What do we know about sprinkler reliability and can this knowledge be used for other water-based extinguishing systems?

How is data on reliability collected, analyzed and presented?

Conclusions and methods.

20th International Water Mist Conference, 27th October 2021

Arnstein Fedøy, M.Sc. Fire Safety/
Extinguishing Systems

Agenda

Part 1.

- How reliable is the reliability data for sprinkler systems?

- Bio
- Background
- Available literature
- Critical literature review
- Some findings
- Lack of analysis / validation tools
- Document analysis
- Findings and conclusions

Agenda

Part 2.

- How can we find or improve reliability data for other water-based systems?
- Who is interested in this data?
- Some pitfalls

Bio

HØGSKOLEN STORD/HAUGESUND

Sammenligning av vanntåke og sprinkling

Hovedprosjekt utført ved

Høgskolen Stord/Haugesund - Avd. Haugesund - ingeniorfag

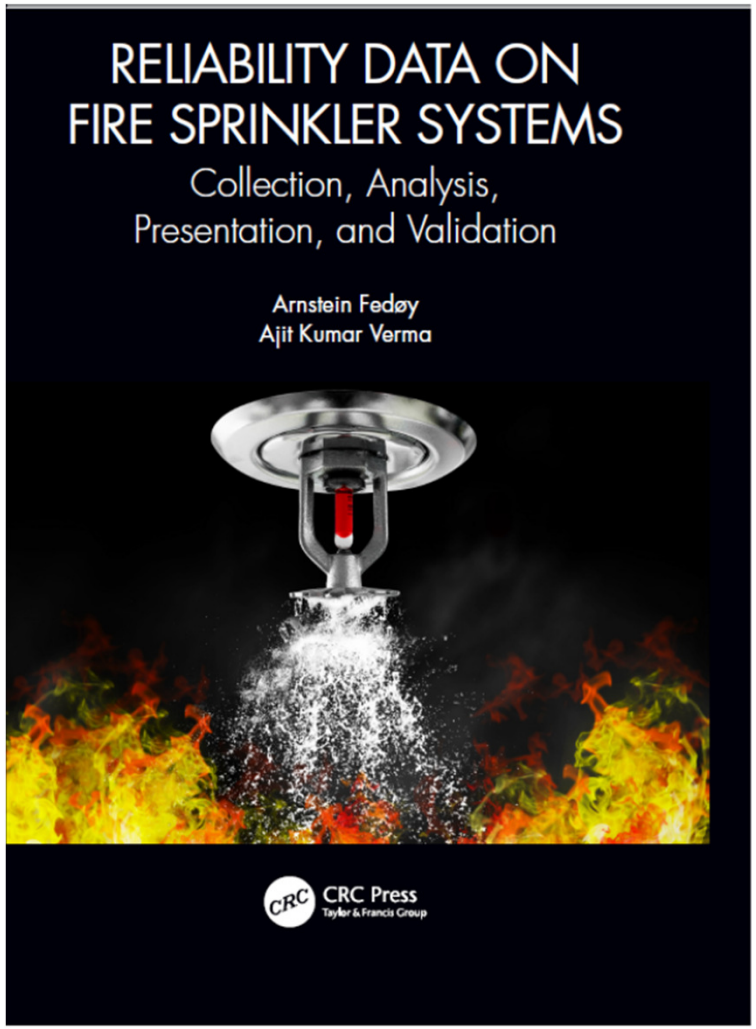
Studieretning: Sikkerhet, Branntekniikk

Av: Max Baretto Kandidat: 3
Arnstein Fedøy Kandidat: 24

Haugesund *Våren 2005*

IGNEUS BRANNSIKKERHET

Bio



IGNEUS
BRANNSIKKERHET

Background

Table 1 Koffel' s overview of previous studies

Reference	Reliability of Success	Comments
Marryat[1]	99.5	Inspection, testing, and maintenance exceeded normal expectations and higher pressures
Maybee[2]	99.4	Inspection, testing, and maintenance exceeded normal expectations.
Powers[3]	98.8	Office buildings only in New York City
Powers[4]	98.4	Other than office buildings in New York City
Finucane et al.[5]	96.9 – 97.9	
Milne[6]	96.6/97.6/89.2	
NFPA[7]	88.2 – 98.2	Data provided for individual occupancies – total for all occupancies was 96.2%.
Linder[8]	96	
Richardson[9]	96	
Miller[10]	95.8	
Powers[11]	95.8	Low rise buildings in New York City
US Navy[12]	95.7	1964 – 1977
Smith[13]	95	UK data
Miller[14]	94.8	
Budnick[15]	92.2/94.6/97.1	Values are lower in commercial uses (excludes institutional and residential)
Kook[16]	87.6	Limited data base
Ramachandran[17]	87	Increases to 94% if estimated number of fires not reported is included and based upon 33% of fires not reported to fire brigade.
Factory Mutual[18]	86.1	1970 – 1977
Miller[19]	86	Commercial uses (excludes institutional and residential)
Oregon State Fire Marshal[20]	85.8	1970 – 1978
Taylor[21]	81.3	Limited data base

Overview of literature

Reference	(Bukowski. R. W., 1999)	(Budnick, 2001)	(Koffel, 2006)
Marryat (Marryat, Rev. 1988)	Yes	Yes	Yes
NFPA (National Fire Protection Association, 1970)	Yes	Yes	Yes
Milne (Milne, 1959)	Yes	Yes	Yes
Powers (Powers, 1979)	Yes	Yes	Yes
Factory Mutual (Miller, 1973)	Yes	Yes	Yes? C
Smith (Smith, How Successful are Sprinklers, 1983)	No, B	No, B	Yes
Richardson (Richardson, 1985)	Yes	Yes	Yes
Finucane, M, and Pickney, D. (Finucane, Reliability of Fire Protection and Detection Systems, 1987)5	Yes	Yes	Yes
Maybee (Maybee, 1988)	Yes	Yes	Yes
Linder (Linder, 1993)	Yes	Yes	Yes
Taylor (Taylor, 1990)	Yes	Yes	No, B
Kook (Kim, "Exterior Fire Propagation in a High-Rise Building," a Master's Thesis,, 1990)	Yes	Yes	Yes
Ramachandran (Ramachandran, 1998)	No, B	No, B	Yes
Budnick (Budnick, 2001)	A		Yes

Table 1

Reference	Reliability of Success	Comments
Marryat[3]	99.5	Inspection, testing, and maintenance exceeded normal expectations and higher pressures
Maybee[4]	99.4	Inspection, testing, and maintenance exceeded normal expectations.
Powers[5]	98.8	Office buildings only in New York City
Powers[6]	98.4	Other than office buildings in New York City
Finucane et al.[7]	96.9 – 97.9	
Milne[8]	96.6/97.6/89.2	
NFPA[9]	88.2 – 98.2 **79,2 – 98,2**	Data provided for individual occupancies – total for all occupancies was 96.2%.
Linder[10]	96	
Richardson[11]	96	
Miller[12]	95.8	

