)	Costa Rica (0.18)	Uzbekistan (0.20)
Costa Rica (0.136)	Hungary (0.18)	Germany (0.21)
Malaysia (0.14)	Croatia (0.20)	Spain (0.21)
Belgium (0.161)	Israel (0.21)	Croatia (0.23)
Republic of Korea (0.173)	Switzerland (0.22)	Israel (0.23)
Japan (0.198)	Australia (0.24)	Mexico (0.25)
Australia (0.204)	Dominican Republic (0.25)	Canada (0.27)
Cuba (0.211)	Poland (0.25)	Panama (0.30)
New Zealand (0.225)	New Zealand (0.28)	Netherlands (0.31)
Panama (0.247)	Turkey (0.29)	Costa Rica (0.32)
Hungary (0.262)	Thailand (0.30)	Brazil (0.33)
Canada (0.281)	Egypt (0.30)	El Salvador (0.34)
El Salvador (0.332)	Bulgaria (0.36)	Malaysia (0.36)
Brazil (0.433)	Japan (0.40)	New Zealand (0.38)
Venezuela (0.496)	Peru (0.40)	Qatar (0.38)
Finland (0.565)	Republic of Korea (0.40)	Australia (0.38)
Peru (0.572)	Panama (0.40)	Belgium (0.39)
Mexico (0.573)	El Salvador (0.46)	Cuba (0.43)
Dominican Republic (0.672)	Canada (0.46)	Uruguay (0.47)
Turkey (0.7)	Venezuela (0.47)	Hungary (0.48)
Egypt (0.704)	Lithuania (0.51)	Mauritius (0.48)
USA (0.876)	Brazil (0.57)	Iran (0.49)
Uzbekistan (1.023)	Philippines (0.61)	USA (0.49)
Poland (1.078)	Mexico (0.71)	Venezuela (0.52)
Philippines (1.103)	United States of America (0.80)	Peru (0.64)
Iran (1.365)	Georgia (0.96)	Kuwait (0.65)
Mauritius (1.788)	Uzbekistan (0.99)	Finland (0.73)
Georgia (1.879)	Kyrgyzstan (1.00)	Dominican Republic (0.78)
Ecuador (1.988)	Iran (Islamic Republic of) (1.06)	Egypt (0.78)
Qatar (2.33)	Ecuador (1.10)	Turkey (0.78)
Kyrgyzstan (2.544)	Jordan (1.24)	Philippines (0.86)
Uruguay (3.081)	Mauritius (1.25)	Ecuador (0.88)
Romania (3.157)	Qatar (1.48)	Georgia (0.98)
Jordan (3.97)	Republic of Moldova (1.51)	Poland (1.01)
Kuwait (4.769)	Uruguay (1.69)	Kyrgyzstan (1.24)
Chile (5.089)	Estonia (1.75)	Kazakhstan (1.55)
Lithuania (5.093)	Romania (1.78)	Jordan (1.56)
Republic of Moldova (6.198)	Latvia (1.97)	Republic of Moldova (1.98)
Kazakhstan (7.288)	Kuwait (2.08)	Lithuania (2.20)
Estonia (16.957)	Kazakhstan (2.21)	South Africa (2.26)
Latvia (21.471)	Chile (2.25)	Estonia (3.73)
South Africa (47.743)	South Africa (6.53)	Latvia (4.19)

For completion, the factor scores on each factor is presented in table C.2.

Table C.2
Factor scores for each factor and country

Factor score for general mortality (factor 1)	Factor score for middle age mortality (factor 2)
South Africa (5.90)	Latvia (4.20)
Chile (1.62)	Estonia (3.73)
Kazakhstan (1.58)	Lithuania (2.20)
Kuwait (1.45)	Republic of Moldova (1.99)
Latvia (1.34)	Kazakhstan (1.56)
Romania (1.14)	Kyrgyzstan (1.25)

