Developing Key Fire Safety Indicators for Retail Buildings

Using a Multi Attribute Decision Making Method with a Hierarchical Approach

Anders Olsson | Department of Fire Safety Engineering
| LTH | LUND UNIVERSITY

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Title

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– Using a Multi Attribute Decision Making Method with a Hierarchical Approach

Titel

Utveckling av nyckeltal inom brandsäkerhet för detaljhandel
– Med användning av en multiattributbeslutsmetod med hierarkistrategi

Author: Anders Olsson

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Abstract

In order to develop indicators measuring the most important aspects of fire safety, the initial approach undertaken was to identify the fire safety components that have the largest importance to a building's overall fire safety, and to let these components form the basis for the indicator development. Through the use of a Multi Attribute Decision Making (MADM) methodology with a hierarchical approach, the most important components in relation to a building's overall fire safety were identified. The indicators were developed using a reasoning approach due to the lack of established documented strategies for indicator development. The most important features of each component were identified through a literature review, and were considered to be suitable features to form the basis for meaningful indicators within the area of fire safety. Based on the three components of sprinkler system, detection system, and personnel, a total of seven indicators were developed. The developed fire safety systems indicators were: sprinkler activations per building area, summarised grade for sprinkler system features, detector activations per building area, and summarised grade for detection system features. The personnel component rendered three components: number of personnel per building area, personnel per customer, and weighted number of fire safety training sessions.

Brandteknik
Lunds tekniska högskola
Lunds universitet
Box 118
221 00 Lund

www.brand.lth.se
Telefon: 046 - 222 73 60

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

www.brand.lth.se
Telephone: +46 46 222 73 60

Abbreviations

AHP	Analytical Hierarchy Process
ICC	International Code Council
ICE	Identification, Collecting, Ending (the ICE-approach)
IEC	International Electrotechnical Commission
ISO	International Organization for Standardization
ITM	Inspection, Testing and Maintenance
KFSI	Key Fire Safety Indicator
MADM	Multi Attribute Decision Making
MCDM	Multi Criteria Decision Making
MODM	Multi Objective Decision Making
NFPA	National Fire Protection Association
OECD	The Organisation for Economic Co-operation and Development
PRA	Probabilistic Risk Analysis
QRA	Qualitative Risk Assessment
RTI	Response Time Index
SAW	Simple Additive Weighting
SFPE	Society of Fire Protection Engineers
TIV	Total Insurable Value
WPM	Weighted Product Method

Nomenclature

y_i	Component grade	[-]
y_i^{min}	Lowest component grade	[-]
y_i^{max}	Highest component grade	[-]
x_i	Component weights	[-]
w_i	Normalised component weights	[-]
n	Number of components	[-]
τ_e	Time constant	[s]
V_g	Gas velocity	[m/s]
t_a	Activation time	[s]
T_a	Activation temperature	[°C]
T_0	Initial temperature	[°C]
T_g	Ambient temperature	[°C]
w_{pt}	Personnel training weight factor	[-]

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Summary

Indicators in various forms have been utilised throughout our history. Today, indicators can be found in practically all parts of society from households to companies and governments. They are commonly utilised to measure performance in terms of, for example, profit, safety, or quality. Examples of common indicators include stock price to earnings ratio (company evaluation), number of tank leakages (process industry), and number of attendants per patient (health care).

The goal with this thesis is to develop meaningful indicators within the field of fire safety, and more specifically the fire safety of retail buildings and retail buildings with high rack storage. In order to develop indicators measuring the most important three aspects of fire safety, the initial approach undertaken was to identify the fire safety components that have the largest importance to the overall fire safety of a building, and let these components form the basis for the development of indicators.

Established methodologies within the area of fire safety used to undertake such a task are examples of Multi Attribute Decision Making (MADM). These methods are used to decide between alternatives that are characterised by multiple attributes ("attributes" are synonymous with objectives, strategies and components in this thesis). As part of the MADM method approach to identifying the most important components in relation to the overall fire safety of a building, a hierarchical approach was taken.

A fire safety hierarchy was generated which set out the policy, objectives, strategies, and components of fire safety. The policy, in other words the overall objective of fire safety, was "a satisfying level of fire safety" and the objectives were "provide life safety", "provide property protection" and "provide business continuance". The strategies encompassed the areas of fire extinguishment, emergency egress, limiting fire and smoke spread, and ignition prevention. Twenty fire safety components including sprinkler system, evacuation alarm, customers, internal linings and fire load were included at the lowest level of the hierarchy.

An expert panel was consulted to weight the attributes in relation to their importance to the policy. Initially, the objectives were weighted in relation to the policy, then the strategies were weighted in relation to the objectives and finally the components were weighted in relation to the strategies. Through matrix multiplication, the component weights in relation to the policy were produced, allowing the components with the highest weight in relation to the policy (the most important components) to be identified. The components identified to form the basis for indicator development were sprinkler system, detection system, personnel, and inspection, testing and maintenance (ITM).

The indicators were developed using a reasoning approach due to the lack of established documented strategies for indicator development. The most important features of each component were identified through a literature review. These features were identified to be the most suitable to form the structure for meaningful indicators within the area of fire safety.

The ITM component was concluded not be appropriate to form the basis for one or more indicators. It was concluded that the multifaceted nature of the component would require too complex an indicator as well as many simplifications.

Based on the components of sprinkler system, detection system and personnel, a total of seven indicators were developed. The developed fire safety systems indicators were: number of sprinkler activations per building area, summarised grade for sprinkler system features, number of detector activations per building area and summarised grade for detection system features. The personnel component rendered three components: number of personnel per building area, number of personnel per number of customers, and weighted number of fire safety training sessions.

Sammanfattning

Indikatorer i olika former har använts så länge det funnits människor. Idag används indikatorer i nästan alla delar av samhället, exempelvis i hushåll, företag och stater. Ofta används de för att mäta prestationer i olika former, såsom vinst, säkerhet, kvalitet etc. Vanligt förekommande indikatorer är pris per aktie (företagsvärdering), antal läckage (processäkerhet) och antal vårdare per patient (sjukvårdskvalitet).

Målet med denna uppsats är att utveckla meningsfulla indikatorer inom brandsäkerhet, och mer specifikt för byggnader som bedriver detaljhandel och detaljhandel med lagringshöjd över 3,7 meter. För att utveckla indikatorer som mäter brandsäkerhetens mest signifikanta delar antogs strategin att identifiera de komponenter i en byggnads brandsäkerhet som är av störst betydelse, och basera utvecklingen av indikatorer på dessa komponenter.

Etablerade metoder inom brandsäkerhet som kan användas för att identifiera dessa komponenter kan sammanfattas med begreppet multiattributbeslutsfattande (MADM). Detta begrepp syftar till metoder som används för beslutsfattande där det finns flera alternativ vilka har karaktären av att de kan delas upp i flera attribut (i denna uppsats synonymt med mål, strategier och komponenter). Som en del i den multiattributbeslutsmetod som valdes, användes en hierarkisk strategi.

En brandsäkerhetshierarki utformades vilken innehöll nivåerna; övergripande mål, mål, strategier och kompententer. ”Säkerställa en tillfredställande brandsäkerhetsnivå” valdes som övergripande mål och ”säkerställa skydd av bygganden”, ”säkerställa skydd av liv” och ”säkerställa kontinuitet i verksamheten” valdes som mål. Strategierna som valdes involverade brandsläckning, utrymning, begränsande av brand- och rökspridning samt förhindrande av antändning. Tjugo brandsäkerhetskomponenter inkluderades i hierarkin, till exempel sprinklersystem, detektionssystem, utrymningslarm, kunder, interna ytskikt och brandbelastning.

En expertpanel tillfrågades för att vikta attributen med avseende på dess betydelse i relation till det övergripande målet. Inledningsvis viktades målen mot det övergripande målet, sen viktades strategierna i relation till målen och slutligen komponenterna i relation till strategierna. Genom matrismultiplikation beräknades komponenternas vikt i relation till det övergripande målet. Komponenterna med den största vikten (den största betydelsen) för det övergripande målet kunde då identifieras. Komponenterna med störst betydelse valdes att utgöra basen för utvecklingen av indikatorerna, dessa var; sprinklersystem, detektionssystem, personal och inspektion, kontroll och underhåll (ITM).

På grund av det begränsade utbudet av etablerade, dokumenterade, metoder för utveckling av indikatorer valdes en resonerande metodik. De viktigaste egenskaperna för varje komponent identifierades via relevant litteratur inom området. Dessa egenskaper utgjorde basen för utvecklingen av meningsfulla indikatorer inom brandsäkerhet för byggnader som bedriver detaljhandel.

ITM komponenten bedömdes inte lämplig att forma basen för utveckling av indikatorer. Komponenten är till sin karaktär mycket mångfacetterad, vilket skulle kräva många förenklingar, samt att indikatorerna skulle bli alltför komplexa.

Utifrån komponenterna sprinklersystem, detektionssystem och personal utvecklades totalt sju indikatorer. De utvecklade indikatorerna för brandsäkerhetssystem var: antal sprinkleraktiveringar per byggnadsarea, summerad värdering för sprinklersystem, antal detektoraktiveringar per byggnadsarea och summerad värdering för detektionssystem. Baserat på personalkomponenten utvecklades tre indikatorer: antal personal per kund, antal personal per byggnadsarea och antalet viktade brandskyddsövningar/brandskyddsträningar.

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1 Introduction

1.1 Background

The fire safety of today's retail buildings is often complex and is encompassed by numerous more or less interrelated fire safety components such as fire extinguishing systems, smoke evacuation systems, personnel and customers (Stollard & Abrahams, 2002). Naturally, the presence, design and other characterising traits of the fire safety components can vary between buildings, depending on how the buildings are designed. By consequence, the level of fire risk may vary as well. To establish that buildings do not exceed a certain level of fire risk, the fire safety regulations of many countries aim to define how buildings are required to be designed in terms of fire safety. In order to evaluate various design alternatives in terms of fire safety, fire risk analysis methods can be utilised. These methods can also be utilised to analyse the fire risk of buildings with existing fire safety designs, in order to evaluate whether the fire risk level still complies with fire safety regulations and/or internal company regulations.

There are several established risk analysis methods developed for the purpose of analysing building fire risk. These methods can be based on for example fire related statistics, fire scenarios or fire safety components. Fire safety methods are often divided into the following three groups, based on the required input and the type of fire risk measure that is produced (ISO, 2017).

- Qualitative methods
- Semi-quantitative methods
- Quantitative methods

This categorisation is made on the basis of the required input and the type of fire risk measure that is produced. Even though these types of methods differ in a number of areas, including for example comprehensiveness and applicability, they have several traits in common. One is that each type of analysis provides a measure of fire risk that is based on the input available for the respective method at the point in time the analysis is undertaken. This has the effect that changes in the fire safety components – behavioural or technical – that occur after the fire risk analysis is undertaken, are not considered in the fire risk level determined by the fire risk analysis. Examples of these behavioural or technical changes to the fire safety components may include upgrades or downgrades to fire safety systems, decreased number of personnel or the removal of a fire wall. These changes have an apparent effect on a building's level of fire risk.

To consider technical or behavioural changes to fire safety components, new fire risk analyses have to be undertaken. Regardless of the type of fire risk analyses chosen for this purpose, a considerable amount of monetary and personnel resources are required. An alternative may be to update previously undertaken fire risk analyses to reflect the changes to the fire safety components. Examples of methods that would allow to be updated as described, include for example various semi-quantitative methods such as the Gretener method (Kaiser, 1979) and other fire risk indexing methods (e.g. Magnusson and Rantatalo (1998) and Frantzich (2000, 2005, 2018)). Small changes in the components may not justify an update to an undertaken fire risk analysis, this as it is possible that the analysis method does not allow for small changes to be incorporated, as well as the resources it would require. Instead of having to undertake new – or update existing – fire risk analyses, a tool that facilitates continuous and simplified monitoring of technical and behavioural changes to fire safety components, which in turn would provide an indication of building fire risk, would be beneficial. A tool which is commonly and widely utilised to monitor central components over time is indicators.