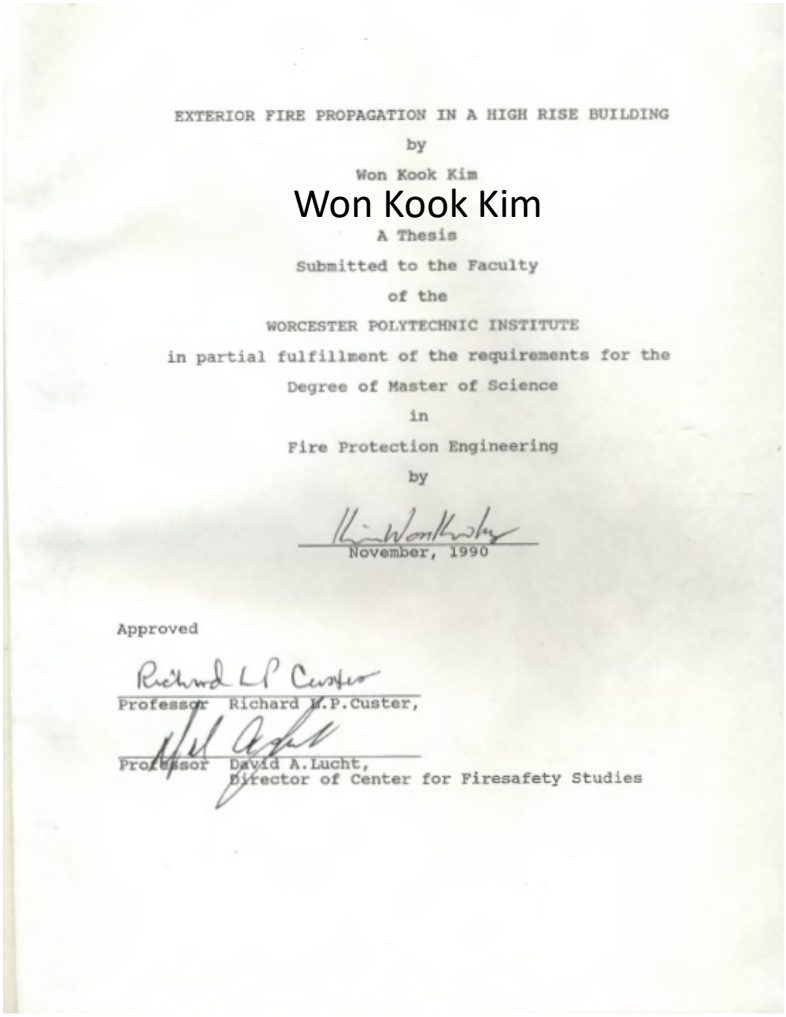
References

In the list, the reliability is listed as 95,8%

In the reference found, it is stated to be 85%

- In the references list Miller, this is listed as *Miller, M. J. (1974), "Reliability of Fire Protection Systems;" Loss Prevention ACEP Technical Manual, 8, 1974*

- I have only been able to find:
  Miller, Myron J. (1973), "The Reliability of Fire Protection Systems;" at Factory Mutual Research Corporation for The AIChE Loss Prevention Symposium, Philadelphia, PA, November 11-15, 1973



EXTERIOR FIRE PROPAGATION IN A HIGH RISE BUILDING

by

Won Kook Kim

A Thesis

Submitted to the Faculty

of the

WORCESTER POLYTECHNIC INSTITUTE

in partial fulfillment of the requirements for the

Degree of Master of Science

in

Fire Protection Engineering

by

November, 1990

Approved

Professor Richard K.P.Custer,

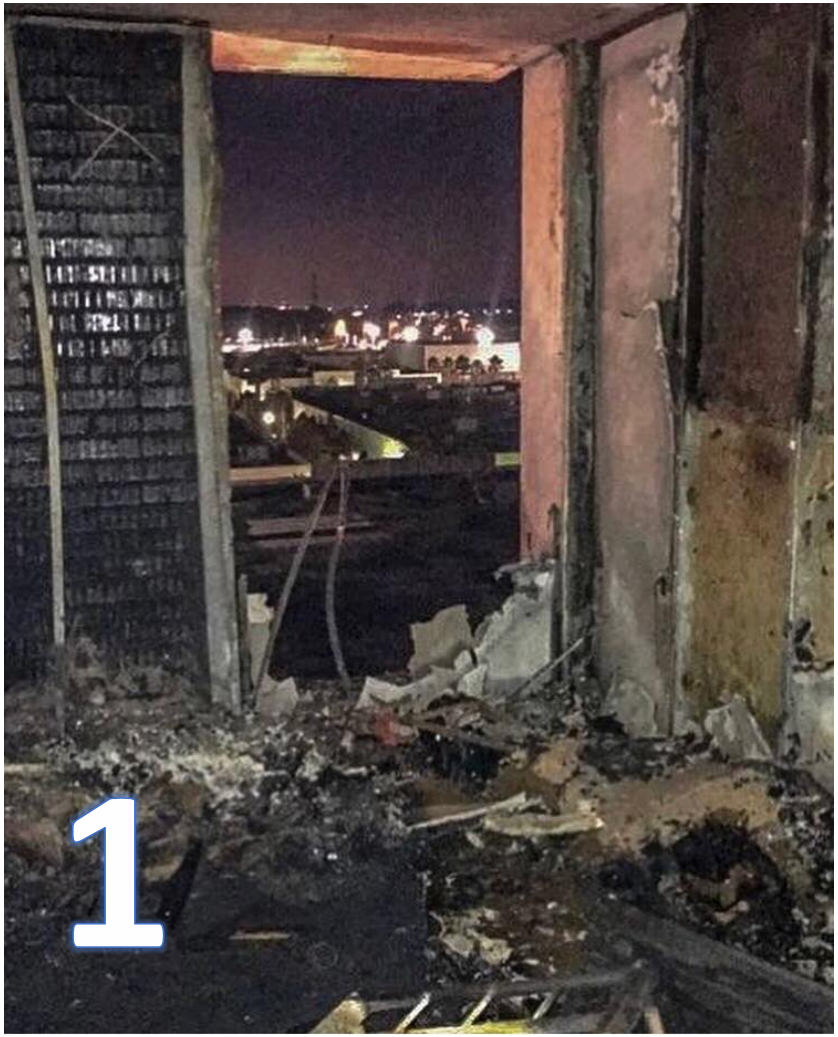
Professor David A.Lucht,
Director of Center for Firesafety Studies

Won Kook Kim

Critical literature review

- Literature review is used to find "gaps" in today's literature, to which the study will hopefully answer in whole or in part
- Literature review is also used to determine whether there is an "abundance" of knowledge in the field
- Literature review is also used as proofreading or comparison of results

- Critical literature review is "usually" not used in the engineering world, but all literature review should be critical in nature.
- As previous reviews have clearly not been critical, and the purpose of this study is to find out why this gap in reliability exists, also within the same country (NFPA vs. FM), this approach becomes even more important.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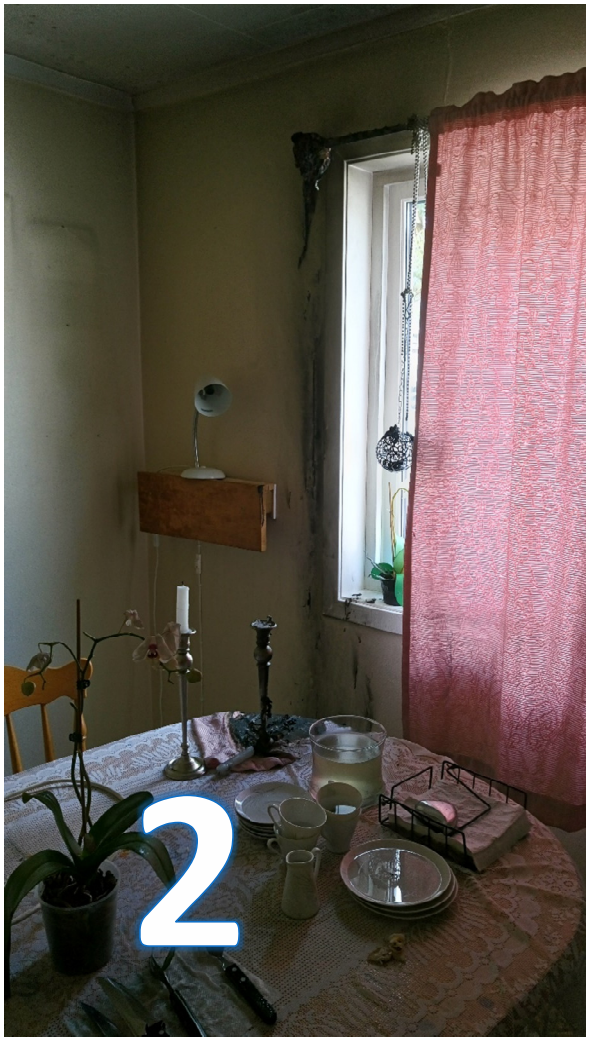
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Selection