Estonia (1.12)	Poland (1.01)
Uruguay (1.06)	Georgia (0.98)
Republic of Moldova (0.87)	Finland (0.74)
Qatar (0.85)	Hungary (0.48)
Mauritius (0.62)	Japan (0.2)
Jordan (0.61)	Denmark (0.15)
Ecuador (0.47)	Republic of Korea (0.13)
Iran (0.43)	Puerto Rico (0.08)
Kyrgyzstan (0.37)	Slovakia (0.03)
Uzbekistan (0.36)	Czech Republic (0.01)
Georgia (0.33)	**Sweden (0.00)**
USA (0.16)	Ireland (-0.02)
Mexico (0.08)	Romania (-0.03)
Philippines (-0.02)	Norway (-0.03)
Brazil (-0.06)	Bulgaria (-0.06)
Lithuania (-0.12)	Serbia (-0.09)
Venezuela (-0.16)	Greece (-0.12)
El Salvador (-0.17)	Chile (-0.13)
Canada (-0.17)	United Kingdom (-0.14)
Japan (-0.23)	Switzerland (-0.15)
Peru (-0.23)	Portugal (-0.17)
Republic of Korea (-0.24)	Austria (-0.18)
Panama (-0.24)	Thailand (-0.18)
Bulgaria (-0.28)	Italy (-0.18)
Thailand (-0.33)	France (-0.19)
Egypt (-0.33)	Uzbekistan (-0.20)
Turkey (-0.34)	Germany (-0.20)
New Zealand (-0.35)	Spain (-0.21)
Dominican Republic (-0.38)	Croatia (-0.22)
Poland (-0.38)	Israel (-0.23)
Australia (-0.40)	Mexico (-0.25)
Israel (-0.42)	Canada (-0.26)
Croatia (-0.43)	Panama (-0.3)
Costa Rica (-0.45)	Netherlands (-0.31)
Hungary (-0.45)	Costa Rica (-0.31)
Finland (-0.47)	Brazil (-0.32)
Serbia (-0.47)	El Salvador (-0.34)
Denmark (-0.48)	Malaysia (-0.36)
Cuba (-0.48)	New Zealand (-0.38)
Norway (-0.5)	Qatar (-0.38)
Belgium (-0.53)	Australia (-0.38)
Austria (-0.57)	Belgium (-0.38)
France (-0.60)	Cuba (-0.43)
Puerto Rico (-0.63)	Uruguay (-0.47)
Sweden (-0.63)	Mauritius (-0.48)
Slovakia (-0.66)	Iran (-0.49)
Ireland (-0.68)	USA (-0.49)
Netherlands (-0.68)	Venezuela (-0.52)
Portugal (-0.72)	Peru (-0.64)
Greece (-0.72)	Kuwait (-0.65)
Germany (-0.73)	Dominican Republic (-0.78)
Malaysia (-0.74)	Egypt (-0.78)
Czech Republic (-0.74)	Turkey (-0.78)
United Kingdom (-0.74)	Philippines (-0.85)
Spain (-0.76)	Ecuador (-0.87)
Italy (-0.79)	Jordan (-1.56)
Switzerland (-0.85)	South Africa (-2.26)

For discussion on the results, refer to section 7.3.

Appendix D – Rekommendationer för praktiker (in Swedish)

The text below is identical to the text in section 8.2. It is only translated into Swedish to increase the availability to the Swedish audience.

I detta kapitel formuleras rekommendationer för praktiker. Rekommendationerna utgår ifrån resultatet från resultaten från studierna som presenteras i denna avhandling, men kombinerat med författarens egna åsikter för att möjliggöra mer normativa uttalanden.

Till att börja med är det mycket tydligt att bränder med dödlig utgång skiljer sig mycket från bränder som primärt leder till egendomsskador både när det gäller scenario och riskgrupp. Därför måste en strategi för brandsäkerhet tydligt skilja på dessa.

Även förebyggande mot dödsbränder behöver skilja mellan olika grupper. Klusteranalysen som presenterades i kapitel 1.2 identifierade sex kluster, men om man tittar närmare på dem så kan man identifiera tre tydliga grupper för oavsiktliga dödsbränder.

i. Äldre personer med reducerad rörlighet

ii. Personer med alkoholmissbruk

iii. Allmänheten

För äldre personer som röker så är rökningen den dominerande riskkällan eftersom det är osannolikt att branden kommer att orsakas av någon annan tändkälla. Det vanligaste startobjektet är personens kläder och i en mindre utsträckning stoppade möbler. De åtgärder som bör rekommenderas är kläder i syntetiskt material, detektoraktiverat sprinklersystem och i vissa fall äldrevård. I många av fallen som drabbar denna grupp så hade resultatet lätt kunnat förutses genom brännmärken på golv, kläder och möbler. En stor majoritet i denna grupp får regelbundet besök av hemtjänst och därför bör det vara relativt lätt att identifiera individerna innan branden inträffar. Det innebär att ökad utbildning och ett ökat ansvar att rapportera farliga förhållanden för hemtjänsten skulle kunna vara en effektiv åtgärd.