Common areas where indicators are frequently utilised include corporate finance (e.g Kotane and Kuzmina-Merlino (2012)), health care (e.g. Khalifa and Khalid (2015)), marketing (e.g. Saura, Palos-Sánchez, and Suárez (2017)) and the oil industry (e.g. Øien et al. (2011b)). Within corporate finance, indicators are for example utilised to monitor aspects of the company that impact its profit, such as generated return on assets, sales margin and sales growth (Robinson, Greuning, Henry, & Broihahn, 2009). Within the field of health care, indicators are often denoted as "quality indicators" and aim to measure various quality aspects of a health care facility (Khalifa and Khalid, 2015). Number of patients per attendant (Spetz, Donaldson, Aydin, & Brown, 2008), hospital admissions for psychiatric patients (Hermann et al., 2006) and number of surgeries per surgeon (Yavorskyy, 2008) are common "quality indicators". The areas of corporate finance and health care have apparent similarities with fire safety in the sense that a primary property – profit, quality and fire safety – are dependent on underlying, non-consistent components. Fire safety is, however, an area to which the concept of indicators has not been applied, despite the apparent utility the use of indicators would contribute to the field. A conceptual description of how indicators within the field of fire safety may be utilised is presented in Figure 1-1. The figure describes that the fire safety components are defined in accordance with fire safety regulations, while the technical and behavioural changes of the components are measured using indicators.

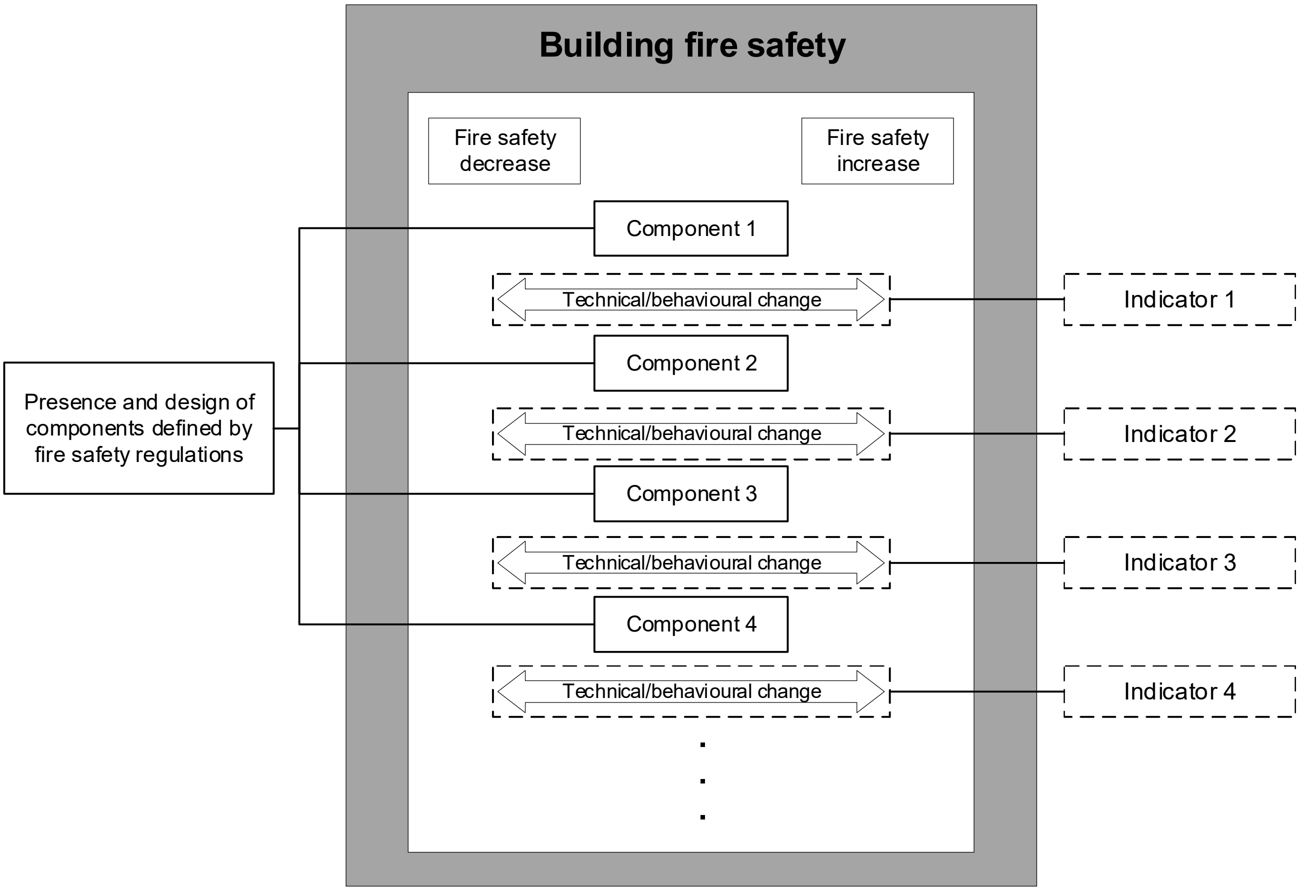


Figure 1-1. Conceptualisation of indicators within the field of fire safety.

1.2 Goal

The goal of this thesis is to develop indicators enabling continuous monitoring of central aspects of the most important fire safety components for retail buildings and retail buildings with high rack storage. The indicators are to be as generally applicable as possible; in other words, are to be applicable to as wide a range of retail buildings as feasibly possible.

1.3 Purpose

The purpose of this thesis is to develop a tool that can provide an indication on how the level of fire safety is affected by technical and behavioural changes in fire safety components.

1.4 Methodology

The initial phase of this thesis consisted of a literature review of fire statistics and a number of countries' fire safety regulations (**Chapter 1**). These findings will be used as part of the identification of the attributes to be included in the fire safety hierarchy (Chapter 5) and the identification of fire safety component features in the "development of indicators chapter" (Chapter 7). To enable indicators to be related and discussed in relation to risk analysis and the Risk Management Process (RMP), a brief literature review of the risk management process was undertaken (**Chapter 2**).

In order to develop indicators within the area of fire safety, a comprehensive review of indicators was undertaken. The review was encompassed by various areas of use, existing indicator types, forms of presentation, and indicator development (**Chapter 3**). The new step was to identify the most important fire safety components for retail buildings and retail buildings of high rack storage. Based on the use of Multi Attribute Decision Making (MADM) within the area of fire safety to quantitatively identify importance weights of fire safety components, it was concluded that a MADM methodology would be a suitable approach to identify fire safety components to base indicators upon. A comprehensive review of MADM theory was hence undertaken (**Chapter 4**).

Following from the MADM methodology discussed in Chapter 4, the first step was to generate a fire safety hierarchy consisting of the four levels; policy, objectives, strategies, and components (together referred to as attributes) (**Chapter 5**). To identify the attributes (policy, objectives, strategies and components) to be included in the hierarchy, literature on existing MADM methods applied within the area of fire safety, fire event statistics, and fire safety regulations were reviewed (Chapter 1). According to MADM methodology, the objectives were to be assigned weights in relation to the policy in accordance with their importance. In the same manner, the strategies were to be assigned weights in relation to the objectives and the components to be assigned weights in relation to the strategies. An expert panel was consulted to assign these weights. Matrix calculations of the weights assigned by the expert panel, produced the attributes that had the largest weight, e.g. highest importance in relation to the policy (**Chapter 6**).

The most important attributes were selected to form the basis for the indicator development. The limited research available on indicator development required that a predominantly reasoning approach was taken towards indicator development. The reasoning approach produced a total of seven indicators (**Chapter 7**). The developed indicators were then applied to fictitious data in order to provide examples of how the indicators could be presented and monitored (**Chapter 8**). Finally, a comprehensive discussion on indicators applied to the area of fire safety was undertaken (**Chapter 9**). The undertaken methodology is graphically presented in Figure 1-2.

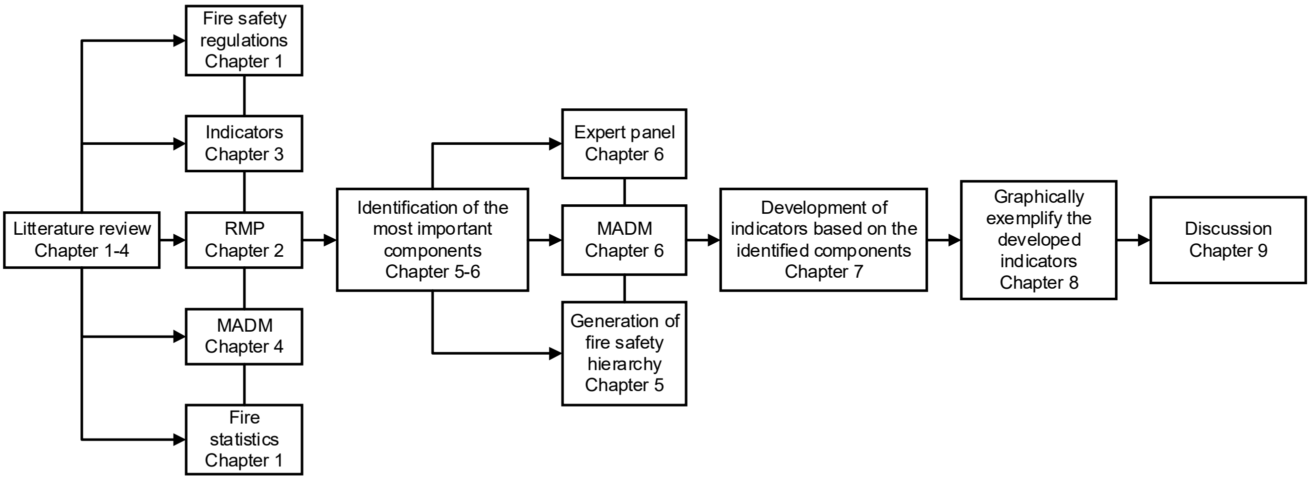


Figure 1-2. The methodology undertaken for the purpose of this thesis.

1.5 Target Group

This thesis is aimed towards anyone that wishes to learn about indicators applied to the area of fire safety. This thesis is especially relevant to building owners and companies managing multiple retail buildings that are considering incorporating indicators as part of their fire safety management.

1.6 Limitations & Delimitations

The indicators developed as part of this thesis are applicable exclusively to retail buildings (and retail units), and retail buildings (and retail units) with high racks storage. However, the MADM methodology undertaken to identify the components upon which the indicators are developed is applicable to other types of buildings as well.

The literature around methods to develop indicators is sparse, and the literature that does exist discusses the issue in very general terms. This requires that indicators be developed in a reasoning manner which allows subjective considerations to affect the indicator development process. Subjective considerations also have an impact on the identification of component to be included in the fire safety hierarchy. This subjective element has been mitigated by a comprehensive review of fire incident statistics, fire safety regulations and fire risk indexing methods.

The expert panel consulted as part of this thesis consisted of only two experts. These experts come from different backgrounds – the insurance industry, risk management and fire protection consultancy – making the composition of the expert panel beneficial. However, the panel would have benefited from three or four additional members in order to improve diversity.

The developed indicators will not be applied to actual retail buildings as part of this thesis. Their practical applicability can therefore not be evaluated.

1.7 Thesis Overview

Chapter 1 Introduction: entails background to the thesis, purpose, limitations, delimitations and the methodology undertaken for the purpose of this thesis, a review of a selection of fire statistics and fire safety regulations.

Chapter 2 Risk Management Process: briefly overviews the notion of risk and the risk management process. A number of risk analysis methods are mentioned while two semi-quantitative risk analysis methods are discussed further.

Chapter 3 Indicators: provides a general and comprehensive review of indicators, including areas of use, measurement types and the development of indicators.

Chapter 4 Multi Attribute Decision Making (MADM): provides a comprehensive review of MADM methods, including its variations and areas of use.

Chapter 5 Generation of Fire Safety Hierarchy: demonstrates the generation of a fire safety hierarchy tree based on the theoretic review of MADM methods as well as the fire statistics and fire safety regulations presented in Chapter 1.

Chapter 6 Component Weights: outlines the process producing the component weights included in the fire safety hierarchy.

Chapter 7 Development of Indicators: entails the development of indicators based on some of the most important components identified as part of the component weighting in Chapter 6.

Chapter 8 Examples of Graphically Presented Indicators: provides examples of graphically presented indicators based on fictitious data.

Chapter 9 Discussion: provides a discussion around the indicators developed in Chapter 7.

Chapter 10 Conclusion: provides the final remarks of this thesis.

Chapter 11 Future Research: provides suggestions for future research with regard to indicators within the area of fire safety.