- Comparative studies, were rejected
  - Only desire to look at raw data studies
- Applicability
  - Small areas, and short time aspect, were rejected
- Time relevance
  - Studies conducted before 1980 were rejected
- Recent studies

Overview of relevant studies

Reference	Success, individually and average (%)	Applied area/ Focus/Comments	Comments
Marryat (Marryat, Rev. 1988)	95.3 – 100 99.5	Inspection, testing, and maintenance exceeded normal expectations, and higher pressures	Data from 1886 – 1986
NFPA (National Fire Protection Association, 1970)	79.2 – 98.2 96.2	Data from 1897 – 1969 was 95.8% in average	Data from 1897 – 1924 and 1925 - 1969
NFPA (National Fire Protection Association Research, 2010)	80 – 94 91	This study was done on sprinkler and other automatic fire extinguishing equipment	Data from NFIRS 2004 – 2008
NFPA (National Fire Protection Association Research, 2017)	81 – 91 88	This study was done only for sprinkler	Data from NFIRS 2010 – 2014
NFSM (Optimal Economics, 2017)[1]	92 – 97.7 93.6[2]	United Kingdom	2017

Order of the critical literature review in the book

- **Marryatt, Fire – A Century of Automatic Sprinkler Protection in Australia and New Zealand – 1886-1986**
- Optimal Economics, Efficiency and Effectiveness of Sprinkler Systems in the United Kingdom: An Analyssis from Fire Service Data, 2017 (2011-2015)
- NFPA*, Automatic Sprinkler Performance Tables, 1970 Edition (1897-1969)
- **NFPA*, U.S. Experience with Sprinkler and Other Automatic Fire Extinguishing Equipment, 2010 (2004-2008)**
- NFPA*, U.S. Experience with Sprinklers, 2017 ((2010-2014)

* National Fire Protection Association

Marryatt, Fire – A Century of Automatic Sprinkler Protection in Australia and New Zealand – 1886-1986

- A nearly 500-page book on sprinklers in New Zealand and Australia, technical aspects, performance analysis, causes of fire, how sprinklers work in many situations, etc.
- It covers 9,022 fires and concludes that 99.46% of the fires were controlled by sprinklers.

- Challenge 1
  - Depending on where in the book you read, you get different numbers for reliability (6 - 10 sprinklers)
- Challenge 2
  - The book itself refers to 99.46% reliability *(See table)*

Table 13 Number of sprinklers operating in US and Australia/New Zealand as a per cent

Number of Sprinklers Operating	United States[1]				Australia and New Zealand		
	Wet System Per Cent	Dry System Per Cent	Total Numbers of Fires	Total System Per Cent	Number of Fires	Total Numbers of Fires	Total System Per Cent
1	42.6%	20.1%	29 733	37.4%	5 816	5 816	64.55%
2 or fewer	61.0%	32.7%	43 396	54.6%	1 431	7 247	80.41%
3 or fewer	70.2%	41.5%	50 769	63.8%	553	7 800	86.54%
4 or fewer	76.2%	48.7%	55 795	70.1%	290	8 090	89.79%
5 or fewer	80.2%	53.7%	59 156	73.4%	189	8 279	91.84%
6 or fewer	83.2%	57.8%	61 814	77.7%	144	8 423	**93.44%**
7 or fewer	85.2%	61.3%	63 724	80.1%	87	8 510	94.40%
8 or fewer	87.0%	64.2%	65 348	82.2%	76	8 586	95.24%
9 or fewer	88.3%	66.4%	66 571	83.7%	50	8 636	95.79%
10 or fewer	89.4%	68.5%	67 629	85.0%	47	8 683	**96.31%**
11 or fewer	90.4%	70.3%	68 533	86.2%	22	8 705	96.55%
12 or fewer	91.2%	72.4%	69 464	87.3%	24	8 729	96.82%
13 or fewer	91.7%	73.8%	69 990	88.0%	31	8 760	97.16%*
14 or fewer	92.6%	75.3%	70 788	89.0%	32	8 792	97.51%
15 or fewer	93.1%	76.2%	71 313	89.7%	22	8 814	97.75%
20 or fewer	95.0%	81.0%	73 347	92.2%	59	8 873	98.39%
25 or fewer	96.0%	84.3%	74 464	93.6%	36	8 909	98.79%
30 or fewer	96.9%	86.7%	75 411	94.8%	23	8 932	99.05%
35 or fewer	97.3%	88.6%	75 976	95.5%	12	8 944	99.17%
40 or fewer	97.7%	90.0%	76 472	96.2%	8	8 952	99.25%
50 or fewer	98.1%	91.9%	77 079	96.9%	6	8 958	99.31%
75 or fewer	98.9%	94.7%	77 995	98.1%	10	8 968	99.41%
100 or fewer	99.4%	96.3%	78 533	98.7%	4	8 972	99.45%
200 or fewer	99.8%	99.7%	79 384	99.8%	1	8 973	**99.46%**
All fires	100.0%	100.0%	79 544	100.0%	49	9 022	100.00%

Marryatt, Fire – A Century of Automatic Sprinkler Protection in Australia and New Zealand – 1886-1986

- A nearly 500-page book on sprinklers in New Zealand and Australia, technical aspects, performance analysis, causes of fire, how sprinklers work in many situations, etc.

- It covers 9,022 fires and concludes that 99.46% of the fires were controlled by sprinklers.

- Challenge 1
  - Depending on where in the book you read, you get different numbers for reliability (6 - 10 sprinklers)

- Challenge 2
  - The book itself refers to 99.46% reliability *(See table)*

- Challenge 3
  - **Wormald International Group of Companies being the only* organization which continued to submit reports to the end of 1986" (* author's highlight)**

- Relability or robustness?