Äldre personer som inte röker har också en förhöjd risk att omkomma i bränder, men den är under en tiondel av risken för rökare i samma åldersgrupp. En vanlig missuppfattning som författaren har hört vid många tillfällen är att spisar är en särskilt stor risk för den här gruppen vilket ofta motiveras med en ökad förekomst av demens. Resultaten visar dock på något annat. Orsaken bakom detta är inte känd, men kan bero på att gruppen oftare får mat levererad från hemtjänsten eller att de eventuellt använder mindre olja och smör på spisen[10]. Vanligare var bränder kopplade till olika typer av elektriska fel, ofta från olika elprodukter som till exempel kylskåp och tvättmaskiner.

Minst 43% av de som omkommer av bostadsbränder har mer än 0,2‰ alkohol i blodet (gränsen för att få köra bil i Sverige), men normalt är nivåerna mycket högre i denna grupp med en median på 2,2‰ och i 95% av fallen mellan 0,32‰ och 3,95‰ (baserat på rådata från 385 fall hämtade från [12]). De flesta personer kan inte klara så höga alkoholnivåer vilket indikerar att det inte är personer som dricker vid enstaka tillfällen utan snarare personer som dricker hela veckan.

Personer som dricker mycket alkohol och som är rökare omkommer väldigt ofta i bränder orsakade av rökning [12], men i motsats till de äldre personerna som beskrevs ovan så antänds oftare stoppade möbler (och särskilt soffor). En möjlig åtgärd skulle kunna vara att distribuera e-cigaretter (eller Heat-Not-Burn-cigaretter) utan kostnad till personerna eftersom inkomstnivåerna normalt är låga. Förutom rökning så är även spisar en stor riskkälla för denna grupp vilket gör att installation av spisvakter sannolikt kan motiveras. Även brandvarnare är en bra åtgärd för denna grupp eftersom de normalt har den fysiska förmågan att utrymma om de vaknar (tyvärr har dock forskning visat att det är svårare att väcka personer som har druckit alkohol). En alternativ metod är såklart att hjälpa personen att begränsa alkoholintaget vilket kommer att ha många andra positiva effekter på personens liv utöver vad som diskuteras här.

För befolkningen i allmänhet så är risken mycket lägre än för de två grupperna ovan så för att en strategi mot dödsbränder ska vara effektiv så krävs ett tydligt och explicit fokus på en eller båda av dessa grupper. Från ett nyttobaserat perspektiv så ger den väsentligt lägre risken att mindre pengar finns tillgänglig för interventioner för denna grupp. Brandvarnare är dock en liten investering med mycket god effektivitet för denna grupp. Brandvarnare kommer även, som bieffekt, att minska

[10] Olja och smör var inblandat i 98% av alla bränder med öppna flammor i ett examensarbete som handleddes av författaren [124]. Annan typ av mat är mycket svår att antända med de temperaturer som kan uppnås på en spis.

egendomsskadorna för denna grupp och forskning har visat att kostnad/nytta-kvoten för brandvarnare är en bit över ett. De nuvarande kraven leder till att sovrum inte blir utrustade med brandvarnare bör dock ändras så att även sovrum utrustas med en brandvarnare. En annan aspekt som är viktigt för denna grupp är att informera om att bara försöka släcka en brand om de har en säker väg ut eftersom ca 20% av alla omkomna i bränder hade möjlighet att utrymma, men gjorde inte det i syfte att istället försöka släcka branden. Praktiskt skulle det kunna genomföras genom de kurser i grundläggande brandskydd som många går på genom sina arbeten där man skulle kunna lära sig att ”tänka som en väktare”. En väktare får lära sig att alltid vara mellan det som är farligt (inbrottstjuven eller liknande) och dörren så att de alltid har en säker reträttväg. Om samma tankebanor skulle kunna spridas till allmänheten gällande brand så skulle nog många liv kunna räddas.

När det gäller att rädda personer från inträffade bränder så visar resultaten från inkluderade studier vikten av både professionella och icke-professionella (t.ex. grannar) aktörer för att rädda liv vid bränder. En räddning är ofta beroende av att grannar agerar genom att antingen direkt utrymma personen eller genom att ringa räddningstjänsten. Det kan därför vara viktigt att fundera på hur viljan att göra något i dessa situationer kan ökas. I några fall i studien av personer som räddats av räddningstjänsten var lägenhetsdörren olåst och branden förhållandevis liten vilket gör att grannar hade kunnat göra en insats. Tyvärr valde de att inte göra det i dessa fallen vilket skulle kunna bero på bristande tillit mellan grannar. Det är också viktigt att betona vikten av tecknen på att en brand har inträffat når till grannarna. I fristående hus så kan det vara svårt att upptäcka bränder hos grannar, men också i moderna lägenheter med täta dörrar (som hindrar röklukt) och höga akustikkrav (som gör det svårare att höra en brandvarnare). Det är viktigt att undersöka alternativa sätt att informera potentiella räddare att en brand har inträffat och för äldre personer så är trygghetslarmet en sådan möjlighet. Redan idag trycker många i denna grupp på trygghetslarmet vid brand (eftersom de ofta är vakna), men det förbättras ytterligare genom att koppla en rökdetektor till trygghetslarmet vilket vissa kommuner gör idag. Tekniska hjälpmedel kan även användas för att uppmärksamma en betrodd granne om branden så att de kan göra en insats.