1.8 Terminology and Building Types

The terminology used in this thesis with regard to buildings, compartmentation and retail buildings is defined and described in this section.

1.8.1 Terminology

The correct terminology to use when referring to forms of compartmentation is not always clear. Compartment, room, space and enclosure are sometimes used interchangeably, and there exists no definition that is generally accepted across branches and countries. For the purpose of this thesis, the forms of compartmentation will be defined according to the glossary of terms published by the National Fire Protection Association (NFPA, 2018b).

The NFPA (2018b, p. 1070) defines an enclosure as a "confined or partially confined volume" and a compartment as a "subdivision of an enclosure". The NFPA (2018b) provides the further description that an enclosure is completely enclosed by walls and a ceiling. Information is also given on enclosure measurements but is disregarded for this thesis. Further, a space is described as a definable area, such as a toilet or kitchen. A room is simply defined as "space or area bounded by walls" (NFPA, 2018b, p. 2769).

The word "building" is frequently used throughout this thesis. The NFPA (2018b, p. 627) defines a building as a "roofed-over structure with or without enclosed walls". The NFPA provides numerous additional definitions of building, but the one mentioned may be considered the most general one. When reading the word "building" in this thesis, the reader can assume that the word "space" could be inserted as well. This thesis will frequently refer to the notions "retail building" and "retail with high rack storage". These notions can equally be referred to as "retail space" and "retail space with high rack storage" as this thesis covers – beyond retail buildings – retail spaces within buildings.

1.8.2 Building Types

Buildings described as retail buildings may take a wide range of forms; everything from warehouses to shopping centres could be included in the meaning of retail buildings. The definition that will be used in this thesis is the NFPA (2018b, p. 2748) definition for a retail establishment: "a facility used for the display and sale of merchandise". The distinction between retail and retail with high rack storage is made based on the storage height. The NFPA (2018b) defines "high-piled storage" as rack storage or shelf storage in excess of 3.7 metres, and they further define a building that encompasses "high-piled storage" as "bulk merchandising retail building". These definitions are used throughput this thesis, but the two types of buildings described will be addressed as "retail building" and "retail building with high rack storage", corresponding to NFPA's definitions of "retail establishment" and "bulk merchandising retail", respectively.

1.9 Fire Event Statistics

The NFPA (2015, 2016) has presented fire statistics for "store and mercantile properties" and "warehouses" for the years 2009-2013 in the United States. These reports provide statistics such as the time of day, day of the week, and area of origin in which the fires have occurred. The statistics presented in the reports that can be considered to be of the greatest interest for the purpose of this thesis are "leading cause" and are presented in Figure 1-3 and Figure 1-4. Both figures have been included in order to provide an as broad a picture as possible with regard to the leading causes for fires in retail buildings and in retail buildings with high rack storage.

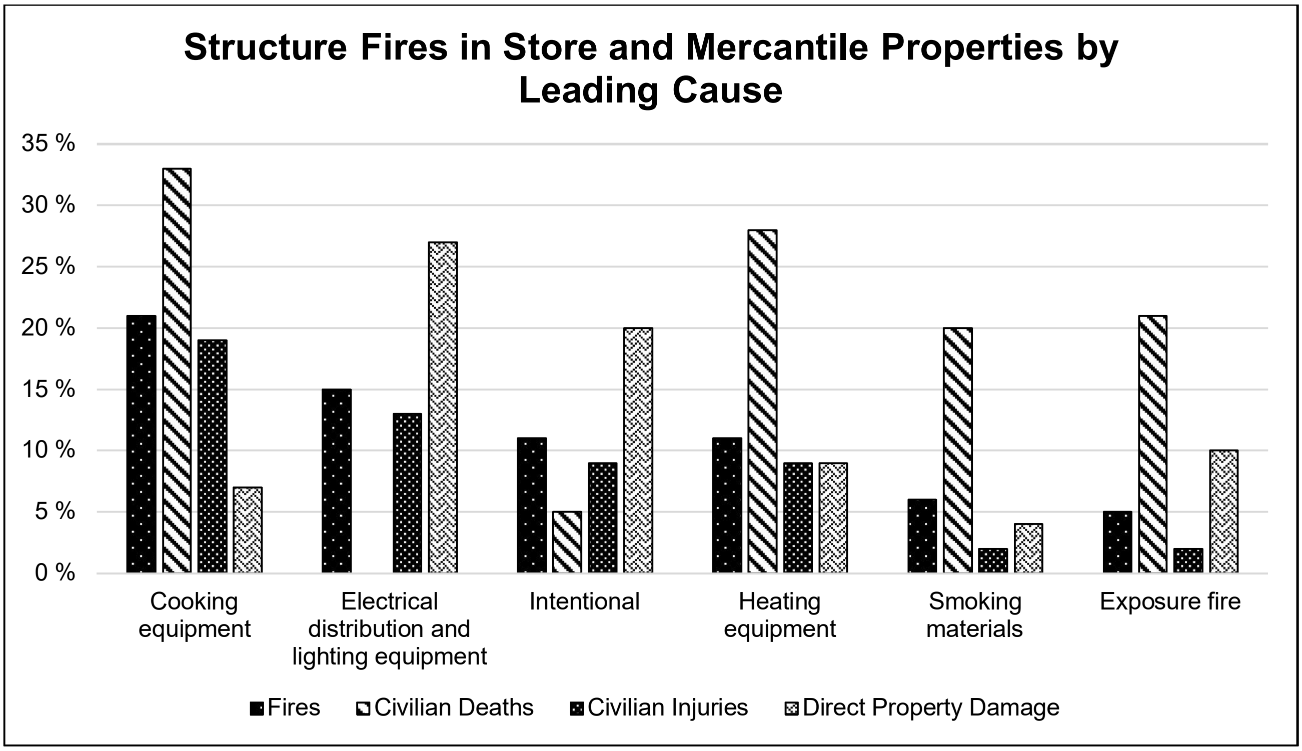


Figure 1-3. Statistics on the leading causes of fire occurrences in store and mercantile properties.

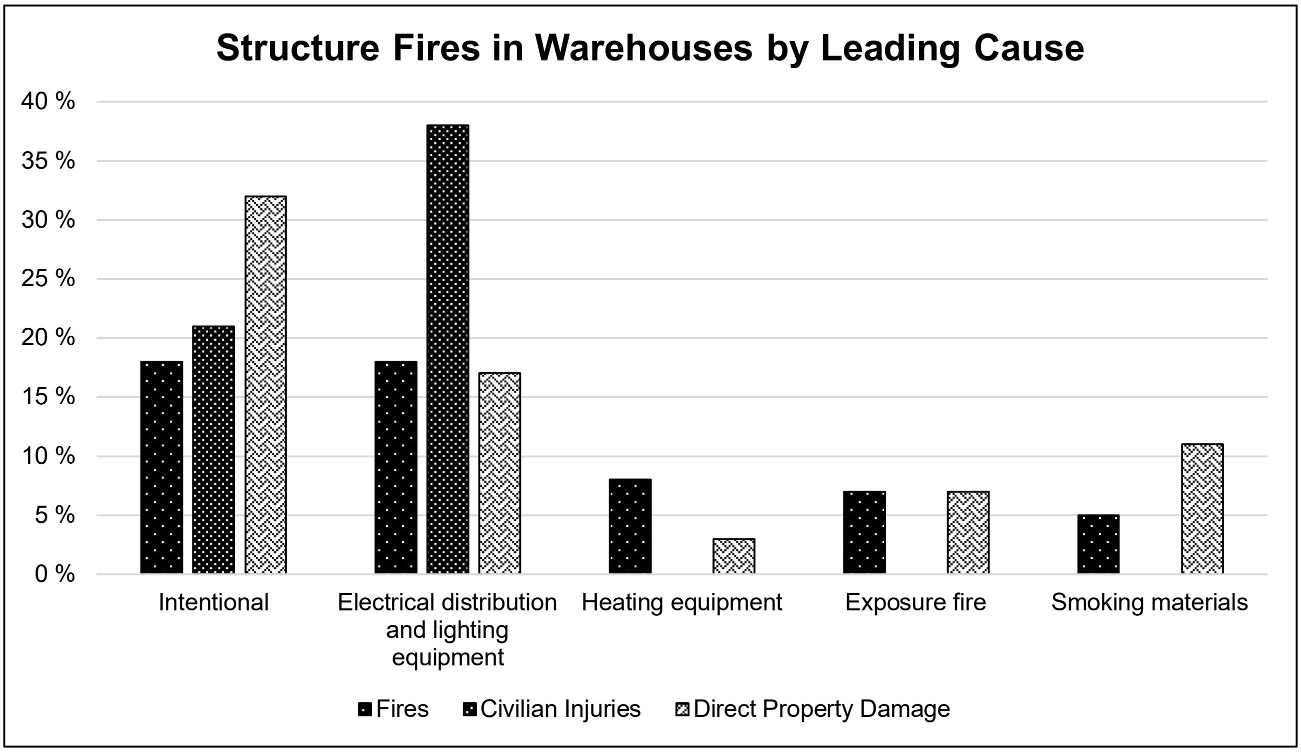


Figure 1-4. Statistics on the leading causes of fire occurrences in warehouses.

It is clear that of the fires caused by cooking equipment, electrical distribution and lighting equipment, and by intention, a very high proportion lead to injuries, deaths and property damage. These causes also constitute a large portion of the total number of fire occurrences. The reason why intentional fires are more common in warehouse than in store and mercantile properties may be derived from the fact that warehouses generally have a larger building area, which may have the consequence of prolonged detection time.

1.10 Fire Safety Regulations

This section will provide a brief overview of the current fire safety regulations in a selection of countries. The overview will be focusing on regulations for retail buildings. Precise requirements will not be specified, rather the chapter will provide a summary of some of the fire safety regulations requirements that are specifically aimed at retail buildings. Prescriptive regulations have been considered only in cases where performance based regulations are available. For each country below, there are other documents than those mentioned which outline requirements for fire safety. Nonetheless, the documents referred to below are the main documents that regulate fire safety within each country.

1.10.1 Sweden

The origin of Swedish fire safety regulations can be found in the Planning and Building Act (SFS 2010:900) (Plan- och bygglagen), where it is stated that buildings must be constructed and situated in a way that provides reasonable protection against the occurrence and spread of fire. This requirement is reinforced in the Planning and Building Ordinance (Plan- och byggförordningen) (SFS 2011:338), and further in chapter five of the National Board of Housing, Building and Planning regulations (Boverket, 2018).

Spaces conducting retail are classified as 2B if the occupancy is more than 150 occupants. The class is based on the type of business or activity that is conducted in the building. Regarding safe egress for class 2B, the regulations entails requirements regarding safe evacuation points, guiding signage and doors to exit paths. Exits must be openable by an outward push or by pressing the handle downwards. Further, a manual fire alarm is required.

Regarding fire development and spread of fire within buildings, the regulations specify that the considered space must be its own firecell. Depending on occupancy and what floor the space is located on, the regulations may have material requirements regarding external facades and the fire safety rating of windows. Further, firewalls are to achieve a specific fire rating depending on the fire load within the space.

There are numerous requirements in excess of those mentioned in this section, however, these are more generally applicable, and not specifically aimed at retail buildings.

1.10.2 England & Wales

In 2006, the Department for Communities and Local Government of England, introduced the Regulatory Reform (Fire Safety) Order 2005 (Department for Communities and Local Government, 2007), which entails all fire safety legislation for England and Wales. Buildings for domestic purposes are not affected by the regulations in this document.

The Regulatory Reform (Fire Safety) Order 2005 does not consider what kind of business is being conducted, or what the occupancy may be, instead the regulations stated in the order are applicable to practically all non-domestic buildings. The standard of compliance for the order is what the “reasonable person” representing the business would do to demonstrate compliance with the requirements of the order.

The order prescribes general requirements for a number of building types, such as factories and warehouses (Department for Communities and Local Government, 2006b), educational premises (Department for Communities and Local Government, 2006a) and offices and shops (Department for Communities and Local Government, 2006d).

The document that may be applicable to buildings conducting retail, “Fire Safety Risk Assessment – Large Places of Assembly” (Department for Communities and Local Government, 2006c), specifies a number of requirements. In England and Wales, every business is required to undertake a fire risk assessment, which will provide the basis for the implementation of fire risk measures. In general, business are required to have a manual or automatic fire alarm system. Regarding fire suppression equipment, business are required to be equipped with fire extinguishers.