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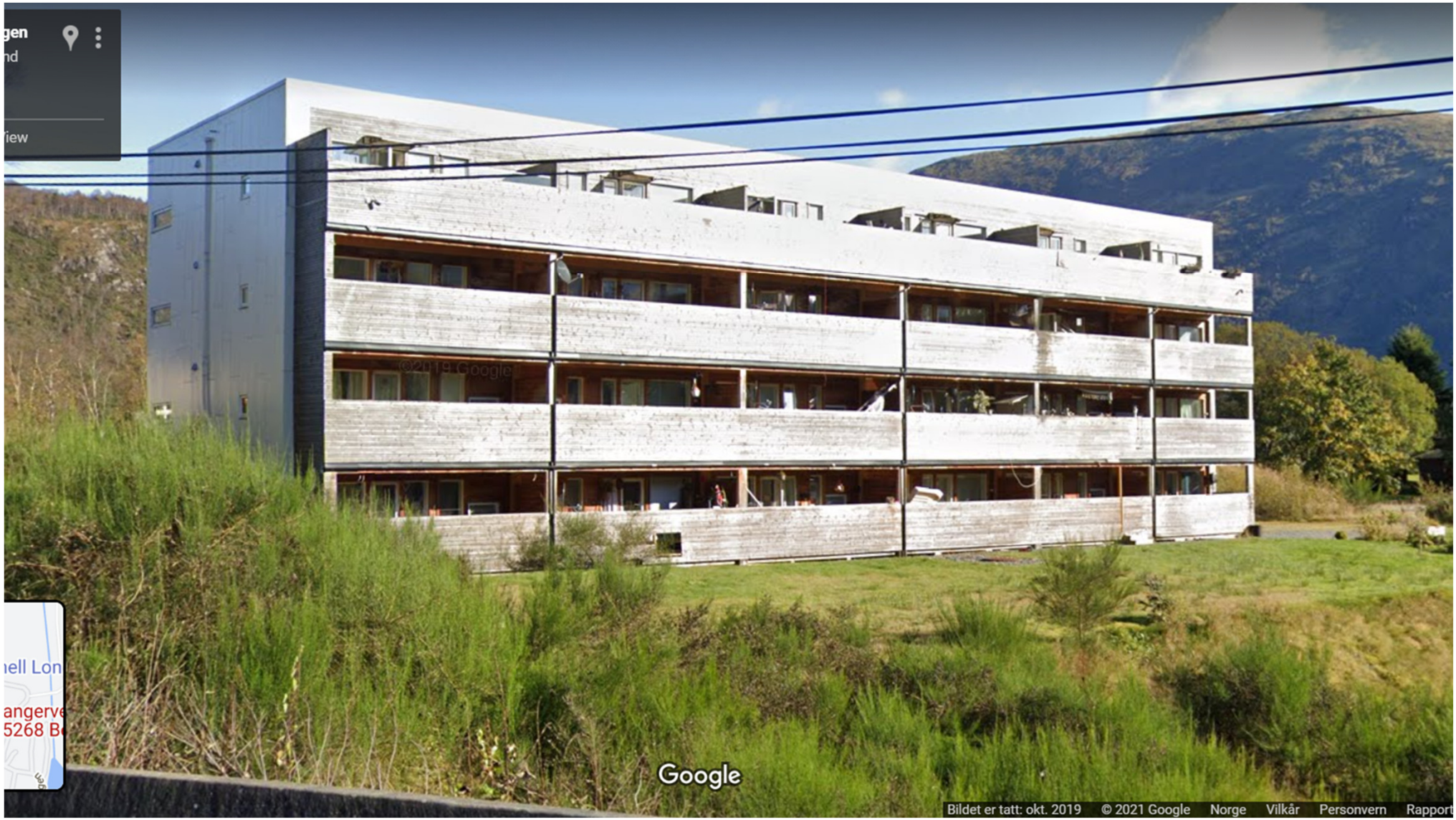
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