För räddningstjänsten är det tydligt att responstiden är viktig, men även vad enheten kan göra när den kommer fram till branden. Möjlighet till rökdykning krävs i många fall, men kan kompletteras med mindre enheter med en mer begränsad uppgiftsrepertoar. Forskningen inom området i denna avhandling är fortfarande explorativ och en viktig rekommendation för statliga myndigheter (till exempel MSB i Sverige) är att systematiskt börja samla in data på räddningar för att möjliggöra fortsatt forskning och utveckling inom området. Även tillämpning av metoden bör testas både genom att implementera ekvationen i en GIS-miljö, samt att genomföra lokala analyser som till exempel kostnad/nytta-analysen av en ny hävare till Grums som den lokala räddningstjänsten utförde [122]. Implementeringen i GIS-miljö skulle vara av värde både för att undersöka förmågan under normala förhållanden och under större insatser som kan göra att många enheter inte finns tillgängliga under en längre tid. Den kommer även att möjliggöra en samlad analys av den geografiska fördelningen av förmågor och risk-nivåer.

För att omsätta resultaten och rekommendationerna i denna avhandling i praktik så är det viktigt att de stora aktörerna kritiskt granskar sina nuvarande arbetssätt och utvecklar ett mer evidensbaserat arbetssätt. Det är därför lovande att både MSB och Brandskyddsföreningen har påbörjat ett sådant arbete.

Det är också viktigt att ansvaret för förebyggandet av dödsbränder, särskilt för de två riskgrupperna som beskrevs ovan, är tydligt i lagstiftningen. Det är tyvärr inte fallet i Sverige idag. Detta är inte ett forskningsproblem utan snarare ett administrativt och/eller juridiskt problem. För att forskningen ska vara av betydelse så krävs det att den omsätts i praktiken och i dagens samhälle med begränsade allmänna medel så måste ansvaret vara väldigt tydligt för att pengar ska prioriteras till brandförebyggande arbete.

Annex

Appended papers

Paper I	Jonsson, A., Runefors, M., Särdqvist, S. & Nilson, F. (2016) *Fire-Related Mortality in Sweden: Temporal Trends 1952 to 2013*, Fire Technology, Vol 52, Issue 6, pp 1697-1707 doi: 10.1007/s10694-015-0551-5
Paper II	Runefors, M., Johansson, N. & van Hees, P. (2016) *How could the fire fatalities have been prevented? An analysis of 144 cases during 2011-2014 in Sweden*, Journal of Fire Sciences, Vol 34, Issue 6, pp. 515-527, doi: 10.1177/0734904116667962
Paper III	Runefors, M., Johansson, N. & van Hees, P. (2017) *The effectiveness of specific fire prevention measures for different population groups*, Fire Safety Journal, vol. 91, pp.1044-1050, doi: 10.1016/j.firesaf.2017.03.064
Paper IV	Runefors, M., Bonander, C. & Jonsson, A. (2019) *Smoke Alarm Effectiveness in Preventing Fire Fatalities – An Assessment Based on Historical Trends and Current Fatalities*, Unpublished manuscript
Paper V	Runefors, M. (2019) *Measuring the Capabilities of the Fire Service to Save Lives in Residential Fires*, Fire Technology, doi: 10.1007/s10694-019-00892-y
Paper VI	Runefors, M., Jonsson, A. & Bonander, C. (2019) *Factors contributing to survival and evacuation in fires involving older adults*, Submitted to international journal

This thesis is about fatal fires and how they can be prevented

The picture on the front page is from one of these fires. The older man who lived alone in the apartment had limited mobility. Because of this, he placed his ashtray on the bed, beside the armchair where he usually sat while smoking. One day in February 2019, he missed the ashtray and his cigarette landed on the bed. The bed ignited and, because of his limited mobility, he was unable to escape. He died as a result of the fire.

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