Sprinklers or fire hose reels may be required depending on the aforementioned fire risk assessment. Emergency lighting must be provided to escape routes and open areas. Further, exit signage must be provided and the staff are required to undergo fire safety training regularly.

1.10.3 USA

The basis for US fire regulations can be found in the International Building Code (International Code Council, 2018a) and the International Fire Code (International Code Council, 2018b), developed by the International Code Council (ICC). The building code is applicable to new buildings whereas the fire code is applicable to existing buildings. According to Hirschler (2017), all states in the US have adopted these codes as a whole or parts of them, and many states have also adopted the NFPA 101 Life Safety Code (NFPA, 2018).

The International Fire Code (International Code Council, 2018b) prescribes that emergency evacuation drills are required to be undertaken regularly. Further, ceiling and walls should achieve a defined fire safety standard. Exit signage and emergency lighting must be provided. Sprinklers may be required depending on what floor level the area in question is located. If an automatic sprinkler system is not required, an automatic smoke detection system is necessary. All fire safety equipment must be tested and controlled regularly in accordance with existing standards.

According the NFPA Life Safety Code (NFPA, 2018), both an automatic sprinkler system and a fire alarm system are necessary, and fire safety systems must be tested regularly. Emergency egress plans are required and regular drills according to the plans must be undertaken. Ceiling height is to be no less than 4.975 m above floor level.

1.10.4 New Zealand

New Zealand fire safety regulations originate from the 2004 Building Act (Ministry of Business, Innovation, and Employment, 2017), and are cemented in the New Zealand Building Regulations and further in the New Zealand Building Code (Ministry of Business, Innovation and Employment, 2014). To meet the objectives stated in the building code, the requirements of the Acceptable Solutions (Ministry of Business, Innovation and Employment, 2016), the prescriptive regulations, must be met.

For retail buildings, the C/AS4 Acceptable Solution for Buildings with Public Access and Educational Facilities (Risk Group CA) (Ministry of Business, Innovation and Employment, 2016) is applicable. For buildings conducting retail, some sort of a fire alarm system is required. If the considered buildings are planned to have more than 1,000 occupants, a sprinkler system must be provided. Fire cells must achieve a fire resisting rating of no less than 60 minutes. Regarding safe egress, the C/AS4 Code specify certain requirements for travel distances, doors and exit ways. Further, guiding signage is required.

2 The Risk Management Process

The notion of risk has been defined in many different ways and is often dependent on the field in which the notion of risk is being observed (Aven, 2011). What is clear is that there is no definition that is unilaterally accepted across different branches. The existing definitions of risk can be divided into two groups. Some researchers have proposed definitions based on probability (e.g. Lowrance (1976)) or expected values (e.g. Willis (2007)), while others base their definitions on consequences and uncertainties (e.g. Aven (2007)).

SFPE uses the following definition for risk (Watts & Hall Jr, 2008, p. 5-4):

"Risk is the potential for realisation of unwanted, adverse consequences to human life, health, property, or the environment"

It could be argued that Watts and Hall Jr's (2008) definition for risk could be placed in either – or both – of the two mentioned groups as it is based on both potential and consequences.

Any action an organisation takes is, to some degree, associated with risk (ISO, 2017). The process in which these risks are continuously managed is referred to as the risk management process (ISO, 2017). The risk management process can refer to an organisation as a whole, but also to specific organisational activities or functions (ISO, 2017). Similarly to the notion of risk, there are many definitions for the risk management process (Berg, 2010). Some definitions solely include the decision making process and exclude risk identification and risk assessment, while others include the entire process from risk identification to risk treatment (Berg, 2010).

The risk management process defined by the International Organization for Standardization (ISO, 2017) is displayed in Figure 2-1. The risk management process (based on ISO (2009)) and the different steps of the process defined by ISO, are outlined in Section 2.1-2.8.

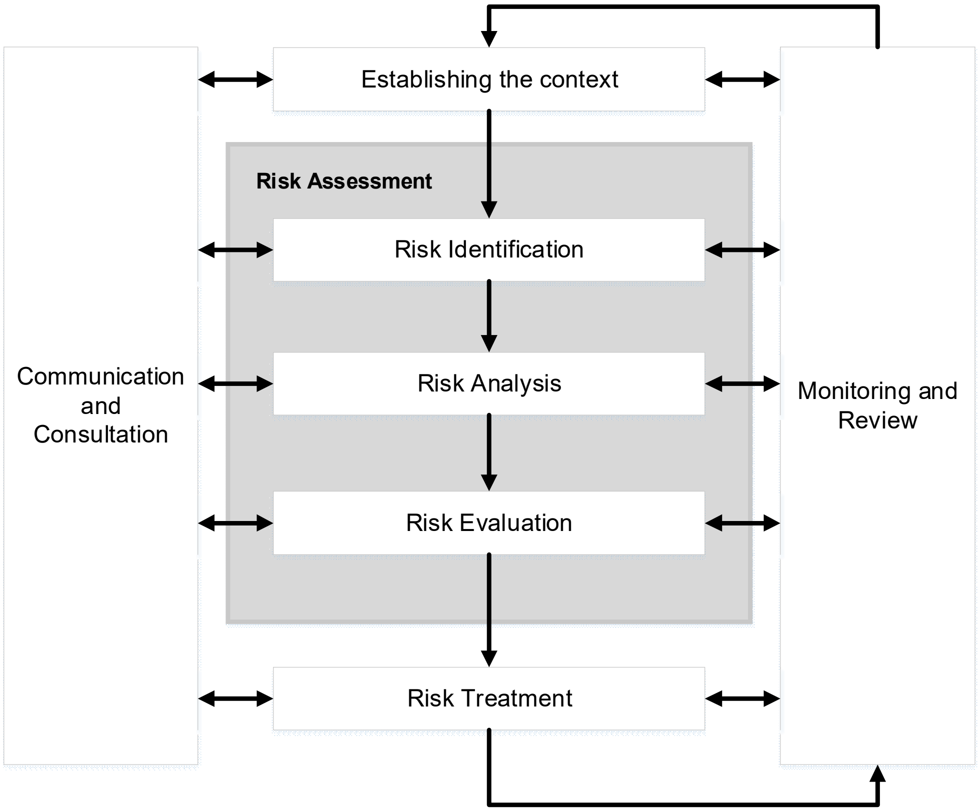


Figure 2-1. The Risk Management Process (based on ISO (2009)).

2.1 Establishing the Context

Establishing the context is the first step of the risk management process. ISO (2017) list a number of activities that should be undertaken as Bart of this step, including defining the purpose and scope of the process, establishment of the environment in which the organisation operates and defining risk criteria.

2.2 Risk Assessment

The risk assessment process refers to risk identification, risk analysis and risk evaluation and underpins the decision making process, where identified risks are directed (IEC, 2009).

2.3 Risk Identification

The first step of the risk assessment entails identification of risks. The risk identification step aims to identify and describe sources of risks that might have an impact on an organisation's ability to reach its objectives (ISO, 2017). As part of the risk identification, the organisation identifies sources of risks, potentially affected areas and potential consequences (ISO, 2017).

2.4 Risk Analysis

The risk analysis refers to developing an understanding of the risks identified (ISO, 2017). The sources of risk, their consequences and the likelihood of these consequences occurring are analysed as part of this step (ISO, 2017).

There are many risk analysis methods available and the method should be chosen based on the nature of the risk and other circumstances (ISO, 2017). The methods that can be used to analyse identified risks can be divided into three categories: qualitative, semi-quantitative and quantitative (IEC, 2009). The methods within these categories are suitable for different settings, depending on the nature of the risk, availability to information and data and the purpose of the analysis. Figure 2-2 displays the categories of risk analysis methods ordered after quantifiability.

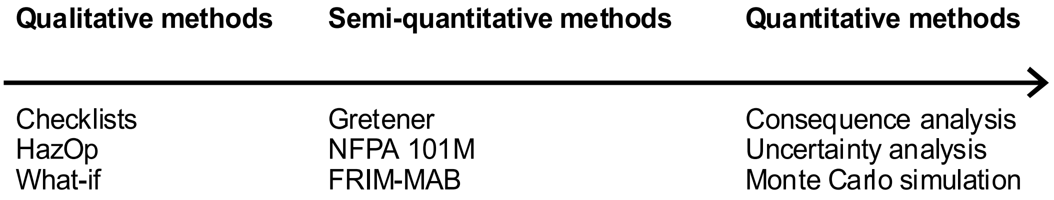


Figure 2-2. Risk analysis methods ordered with respect to quantifiability (based on Olsson and Frantzich (1999)).

2.4.1 Qualitative Methods

Qualitative risk analysis describes the risks in non-numerical terms (Rovins, Wilson, Hayes, Jensen, & Dohaney, 2015). As an example, consequences may be described as "high", "medium" or "low" and probabilities as "likely", "unlikely" or "rare" (Valis & Koucky, 2009).

Qualitative methods differentiate from other risk analysis methods in the sense that they are less time consuming, this since they seldom require calculations (Rovins et al., 2015). Instead, they are often based on expert opinions, which, on the other hand raises the question of bias when analyses undertaken by different experts are compared (Rovins et al., 2015). It is also important to note that qualitative methods are subjective in their nature (Todinov, 2006). Examples of qualitative methods include the what-if analysis, the Hazard and Operability (HazOp) study and the Failure Mode and Effect Analysis (FMEA) (Alverbro, Nevhage, & Erdeniz, 2010).

2.4.2 Quantitative Methods (QRA)

Quantitative risk analysis methods describes risk in numerical terms (Rovins et al., 2015). Quantitative risk analysis methods are applicable when there are available quantifiable information on likelihood and consequence, for example in form of statistical databases (Borghesi & Gaudenzi, 2013). This however, is only required when undertaking a probabilistic analysis, which is based on both likelihood and consequence data; a deterministic approach, on the other hand, does not consider the likelihood of an occurrence (Frantzich, 1998b). As an example of a probabilistic approach, the consequence can be assigned the value 0.5 and the likelihood the value 0.1 with a total risk given by the product of consequence and likelihood, equalling 0.05. Kaplan and Garrick (1981) suggests that quantitative risk analysis can be described through a "set of triplets", where the sets consists of three questions; what can happen? (s_i), how likely is it that it will happen? (p_i), if it does happen, what are the consequences? (x). The risk is calculated as a function of these three variables in accordance with Formula 1:

$$R = \{\langle s_i, p_i, x_i \rangle\}$$

where $i = 1, 2, \dots, N$.

Formula 1

Quantitative methods are often labour and time intensive and are also the most extensive compared to qualitative and semi-quantitative methods (Frantzich, 1998). The variables included in a quantitative risk analysis are, however, associated with uncertainty (Frantzich, 1998), hence a sensitivity analysis should be undertaken to identify the impact different variables have on the result (ISO, 2009). Examples of quantitative methods include consequence analysis, uncertainty analysis and Monte Carlo simulation (Kwak & Ingall, 2007; Olsson & Frantzich, 1999).

2.4.3 Semi-Quantitative Methods

Semi-quantitative risk analysis methods can be applicable when neither qualitative nor quantitative methods are suitable for the situation (Borghesi & Gaudenzi, 2013). In semi-quantitative methods, both quantitative tools and qualitative approaches are involved to analyse the risks (Borghesi & Gaudenzi, 2013). Instead of using numerical descriptions of likelihood and consequence, semi-quantitative methods seek to assign scores to the risks, making comparisons between different risks possible (Simmons et al., 2017). The methods within this category can be placed somewhere between qualitative methods and quantitative methods with regards to their comprehensiveness (Borghesi & Gaudenzi, 2013). Utilising both qualitative and quantitative techniques, semi-quantitative methods are often considered a balanced compromise between subjectivity and comprehensive, objective techniques (Borghesi & Gaudenzi, 2013).

Within the area of fire safety semi-quantitative methods are often referred to as indexing methods or ranking methods. Examples of these methods, including the Gretener method and the Fire Safety Evaluation System (FSES or NFPA 101M) are briefly described below.