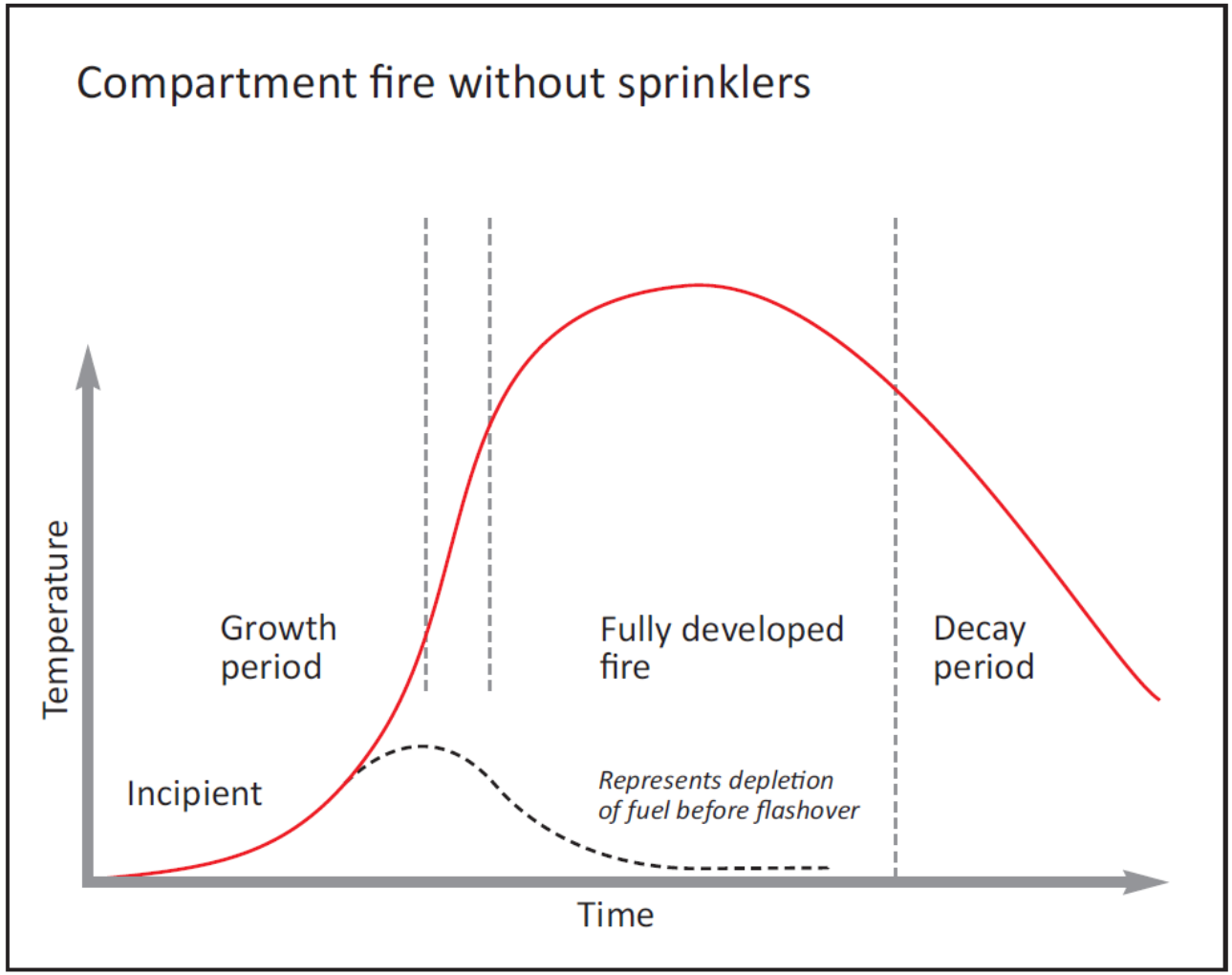
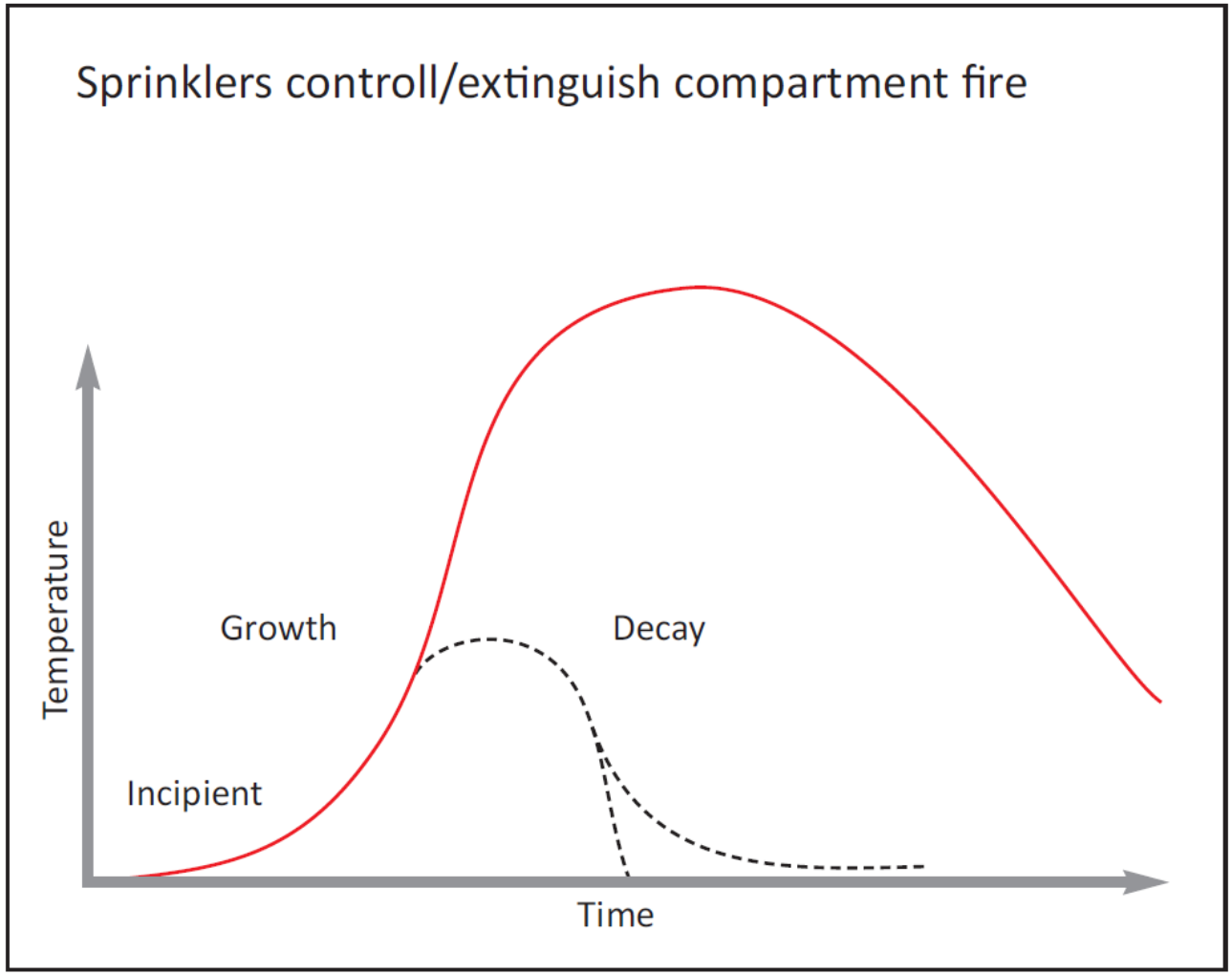
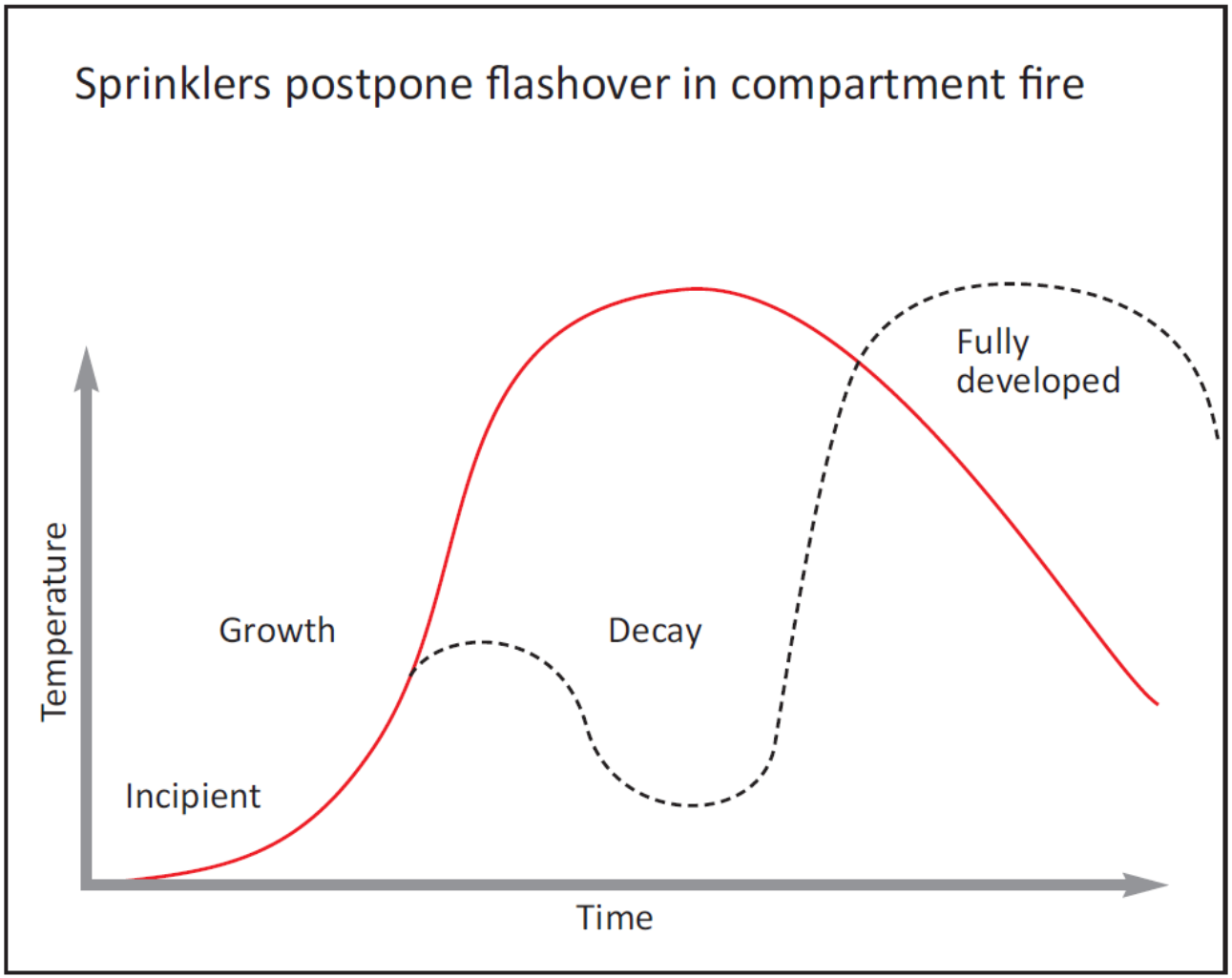
Norge
Vilkår
Personvern
Rapport