Gretener method

The Gretener method, or SIA 82, was originally developed in the 1960s by Max Gretener, director of the Swiss Brandverhütungsdienst für Industrie und Gewerbe (Kaiser, 1979). He had commenced his work on risk evaluation in 1961, and presented several papers on the matter during the 1960s and 70s (Kaiser, 1979). The idea of the Gretener method is that fire risk is calculated by multiplying fire hazard (or degree of danger, or probable severity) by the probability of fire occurrence (see Formula 2) (Watts, 1991; Kaiser, 1979).

$$R = A \times B$$

Formula 2

R = Fire risk

A = Probability of fire occurrences

B = Fire Hazard

The parameter B is divided further into two groups: fire hazards and counter measures (Kaiser, 1979). "Fire hazards" refer to the possible dangers (P), whereas "counter measures" are encompassed by standard measures (N), special measures (S) and fire resistance of the building (F) (Formula 3).

$$R = B \times A = \frac{P \times A}{N \times S \times F} \qquad \text{Formula 3}$$

Fire Safety Evaluation System (NFPA 101M)

The Fire Safety Evaluation System (FSES) was developed by the Centre for Fire Research in the 1970s with the purpose of determining how to meet the requirements of the 1973 Life Safety Code for health care facilities (Nelson & Shibe, 1978), it has, however, been updated regularly to comply with the current Life Safety Code (Fire Protection Research Foundation, 2014). The system aimed to test whether a combination of fire safety systems and design features met the requirements of the life safety code.

The system makes a distinction between risk factors and safety features. Five risk factors related to fire safety in health care facilities are weighted by an expert panel in accordance with their importance to the overall risk. These factors are: ratio of patient to attendants; patient density; patient mobility; fire/smoke zone location; and patient average age. The total risk is given by multiplying the actual values for the five risk factors.

As part of the system, thirteen fire safety features are assigned values by the same expert panel in accordance with each feature's characteristics. For example, interior finishes are to be valued in accordance with their fire safety classification. These features are then related to fire safety strategies defined by the expert panel. The next step is to multiply the values assigned to each feature relating to each strategy. The final measure of fire safety is given by multiplying the calculated product with the product of the weights of the five risk factors. This measure is then compared to the aforementioned total risk.

2.5 Risk Evaluation

The risk evaluation is based on the outcome of the risk analysis and aims to assist in the decision-making process in the risk treatment step (ISO, 2009). The risk levels calculated as part of the risk analysis are compared to established risk criteria (ISO, 2009).

2.6 Risk Treatment

The purpose of risk treatment is to apply measures to diminish the probability of unwanted events to occur and to mitigate the effects of risks (IEC, 2009). The selected measures are implemented in order to meet predefined risk criteria (IEC, 2009).

2.7 Monitoring & Review

Monitoring and review are undertaken continuously throughout the risk management process (ISO, 2009). The purpose is to ensure that implemented risk treatment measures are efficient, to identify changes in regards to risks and risk criteria, and to analyse and learn from failures and improve the risk management process (ISO, 2009).

2.8 Communication & Consultation

As for monitoring and review, communication and consultation are also undertaken throughout the risk management process. Stakeholders are continuously consulted to ensure that all perspectives are considered (IEC, 2009).

3 Indicators

The Oxford English Dictionary (2002) defines an indicator as “one who or that which points out, or directs attention to, something”. The word is commonly used within organisations when describing performance and result measurement methods. It is also used within areas such as process safety, organisational risk or quality measurements (Section 3.5-3.6). Indicators can be used in several ways; hence, the existing definitions are numerous (Øien, Utne, & Herrera, 2011). Nevertheless, indicators are probably most commonly utilised as various kinds of performance measures.

Performance measures are used daily throughout society. Governments are measuring their gross domestic product (GDP), schools are measuring average grading or the graduation rate and workplaces may measure the efficiency of their employees and profits. Even households and individuals use performance measures, more or less formally, when they measure salary increase or when they are setting saving goals. How these measurements are performed will vary across organisations, branches and countries. What is clear is that performance measurements are frequently used in our daily lives. Parameter (2012) has divided performance measurements into four categories (Section 3.1-3.4). As these indicator types focus in different aspects of an organisation, and hence complement each other, it is common that organisations utilise all the indicators. It is important to note that that these four categories should be viewed in the context of an organisational environment.

The theory in this chapter will also encompass other indicator types, types of measurements, methods of indicator presentation and indicator development. The other indicator types that will be discussed are branch-specific to a larger extent and include risk, safety and quality (Section 3.5-3.6).

3.1 Key Result Indicators (KRIs)

Parameter (2012) defines KRIs as the results that are produced by multiple teams and multiple actions, thus making KRIs a suitable tool for managers to monitor the results within the organisation. Parameter (2012) further points out that KRIs are often confused with KPIs, which has caused problems for organisational management. According to Niedritis, Niedrite, and Kozmina (2011), KRIs do not offer any understanding about what should be improved in the organisation. KRIs can be financial as well as non-financial (Niedritis et al., 2011). Examples of KRIs are return on capital employed, employee satisfaction and net profit before tax (Parameter, 2012).

3.2 Result Indicators (RIs)

The RI focuses on fewer teams than the KRI, but more than one team, thus making the RI a suitable tool to evaluate how teams perform together (Parameter, 2012). As the name of the indicator testifies, the indicator is based on results (Parameter, 2012). All financial performance measures can be categorised as RIs, this since the results are produced by numerous teams such as marketing and financial teams (Parameter, 2012). All RIs are financial at their core (Niedritis et al., 2011). Examples of RIs are weekly hospital bed utilisation, number of staff trained to use certain systems and number of managers having undertaken leadership training (Parameter, 2012).

3.3 Performance Indicators (PI)

PIs are non-financial and are related to a discrete activity, thus giving information on what can be improved within the organisation (Niedritis et al., 2011). The PIs are distinct from KPIs as they are not measuring critical aspects of the organisation (Parameter, 2012). Examples of PIs are late delivery to customers, number of training hours for staff and number of media coverage events (Parameter, 2012).

3.4 Key Performance Indicators (KPI)

KPIs measure the most crucial aspects of an organisation’s performance and, like the PIs, are non-financial (Parameter, 2012). These indicators provide information on what can be improved to increase organisational performance, more extensively than with PIs (Niedritis et al., 2011). Those aspects which are considered as crucial varies depending on the organisation.

3.5 Risk indicators & Safety Indicators

OECD (2001) defines a risk indicator as that which "[…] estimates the potential for some form of resource degradation using mathematical formulas or models". Risk indicators are predominantly used to measure organisational risk but are also utilised to measure risk for health related issues (Gran, 1995) and risks within the offshore industry (e.g. Vinnem (2010)). Øien et al. (2011) list examples of risk indicators used within the offshore industry such as number of leaks, number of workover days. What seems to be a common theme within literature on risk indicators is that these indicators are predictive; this is consistent with the OECD's (2001) definition of indicators as estimators of potential resource degradation.

Safety indicators or safety performance indicators are most frequently used within process industries and chemical safety. OECD (2005) defines safety performance indicators in the context of chemical safety as "means for measuring the changes over time in the level of safety (related to chemical accident prevention, preparedness and response), as the result of actions taken". There seems to be some confusion around the distinction between risk and safety indicators. Many articles often describe measurements of similar activities and labelling the indicators differently. One example is number of leakages, described by Leveson (2015) as a safety indicator and by Øien et al. (2011) as a risk indicator.

3.6 Quality Indicators

Quality indicators are primarily utilised as a tool to measure and improve treatment quality. Nevalainen et al. (2000) have undertaken studies in laboratory medicine which include indicators such as number of sample errors and duplicate test orders. These are labelled as quality indicators. The term also appears when describing indicator tools used for disease or injury screening (Nguyen et al., 2007).

3.7 Types of Measurement

Indicators can be configured in different ways depending on its purpose and what it intends to measure. Jasch (2009) and the Health Information and Quality Authority (2010) have defined different indicator measurement types. These are briefly outlined in Section 3.7.1-3.7.4.

3.7.1 Count Indicators or Absolute Figures Indicator

The Health Information and Quality Authority (2010) define count indicators, in the context of health care, as indicators without a denominator. An example that is provided is "newly detected cases of tuberculosis in a given year". Jasch (2009) label this indicator measurement type as "absolute figures".

3.7.2 Proportion Indicators, Percentage Indicators or Index Indicators

According to the Health Information and Quality Authority (2010), proportion indicators are required in order to allow for comparisons between organisations and trends. Proportion indicators contain a numerator and a denominator with the same unit, hence, the indicator is often expressed as a percentage (Health Information and Quality Authority, 2010). An example is the proportion of pupils that pass a test. Jasch (2009) describes this indicator as a relation to a baseline, for example hazardous waste as percent of total waste.

3.7.3 Ratio Indicators or Relative Figurers Indicator

This indicator differs from the proportion indicator in the sense that it does not require that the numerator and the denominator be described with the same unit. This has the effect that the indicator is expressed as a ratio, meaning that it includes both a numerator and a denominator (Formula 4). The Health Information and Quality Authority (2010) uses the example of the ratio of male to female cardiovascular related deaths. According to Jasch (2009), common denominators are production hours and number of employees.

$$Ratio = \frac{Numerator}{Denominator}$$ Formula 4

3.7.4 Weighted Indicators

A weighted indicator according to Jasch (2009) is built on data that is weighted in accordance with its importance.

3.8 Leading Indicators & Lagging Indicators

Leading and lagging indicators are concepts that are mainly used within the fields of safety and economics. The distinction between these indicator types can be explained by an example from the process industry where the safety of pressurised gas tanks is assessed. An example of a leading indicator in this situation is the "percentage of safety critical instruments and alarms that correctly indicate the process conditions" and a lagging indicator the "number of times a bulk tank or a road tanker is overfilled due to failure in the level indicator or alarms" (Health and Safety Executive, 2006, p. 44). Mobley and Smith (2008) have a similar view when suggesting that leading indicators lead to results, while lagging indicators are the results.

Within the field of process safety, Kongsvik, Bye, Almklov, and Kleiven, (2017) means that lagging safety indicators are based on accidents; likewise Dyreborg (2009) refers to lead indicators as a tool to prevent accidents from happening (see Figure 3-1). Holmberg, Laakso, Lehtinen, and Johansson (1994) have a similar view on leading and lagging indicators, but instead refer to lagging indicators as direct indicators and leading indicators as indirect indicators.

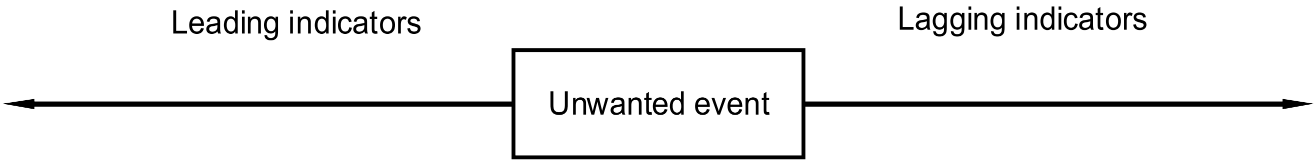


Figure 3-1. Conceptual representation of leading indicators and lagging indicators relation to an unwanted event (based on Usrey (2016)).

Within the field of economics, the distinction between leading and lagging indicators is not made on the basis of an event such as an accident. Instead, a lagging indicator reflects past results, such as the results of the previous quarter while leading indicators can offer actionable information on ongoing processes, for instance production inefficiencies (Paulson Gjerde & Hughes, 2007).

Researchers within the field of safety (e.g. Øien et al. (2011) and Wang, Zio, Fu, Zhang, and Yan (2017)) have contextualised leading and lagging indicators by applying the concepts to Reason's accident model (Reason, 1997). In Reasons model (Figure 3-2), Øien et al. (2011), suggest that the barriers – the layers of defence – can be seen as leading indicators, and the holes through the barriers represent lagging indicators.

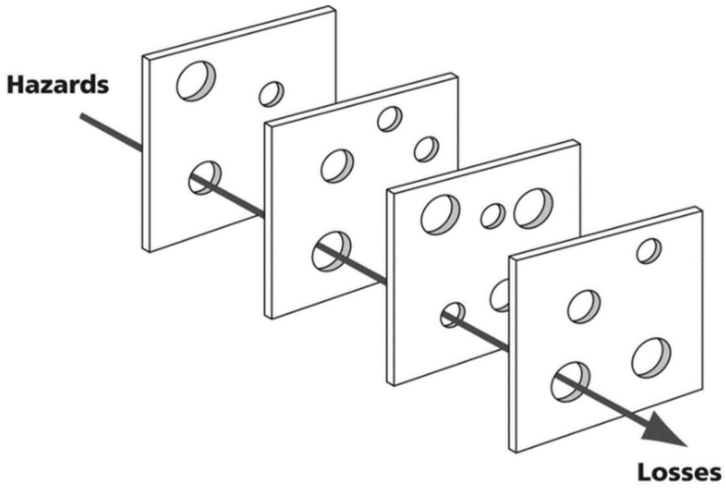


Figure 3-2. The Swiss cheese model (figure by Mack, 2014, licensed under CC BY-SA 3.0).

Parameter (2012) offers another perspective on leading and lagging indicators. He questions the usefulness of defining indicators as leading or lagging. An argument he puts forward is that there are events or processes that are not easily identifiable either as leading or lagging indicators.

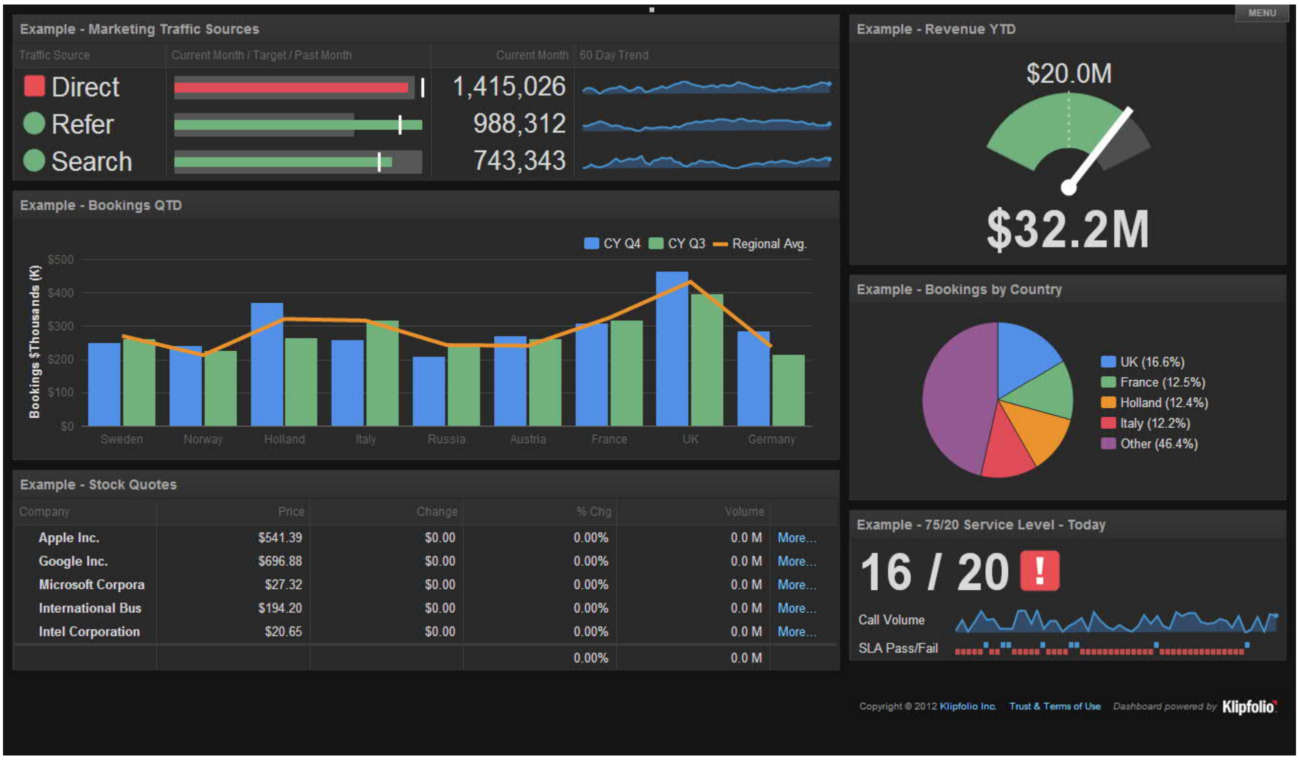
3.9 Dashboards and Balanced Scorecards

To explain the concepts of dashboards and balanced scorecards, an analogy entailing the instrument panel of a car or plane has been used. The indicators of current speed, fuel level, engine temperature, and so forth, convey information that the pilot or driver requires to navigate and make the right decisions, e.g. slow down, make a turn or break (Kaplan & Norton, 1992; DeBusk, Brown, & Killough, 2003). A broad description, in a more concrete manner, of both dashboards and balanced scorecards can be phrased as tools that enable monitoring of organisational metrics (Parameter, 2012; Galloway, 2010). The data presented is often in the form of various indicators, presented either graphically or numerically (Few, 2006; Sim & Koh, 2001).

However, on a more detailed level, the differences between these concepts of dashboards and balanced scorecards appear more clearly. Galloway (2010) defines a dashboard as a computer interface that is able to receive, manipulate and display organisational data, which is able to be acted upon by decision makers. Although the definitions vary, Few (2006) claims that there seems to be a consensus that dashboards must include graphical display of information to qualify as dashboards. Further, Few (2006) suggests that a dashboard is required to fit on one computer screen, this to enable easy overview.

According to Kaplan and Norton (1992), balanced scorecards should provide the answers to the following four questions: How do customer see us? What must we excel at? Can we continue to improve and create value? How do we look to shareholders? These four questions represent four perspectives: the customer perspective, the internal perspective, the innovation and learning perspective and the financial perspective (Kaplan & Norton, 1992). When comparing the views of Kaplan and Norton (1992) with the views of Galloway (2010) and Few (2006), it is clear that balanced scorecards are more intrinsically linked with organisational goals than dashboards, which generally seem to have more of an informative role.

Figure 3-3 and Figure 3-4 displays examples of a dashboard and a balanced scorecard, respectively. It is important to note that their designs vary considerably depending on what is measured and within what type of organisation they are utilised. The balanced scorecard example is just a template and the goals and measures are to be filled out by the responsible body. It should be noted that the balanced scorecards does not allow for indicators to be monitored over time, as only the latest indicator measure can be displayed.



Example - Marketing Traffic Sources

Traffic Source	Current Month / Target / Past Month	Current Month	60 Day Trend
🟥 Direct		1,415,026	
● Refer		988,312	
● Search		743,343	

Example - Stock Quotes

Company	Price	Change	% Chg	Volume	
Apple Inc.	$541.39	$0.00	0.00%	0.0 M	More...
Google Inc.	$696.88	$0.00	0.00%	0.0 M	More...
Microsoft Corpora	$27.32	$0.00	0.00%	0.0 M	More...
International Bus	$194.20	$0.00	0.00%	0.0 M	More...
Intel Corporation	$20.65	$0.00	0.00%	0.0 M	More...
			0.00%	0.0 M	

Figure 3-3. Example of finance dashboard (Dashboard, 2012, under GNU General Public License 2.0).

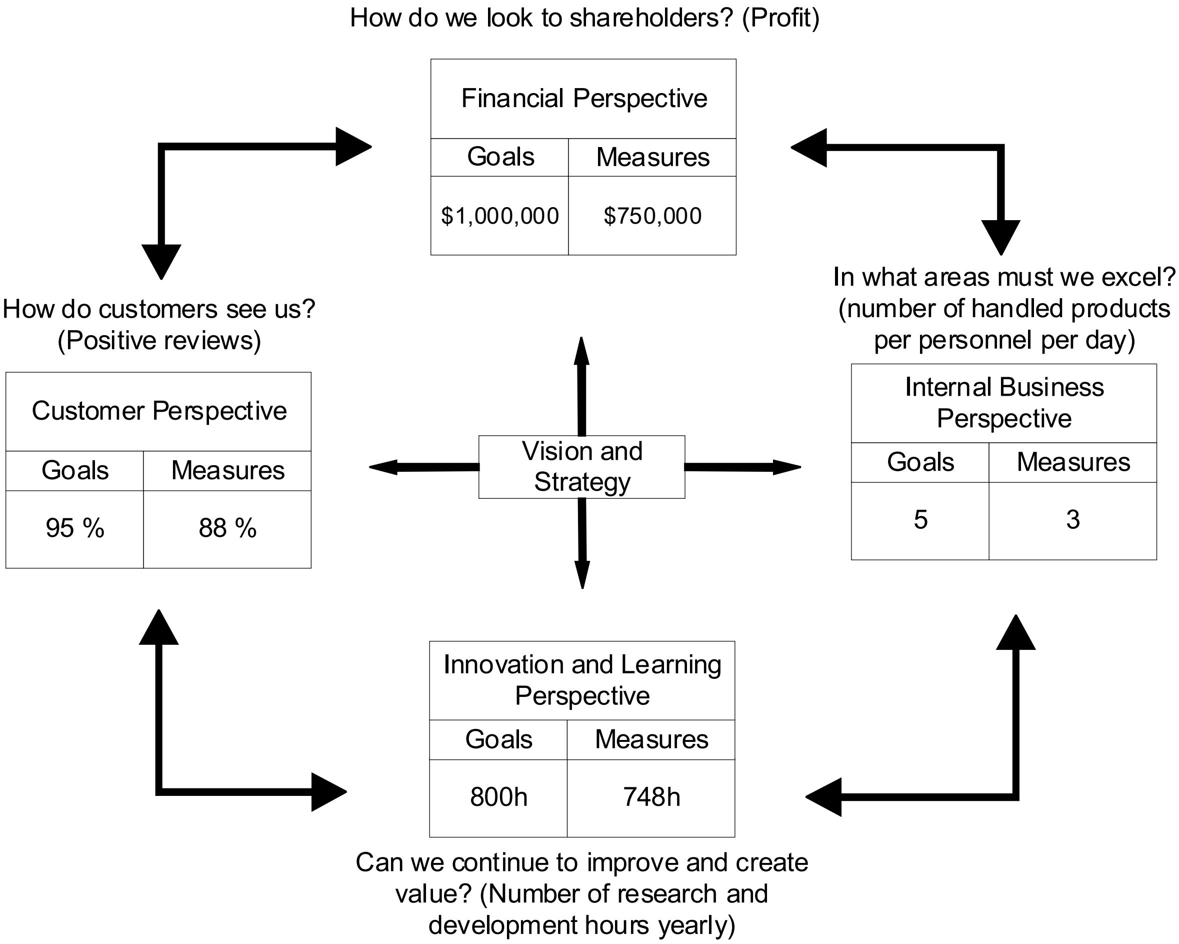


Figure 3-4. Example of a balanced scorecard (based on Sim and Koh (2001)).

3.10 Areas of Use

Some areas in which indicators are used have been mentioned throughout this section. Section 3.10.1-3.10.5 will provide a brief overview of some of those areas in which indicators are frequently utilised.

3.10.1 Aviation

Based on the available literature on indicators utilised within aviation, the predominant areas of use are aviation safety and aviation management. Indicators within the area of aviation safety are generally denoted as safety performance indicators, key safety performance indicators or safety indicators (U.S. Department of Energy, 2012; Verstraeten, Roelen, & Speijker, 2014; Øien, Utne, Tinmannsvik, & Massaiu, 2011b). Verstraeten et al. (2014) argue that the shift towards performance based regulations within aviation safety has actualised the need for continual safety monitoring, in which indicators have an important role. Verstraeten et al. (2014) define a number of indicators aimed at monitoring aviation safety, which ranges across a wide spectrum of aviation safety issues including safety impact of structural changes to airports, number of formal meetings with analysts, discussion performance measurements and bird strike rate.

The US Department of Energy (2012) applies indicators to a broader range of issues, exceeding the field of safety. They also apply indicators to the construction processes of aircrafts and airports, and to the management of aircraft crew and related equipment. They define indicators aimed at monitoring efficiency, for example customer scheduling effectiveness and pilot availability rate. Indicators more aimed at safety performance include incident rate and injury rate.

3.10.2 Healthcare

As mentioned in Section 3.5 and 3.6, indicators utilised within the area of healthcare are sometimes referred to as risk indicators or quality indicators. This can be explained by the fact that indicators within the area of healthcare are often applied to issues surrounding patient risks (e.g. Gran (1995) and Nguyen et al. (2007)).

Khalifa and Khalid (2015) suggest a range of health care indicator categories encompassing patient access, operating room utilisation, patient safety, infection control, and so forth. Within these categories, Khalifa and Khalid (2015) identify a total of 48 indicators, for example number of surgeries, mortality rate and patient satisfaction, which are meant to assist hospitals in monitoring their overall performance and direct resources to areas that need to be improved.