Compartment fire without sprinklers
Temperature
Growth period
Fully developed fire
Decay period
Incipient
Represents depletion of fuel before flashover
Time


Sprinklers controll/extinguish compartment fire
Temperature
Growth
Decay
Incipient
Time


Sprinklers postpone flashover in compartment fire
Fully developed
Temperature
Growth
Decay
Incipient
Time

NFPA, U.S. Experience with Sprinkler and Other Automatic Fire Extinguishing Equipment, 2010 (2004-2008)

- Data comes from U.S. Fire Administration's National Fire Incident Reporting System (NFIRS) and is scaled through NFPA's survey. About. 500,000 fires and 11% (55,310) involve fires in buildings with fire extinguishing systems.

- Sprinklers activated in 91% of cases where the fire was large enough and were effective 96% of the time.
  Reliability 91 * 96 = 87%.

- Challenge 1:
  - There are no definitions or explanations for keywords / phrases. No one has investigated what big enough or too small means. Neither theoretical nor empirical.
- Challenge 2:
  - The report is based on several assumptions.

- "As noted, for most rooms in most properties, **effective performance is indicated by confinement of fire to the room of origin***. For the few rooms where the design area is smaller than the room, a sprinkler system can be ineffective in terms of confining fire to the design area but still be successful in confining fire to the larger room of origin. Therefore, one might expect the percentage of fires with flame confined to room of origin to be slightly larger than the combined performance (operating effectively) for any given property use."

- "***Effectiveness declines when more sprinklers operate.*** *When more than 1-2 sprinklers have to operate, this may be taken as an indication of less than ideal performance."*

Summary so far

- The critical literature review has given several questions and few answers
- Lack of traceability, understanding, logical justifications and common vocabulary / definitions (success, performance, performance effectiveness, operating reliability, operational efficiency, and effectiveness)
- It seems that common scientific principles, including calculation rules for reliability calculations do not apply to the fire field
- What do you do then? You turn around and see how other scientific disciplines do the same job.

Document analysis

- **Document analysis** or source research is analysis of documents (secondary data) to seek to answer the research question (problem) by collecting and analyzing other words, sentences and / or stories about a topic and reports
- A **literature review** attempts to find theory or practice gaps (*or abundance*)
- **Document survey is a systematic tool** for examining all types of documents to find the answer to the question / questions.

1. It is impossible to get primary data
2. One wants to learn how others have interpreted situation, event or data
3. One wants to learn what has been done or said

How to perform a survey?

1. Development of problem and purpose
2. Choice of design
3. Type of data (*qualitative or quantitative*)
4. Method of data collection
5. Selection and limitation of data
6. Analysis of data
7. Quality assurance of the analysis
8. Discussion and presentation of results

Table 25 General overview of document analysis validation

Preparation and collection		Analysis		Presentation	
1. Development of problem and purpose		6. Analysis		8. Discussion and presentation	
2. Choice of design		7. Quality assurance of the analysis			
3. Type of data					
4. Method of data collection					
5. Selection and limitation					

Quality assurance of the steps in the document analysis

Preparation and collection		Analysing		Presentation	
1. Development of problem and purpose a) Is the issue clear? b) Is it explanatory (causal) or descriptive? c) Can it be generalized?		6. Analysis		8. Discussion and presentation a) Methodological discussion b) Substantial discussion (connection of findings and theory) c) Presentation (also uncertainty)	
2. Choice of survey design a) intensive (deep) or extensive (width) study design. b) Descriptive or explanatory		7. Quality assurance of the analyse a) Conceptual validity b) Validation of contexts c) External validity d) Are the results trustworthy?			
3. Type of data (qualitative or quantitative)					
4. How to collect data? a) Operationalization, make a concept measurable b) Design of the survey c) Source and use of sources					
5. Selection and limitation					

Table 46 Document analysis of *Fire - A Century of Automatic Sprinkler Protection in Australia and New Zealand - 1886-1986*

Preparation and collection		Analysis		Presentation	
1. Development of problem and purpose	No[4]	6. Analysing	No[14]	8. Discussion and presentation	No[23]
a) Is the issue clear?	No[1]			a) Methodological discussion	No[20]
b) Is it explanatory (causal) or descriptive?	No[2]			b) Substantial discussion (connection of findings and theory)	No[21]
c) Can it be generalized?	Yes[3]			c) Presentation (also uncertainty)	No[22]
2. Choice of overall study design	Yes[7]	7. Quality assurance of the analysis	No[19]		
a) Intensive (deep) or extensive (width) study design.	No[5]	a) Conceptual validity	No[15]		
b) Descriptive or explanatory	Yes[6]	b) Validation of correlations	No[16]		
		c) External validity	Yes[17]		
		d) Are the results trustworthy?	No[18]		
3. Type of data (qualitative or quantitative)	Yes[8]				
4. Method of data collection	No[12]				
a) Operationalization: make a concept measurable	Yes[9]				
	No[10]				
b) Design of the study					
c) Source and use of sources	No[11]				
5. Selection and limitation	No[13]				

Oppsummering

Table 48 Overview of document analysis validation for the examined studies

Reference	1.	2.	3.	4.	5.	6.	7.	8.	SUM
Marryat (Marryat, Rev. 1988)	No	Yes	Yes	No	No	No	No	No	**No**
NFPA (National Fire Protection Association, 1970)	No	Yes	Yes	No	Yes	Yes	Not sure	No	**No**
NFPA (National Fire Protection Association Research, 2010)	No	Yes	Yes	No	Yes	Yes	No	No	**No**
NFPA (National Fire Protection Association Research, 2017)	No	Yes	Yes	No	Yes	Yes	No	No	**No**
NFSM (Optimal Economics, 2017)	No	Yes	Yes	No	No	Not sure	No	No	**No**

1. Development of problem and purpose
2. Choice of overall study design
3. Type of data
4. How to collect data
5. Selection and limitation
6. Analysis
7. Quality assurance of the analysis
8. Discussion and presentation

Summary

The validation showed that all surveys fail in four out of eight areas

1. Unclear issues, including lack of definitions and purpose of the surveys
2. Uncertain data collection process
3. Varying quality of analysis and lack of quality assurance
4. Lack of systematics in presentation and discussion

Unclear issues, including lack of definitions and purpose of the surveys.

- What is reliability?
  The word reliability is often used inaccurately, but here reliability means the ability to function as intended. More precisely, it is the characteristics or expressions of the ability of a component or system to perform an intended function.

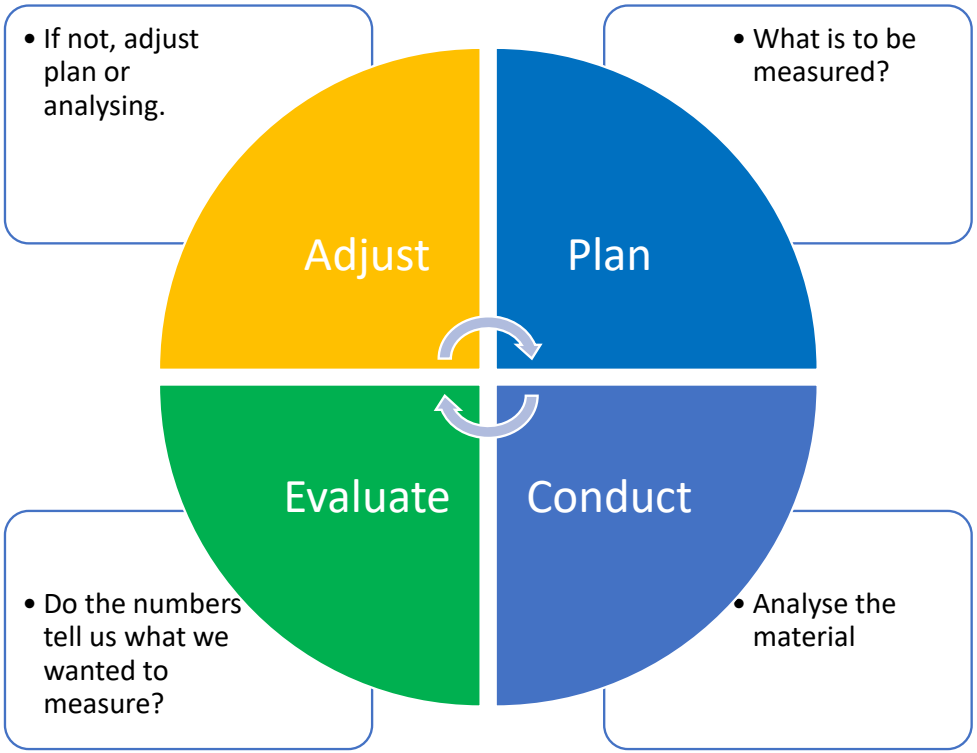
- Reliability for sprinkler systems is the ability to function as designed (designed and installed) according to the current/chosen standard.

Uncertain data collection process

- What does the ability to function as designed for a sprinkler system mean? Well, it comes down to what kind of sprinkler system is of interest.
- "*NFPA 13D,1.2.2 A sprinkler system designed and installed in accordance with this standard shall be* ***expected to prevent flashover*** *(total involvement) in the room of fire origin, where sprinklered, and* ***to improve the chance for occupants to escape or be evacuated.***"
- "*NFPA 13, 1.2.1 The purpose of this standard shall be to provide a* ***reasonable degree of protection for life and property*** *from fire through standardization of design, installation, and testing requirements for sprinkler systems, including private fire service mains, based on sound engineering principles, test data, and field experience.*"

- None of the studies have looked at whether there are fundamental differences, e.g., between a residential sprinkler system with two dimensional sprinklers and an ESFR system.

Varying quality of analysis and lack of quality assurance



Lack of systematics in presentation and discussion.

- Discussions, comparisons with previous or other studies, trends if possible and honest presentation of uncertainty must be presented to the reader.

- "*Wormald International Group of Companies being the only organization which continued to submit reports to the end of 1986.*"

Summary

- None of the surveys has looked at whether there are fundamental differences, e.g., between residential sprinkler systems with two dimensional sprinklers and ESFR systems
- None of the studies examined have looked at reliability as the ability to function as designed
- None of the examined reports can be taken as income for a general documentation of reliability

The New Zealand (Department of Building and Housing, 2005) stats

- "*….recognise that there is* ***as yet inadequate data for fire engineering to achieve the accuracy that is expected*** *from, for example, structural engineering. In particular, the probabilities used for a fire analysis must be based on fire statistics derived from a comparatively small data pool of mainly overseas buildings of unknown design.* ***That applies not only to fire scenarios but also to the proper functioning of critical systems including the sprinklers****, ….*
- *There appears to be* ***no certainty*** *as to the extent to which those statistics and probabilities are appropriate for use in the New Zealand context.*"

- Before part 2, any question?

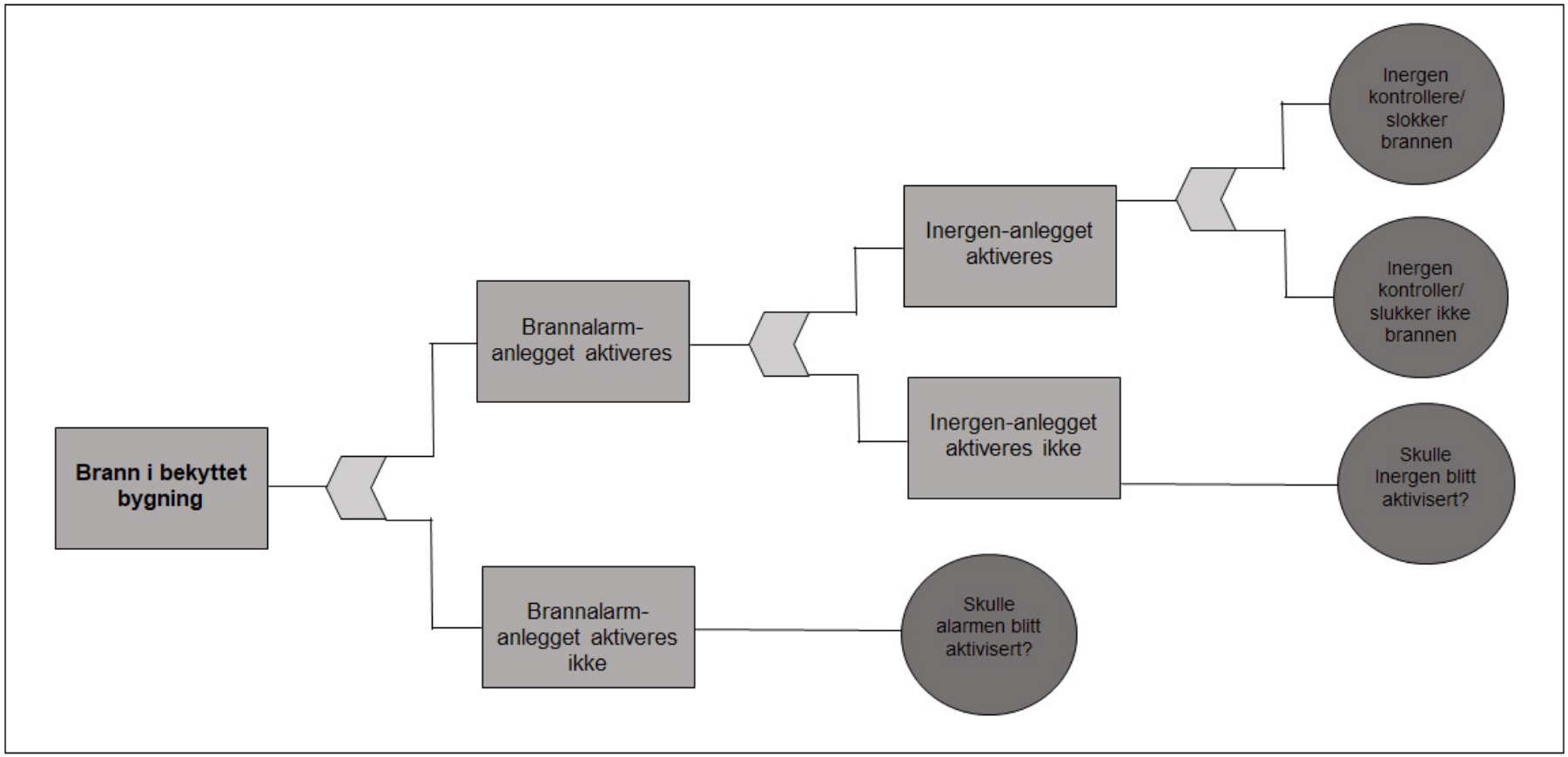
Part 2. How can we find or improve reliability data for other water-based systems?