3.10.3 Internet Marketing

Indicators in various forms are common within the field of internet marketing. They are usually denoted as “key performance indicators” and are aimed at monitoring companies’ internet marketing performance. According to Saura, Palos-Sánchez, and Suárez (2017), the use of indicators in internet marketing can increase a company’s visibility on the internet. Common indicators that Saura et al. (2017) and Saura, Palos-Sánchez, and Suárez (2017) refer to include meaningful conversion rate (with regard to number of clicks on adds and links per finalised transaction), which key words are searched before entering the website, and time on site. Järvinen (2016) claims that, beyond monitoring internet marketing performance, indicators can also be used as a tool to compare the internet marketing performance of different companies.

3.10.4 Finance

Indicators used within finance are sometimes referred to as financial ratios (e.g. Kotane and Kuzmina-Merlino (2012) and Robinson et al. (2009)). Financial ratios can, according to Robinson et al. (2009), be divided into five theoretical groups: activity ratios, liquidity ratios, solvency ratios, profitability ratios and valuation ratios; Table 3-1 sets out examples of these ratios. These types of ratios, or indicators, can measure a broad range of aspects relating to a business performance.

Table 3-1. Ratios (or indicators) utilised within the area of finance (based on Robinson et al. (2009)).

Type of ratio (=indicator)	Example of ratio	Numerator	Denominator
Activity ratios	Inventory turnover	Cost of goods sold	Average inventory
Liquidity ratios	Cash ratio	Cash and short-term marketable investments	Current liabilities
Solvency ratios	Debt-to-assets ratio	Total debt	Total assets
Profitability ratios	Gross profit margin	Gross profit	Revenue
Valuation ratios	P/E	Price per share	Earnings per share

According to Robinson et al. (2009), financial ratios can be used to compare various measurements from year to year within the same business, and further, with other business within the same branch.

3.10.5 Fire Safety

The use of indicators within the field of fire safety is not common. There are examples, predominantly concerning components affecting forest fires, where methods that include the use of indicators are used. In these cases component weights for components such as rainfall, air humidity, and air temperature are identified (Pourtaghi, Pourghasemi, Aretano, & Semeraro, 2016; Nurdiana & Risdiyanto, 2015). This research describes the weight of every component that has an effect on risk for forest fires, which later can be used by applying the findings to different areas and assess the overall risk for forest fire.

In the Society for Fire Protection Engineering (SFPE) handbook, Barry (2002) suggests using indicators when measuring performance success of fire protection systems. This measurement is suggested to be based on past system failures, more specifically, the response effectiveness (RE), online availability (OLA) and operational reliability (OR) of past failure experiences (Barry, 2002). Barry (2002) proposes a simple factor multiplication to define the probability of fire protection system success, P_S (Formula 5).

$$P_S = P_{RE} \times P_{OLA} \times P_{OR} \qquad \text{Formula 5}$$

P_{RE} = Probability of response effectiveness
P_{OLA} = Probability of online availability
P_{OR} = Probability of operational reliability

Barry (2002) further proposes similar methods for system response time and design application basis.

3.11 Benchmarking for Indicators

Bhutta and Huq (1999, p. 254) suggest that the essence of benchmarking is ”[…] the process of identifying the highest standards of excellence for products, services, or processes, and then making the improvements necessary to reach those standards […]. Gillen (2017) defines benchmarking in simpler terms: “it is an instrument for providing a reference point”. The process, or instrument, for providing the reference point consists primarily of regular measurements within and outside the business (Gillen, 2017; McGregor, 2000). Within the area of healthcare, the Health Information and Quality Authority (2010) suggests that the way indicators can facilitate performance improvement in its context is via benchmarking. The organisation means that indicator benchmarks enable caregivers to direct resources to where they are most required.

3.12 Methods to Develop Indicators

As for the numerous types of indicators, the perspectives on and interpretations of the methods to develop indicators vary across branches and areas of use. It would be beneficial having a unanimous method to develop indicators, which was applicable for every situation, but this is not a reality. Øien et al. (2011) emphasises that several methods may be required to achieve the best results in any given situation, which by consequence means developing the most efficient indicators.

Kibira, Brundage, Feng, and Morris (2017) proposes a four-step method for developing KPIs in the area of sustainable manufacturing: establishment of KPI objectives, identification of KPIs, selection of KPIs and composing KPIs. The KPI identification step includes searching within relevant literature to find candidate KPIs. The following selection step entails letting experts and stakeholders rank the candidate KPIs against predefined criteria related to sustainable manufacturing. The last step of the method is to assign weights to the chosen KPIs, based on the indicators' relative importance to the overall objective.

Brown (2009) proposes a similar approach to develop indicators within the area of sustainable development, consisting of five steps: establishing the purpose of the indicators, designing the conceptual framework, selecting and designing the indicators, interpreting and reporting the indicators and maintaining and reviewing the indicators. As can be seen, Brown (2009) includes steps after the indicators have been selected, which are related to interpreting, reporting and reviewing. Brown (2009) suggests a similar approach to indicator selection as Kibira et al. (2017), who suggests that external experts and stakeholders be consulted in the selection process. Both Brown (2009) and Kibira et al. (2017) advocate that the selection be based on predefined criteria.

The Health Information and Quality Authority (2010), Mainz (2003) and von Schirnding (2002) present a number of criteria that should be considered when developing indicators within the area of health care. The most reoccurring criteria include feasibility, sensitivity to changes in the conditions in question, consistency and comparability over time and space, ability to be easily understood and applied by potential users, and timeliness. The feasibility criteria refer to the conditions around data collection, meaning that collection of relevant data must be defendable in time and monetary terms (Health Information and Quality Authority, 2010). According to the timeliness criteria, data must be made available within a reasonable time period, where the reasonableness depends on the nature or the purpose of the collected data, in other words the indicator terms (Health Information and Quality Authority, 2010). Some of these criteria are also mentioned by Brown (2009), however he adds that indicators must be relatable to other indicators where appropriate, and that they be valid and meaningful such that the indicators mirrors effectively what it intends to measure. In addition, Rockwell (1959) suggests a quantifiability criteria, meaning that an indicator must be quantifiable. The indicator criteria mentioned by the authors referred to in this section are summarised as follows:

- Feasibility
- Sensitivity to change in the conditions in question
- Consistency and comparability over time and space
- Easily understood and applied by potential users
- Timeliness
- Valid and meaningful
- Relatable to other indicators where appropriate
- Acceptability
- Safe
- Avoid duplication
- Quantifiability

Brindusa (2015) raises the concern of choosing indicators based on the wrong criteria. She argues that it is far too common for managers to choose indicators that are easy to measure and for which it is easy to collect data. The potential consequences of this method include the development of indicators that are of no meaningful use to the organisation. This approach to indicator development is called the ICE-approach (Figure 3-5).

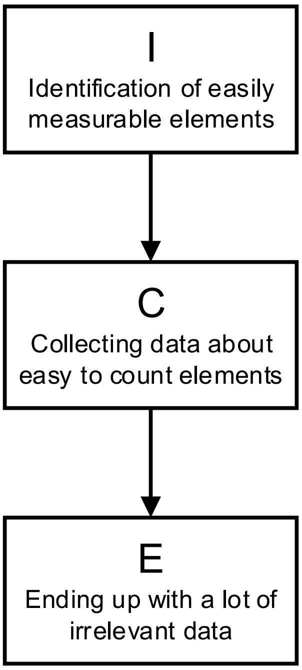


Figure 3-5. The ICE-approach (based on Brindusa (2015)).

3.13 Method for Component Identification

As outlined in Section 3.12, Kibira et al. (2017) and Brown (2009) include "selecting indicators" as one of the steps in the indicator development process. Both advocate for candidate indicators being selected and experts being consulted to choose the final indicators. This methodology assigns a significant responsibility to the developer of the indicators in the sense that all relevant indicators must be included in the selection of indicators presented to the experts. An alternative approach is for the developer to take a step back and focus more directly on components upon which the indicators are configured. The components that are of the greatest importance to their respective purposes can then form the basis for indicator development. An argument for this approach is that the level of abstraction should be lower and hence more comprehensible for the indicator developer.

Within the area of fire safety, a number of fire risk analysis methods have been used to weight fire safety components in accordance with their importance in relation to an overall fire safety policy. These types of methods are generally denoted as "semi-quantitative methods" and are briefly described in Section 2.4.3. A yet more general term that stretches beyond the area of risk analysis across many areas of application is Multi Attribute Decision Making. The theory behind MADM methods is covered in the next chapter.

Quantitative methods and qualitative methods can be considered to undertake such a weighting, but there are a range of disadvantages that makes both of these methods unsuitable for this purpose. The quantitative methods generally require data on probability and consequence, which is not feasible when considering weighting of fire safety components. The qualitative methods are related to subjective opinions, as are semi-quantitate methods but to a lesser extent.

4 Multi Attribute Decision Making (MADM)

Many of the decisions people make in their day-to-day lives have the character of "one criteria decisions". Huang and Tzeng (2011) suggest that these types of decisions are intuitive and are made solely on the basis what preference rating the decision maker ascribed to the alternatives. However, when numerous criteria are involved, with differing importance and interdependencies, the decision making process becomes much more complicated. Hence, a more advanced method that considers these circumstances must be applied (Huang & Tzeng, 2011).

Multi criteria decision making (MCDM) is an umbrella term for decision making methods that are applied to decision making situations where numerous criteria are involved. The term can be divided into two groups of methods: multi attribute decision making (MADM) and multiple objective decision making (MODM) (Yoon & Hwang, 1995). MODM is a decision making method that is used to identify the best choice with regards to different objectives (Yoon & Hwang, 1995). For example, in a situation where a company faces a decision regarding which product to produce in order to make the highest profit against other objectives such as limiting their carbon footprint, the company might use MODM. While the MODM methods are more geared towards planning and designing, the MADM methods are more focused on evaluation (Tzeng & Huang, 2011). According to Yoon and Hwang (1995), the term MADM includes several methods with similar properties (see Figure 4-1). Some of these methods will be discussed in Section 4.3.2 and 4.6.1-4.6.2.

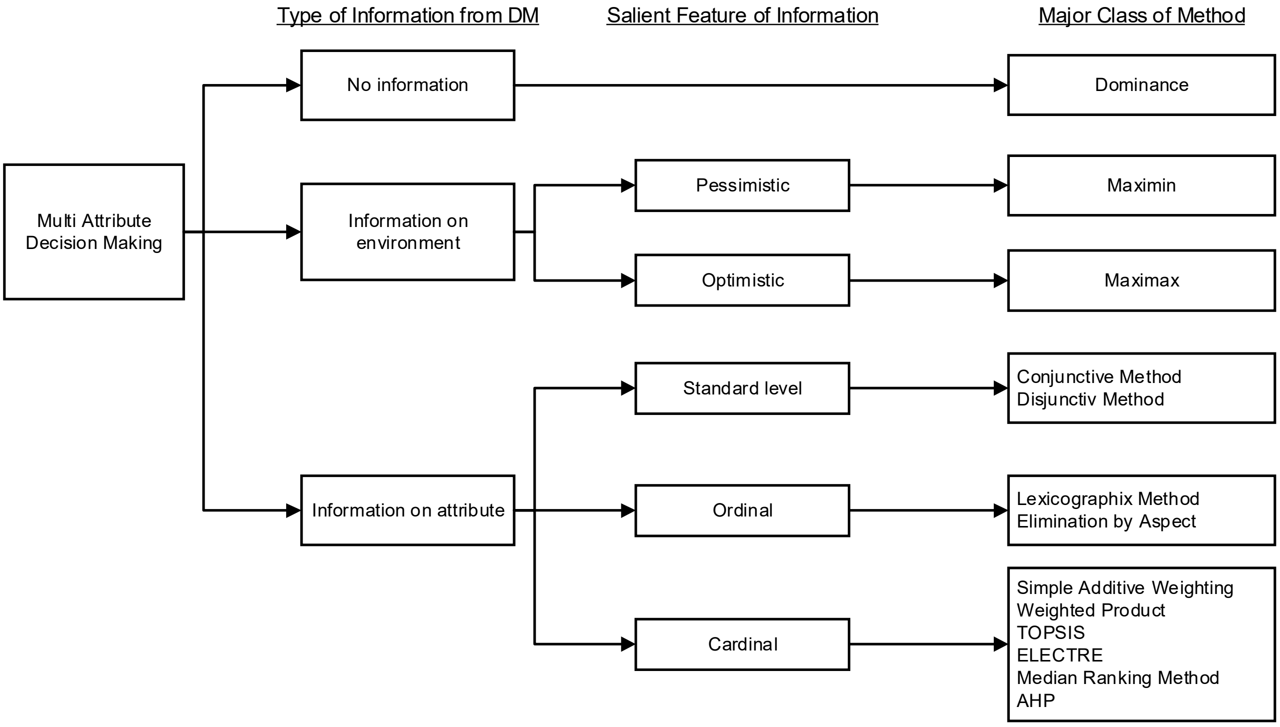


Figure 4-1. A taxonomy of MADM methods (Hwang and Yoon, 1981), reproduced with permission.