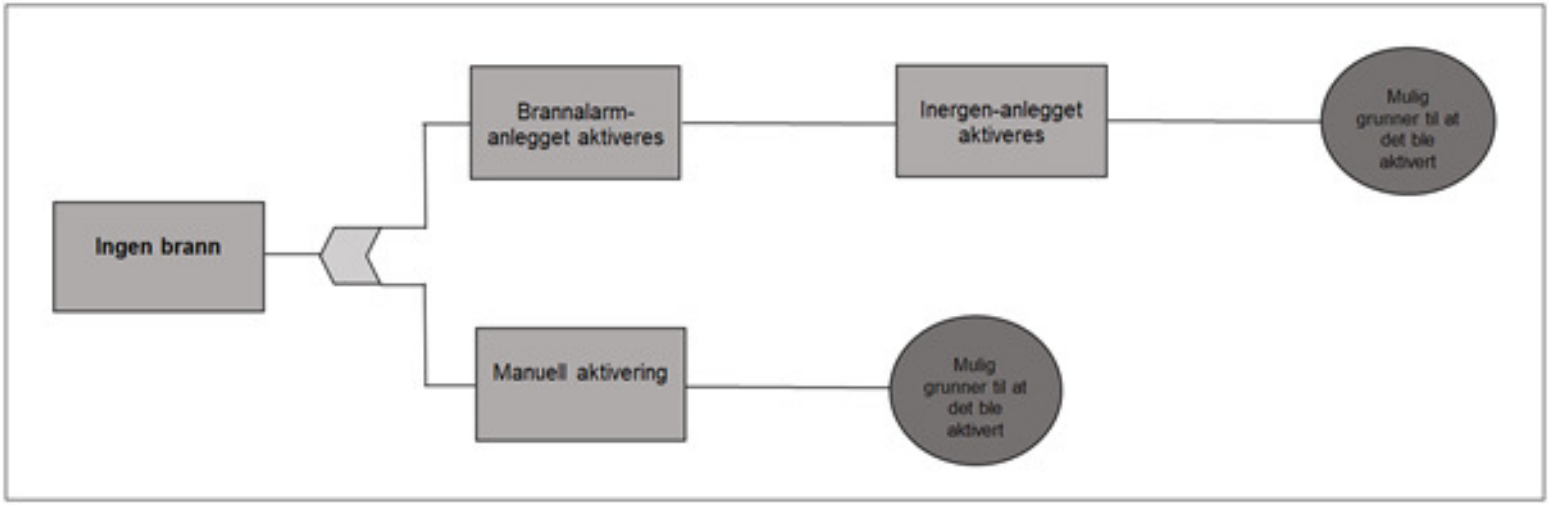
- What is the context?
  - The system or a manufacturer?
- Regulations.
  - Demands or comparison?
- Collection of data.
  - One person, one group or by others?
- Limitations of analysis
  - Less is more (or better)

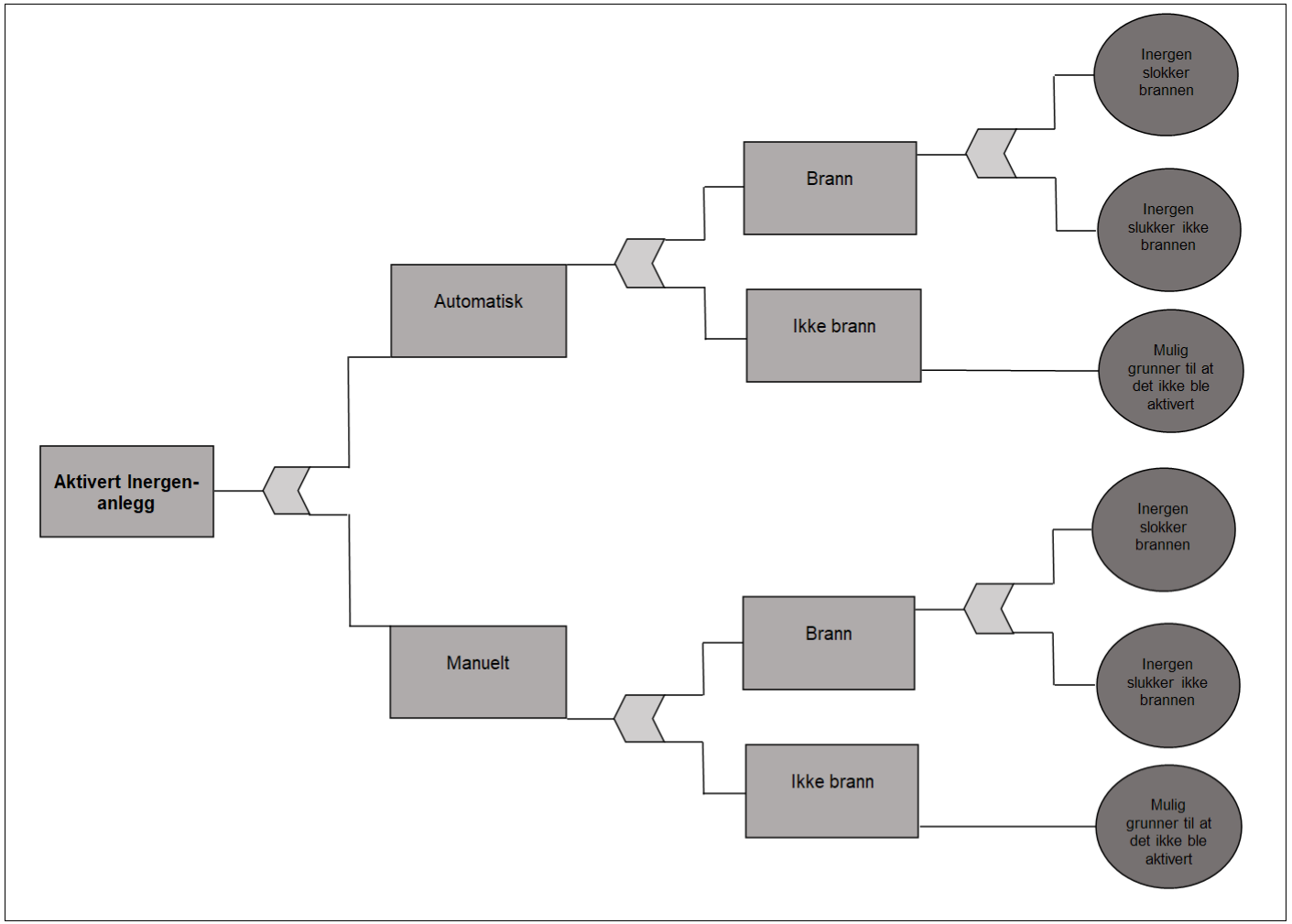
Main division in a reliability study

Preparation and collection		Analysis		Presentation	
1. Development of problem and purpose		4. Analysis		6. Discussion and presentation (report)	
2. Choice of design on the survey (descriptive or explanatory)		5. Quality assurance of the analysis			
3. Method of data collection					

Table 1 Overview of phases, and division of the steps in the study


Brann i bekyttet bygning
Brannalarm-anlegget aktiveres
Brannalarm-anlegget aktiveres ikke
Inergen-anlegget aktiveres
Inergen-anlegget aktiveres ikke
Inergen kontrollere/ slokker brannen
Inergen kontroller/ slukker ikke brannen
Skulle Inergen blitt aktivisert?
Skulle alarmen blitt aktivisert?


Ingen brann
Brannalarm-anlegget aktiveres
Inergen-anlegget aktiveres
Mulig grunner til at det ble aktivert
Manuell aktivering
Mulig grunner til at det ble aktivert


Aktivert Inergen-anlegg
Automatisk
Manuelt
Brann
Ikke brann
Brann
Ikke brann
Inergen slokker brannen
Inergen slukker ikke brannen
Mulig grunner til at det ikke ble aktivert
Inergen slokker brannen
Inergen slukker ikke brannen
Mulig grunner til at det ikke ble aktivert

- Thank you for your attention ☺

https://www.crcpress.com/Reliability-Data-on-Fire-Sprinkler-Systems-Collection-Analysis-Presentation/Fedoy-Verma/p/book/9780367251857

Paperback 50€, Hardback 165€ and eBook 45€.