4.1 General Discussion of MADM Methods

According to Yoon and Hwang (1995, p. 2), MADM refers to "[…] making preference decisions (e.g., evaluation, prioritising and selection) over the available alternatives that are characterised by multiple, usually conflicting, attributes." MADM methods have four common traits, including alternatives (synonymous with policy, action or candidate (Yoon & Hwang, 1995)), attributes (synonymous with goals or criteria (Yoon & Hwang, 1995)), attribute weights, and measures of the performance of alternatives with respect to the attributes (Rao, 2007). Yoon and Hwang (1995) also includes incommensurable units, referring to non-comparable measurements of the attributes (e.g.

monetary measurements and non-numerical measurements). The last trait, suggested by Yoon and Hwang (1995), is the decision table, this referring to a way of expressing the MADM problem in a consistent, structured way.

According to Yoon and Hwang (1995), the purpose of MADM is to obtain an index that can be used to compare different decision alternatives. The first step in obtaining this index is to generate attributes that affect the decision under consideration. This generation of attributes can be undertaken in different ways. Keeney and Raiffa (1976) suggest reviewing available literature on the attributes that affect the decision. Yoon and Hwang (1995) on the other hand, advocate the use of a hierarchical approach. They argue that this approach limits the risk of leaving out important attributes. The hierarchical approach is outlined in Section 4.2.

The identified attributes are often of various importance to the overall policy, or using Yoon and Hwang´s (1995) terminology, the alternative. To account for these differences in importance, almost all MADM methods include weighting the attributes in accordance with their respective importance to the alternative (Yoon & Hwang, 1995). This is further covered in Section 4.3. Besides assigning a weight to each attribute, the attributes must also be rated with respect to their individual performance (Rao, 2007). Take for example a car factory where a type of machine has been assigned a large weight in the overall policy to produce safe and cheap cars. In this scenario, the importance of the machine has been accounted for, but the age of the machine, the number of machines that exist within the company, and so forth, are not. This can be considered by rating the performance of the machines from various aspects. The results from these weightings and ratings can be summarised and displayed in a decision table (Yoon & Hwang, 1995; Rao, 2007). It is important to note that how this weighting and rating is undertaken differs between different MADM methods. Some of these methods are described in Section 4.3.1-4.3.2 and 4.5.

MADM methods have been used within the field of fire safety, predominantly in the context of risk indexing methods. General descriptions of the methods have been given by, among others, Stollard (1984) and Watts (1997), and been applied by for example Frantzich (2000, 2005, 2018), Shields and Silcock (1986), Budnick et al., (1997) and Magnusson and Rantatalo (1998). In the MADM methods outlined and utilised by these authors, a hierarchical approach has been used to structure and identify the elements that affect fire safety.

4.2 Hierarchical Approach

In the early 1960s, Simon (1962) published his article “Architecture of Complexity”, where he sheds light on how complex systems often can be viewed as composed by numerous interrelated sub-systems in the form of a hierarchy. Various types of hierarchies can be observed throughout society, for example organisational structures, composition on political systems or in a high school class. In these examples, the hierarchy relates to aspects such as power and social status. However, within the field of decision making the hierarchical approach can aid the derivation of attributes from a defined policy or alternative (Yoon & Hwang, 1995). These attributes can have different names and be defined at different levels in the hierarchy depending on the level of formalisation of the policy or alternative that is required (Yoon & Hwang, 1995).

As mentioned earlier in this chapter, the hierarchical approach is commonly used within the area of fire risk indexing. The use of the hierarchical approach within fire safety was first introduced by Stollard (1984) and Merchant (1988), and has been developed further by Shields and Silcock (1986). It has later been applied by for example Budnick et al. (1997), Frantzich (2000, 2005, 2018) and Karlsson (2000). In common for these applied hierarchical approaches is that at least four levels have been included in the applied hierarchy. The different levels in this type of fire safety hierarchies are further described in Section 4.2.1-4.2.5.

Before going further in this chapter, it is important to touch upon the terminology used within the area of MADM. It is clear, throughout this chapter, that the terminology differs depending on author and in what area the MADM methods and the hierarchical approach are applied. Within the field of fire safety, the terminology outlined in Table 4-1 is commonly utilised.

Table 4-1. Definitions of the levels of fire safety hierarchies (based on Watts (2008)).

Level	Label	Description
1	Policy	Course or general plan of action adopted by an organisation to achieve security against fire and its effects.
2	Objectives	Specific fire safety objectives to be achieved.
3	Strategies	Independent fire safety strategies, each of which contributes wholly or partly to the fulfilment of fire safety objectives.
4	Components	Components of fire risk that are determinable by direct or indirect measure or estimate.
5	Sub-components	Measurable feature that serves as a constituent part of a fire safety component.

The description of the hierarchy levels in Section 4.2.1-4.2.5 are primarily given in a fire safety context. A corresponding description of the levels could, however, be given in any other context where a hierarchical approach is applied. The levels would be defined differently in another setting to be applicable to that context.

4.2.1 Policy

Yoon and Hwang (1995) labels this level as “alternative”, and is described as an alternative in a decision process, which are to be analysed using a MADM method. In the context of fire safety, the policy is described as “course or general plan of action adopted by a government, party or person, to achieve security against fire and its effects” (Stollard, 1984, p. 146). This policy is often vague by its nature, and is commonly defined as “fire safety” (e.g. Shields and Silcock (1986) and Budnick et al. (1997)) but is sometimes more specific (e.g. Magnusson and Rantatalo (1998) and Frantzich (2005)). The vagueness of the policy is reflected upon by Keeney and Raiffa (1976), which states that the policy is not aimed for operational purposes, instead it is more of an indication of what is of interest in the decision analysis.

4.2.2 Objectives

The objectives are specified goals to be achieved in order to comply with the policy (Stollard, 1984). Within the area of fire safety, “life safety” and “property protection” is practically always included as objectives. When it comes to businesses or organisations that have a strong incentive to maintain their operations, an objective covering this aspect is often included (e.g. Stollard (1984) and Budnick et al. (1997)). Nevertheless, the objectives can be chosen to serve other areas as well. Frantzich (2000), for example, mentions the preservation of cultural heritage as a possible objective.

4.2.3 Strategies

The strategy (sometimes called tactic, e.g. Shields and Silcock (1986)) level entails strategies that are identified to achieve the objectives specified in level two (Watts, 2008). Within the area of fire safety, these strategies are often focused on for example prevention of ignition, limiting fire and smoke spread, fire extinction and provision of safe egress etc. (e.g. Shields and Silcock (1986)). The identified strategies can be phrased slightly differently, but they are usually defined in a way that is basically consistent with other phrasings.

4.2.4 Components

The components are described by Watts (1991, p. 461) as the “ingredients of fire safety”. These are all the factors that have an impact on the fire safety strategies in level three. One of the identified components may have an effect on all or none of the previously identified strategies (Stollard & Abrahams, 2002). The number of components that are included in a hierarchy tree is practically infinite, but it is wise to limit the number of components to allow for the intended applications of the hierarchy tree. Watts (1997) argues that a relatively small number of components can be related to causing a large portion of fire related deaths. This would further motivate the use of a limited number of components, conditioned by the chosen components being those having the largest impact on the overall fire safety. In the available works on fire safety hierarchies, the number of included components ranges from 17 to 25 (e.g. Frantzich (2000, 2005, 2018), Karlsson (2000), Shields and Silcock (1986) and Stollard (1984)).

Stollard and Abrahams (2002) emphasis that the fire safety components must not only be comprised by intuitive ones, such as fire extinguishers or other fire safety equipment or systems. Components such as management of the occupants and linings must be included as well (Stollard & Abrahams, 2002).

4.2.5 Sub-Components

Sometimes, there is a need for a higher level of formalisation, such that a fifth level for sub-components can be introduced. Sub-components are defined by Stollard (1984, p. 147) as "essential parts of components which can be readily identified". If taking the potential component "evacuation alarm" as an example, possible sub-components could be how the evacuation alarm is activated as well as the signal type of the alarm.

4.2.6 Hierarchy Tree

It is important to assume that the components, strategies and objectives of a hierarchy tree are independent of each other, both within each level and between each level of the hierarchy. It is, however, possible that some of the components, strategies and objectives are correlated to some degree. Yoon and Hwang (1995) and Stollard (1984) discuss this matter and conclude that not taking account for this small correlation will not have a significant impact on the result.

An example of a hierarchy within the area of fire safety is presented in Figure 4-2. Figure 4-3 presents an example of an entirely different application of the hierarchical approach and the hierarchy tree. This example should be seen in the context of an investment bank looking to hire a new stockbroker. No levels in the hierarchy are defined and some potential empty sub-components have been included (dotted lines).

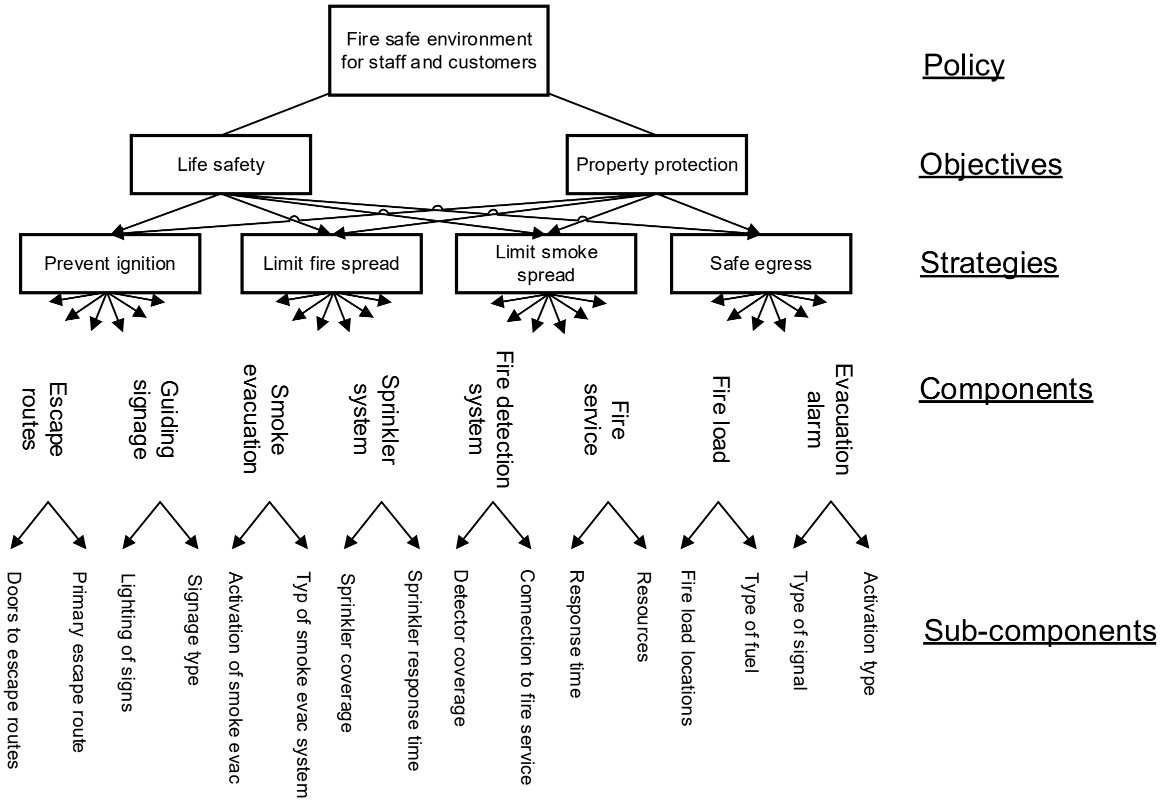


Figure 4-2. Example of a hierarchy tree within the area of fire safety.

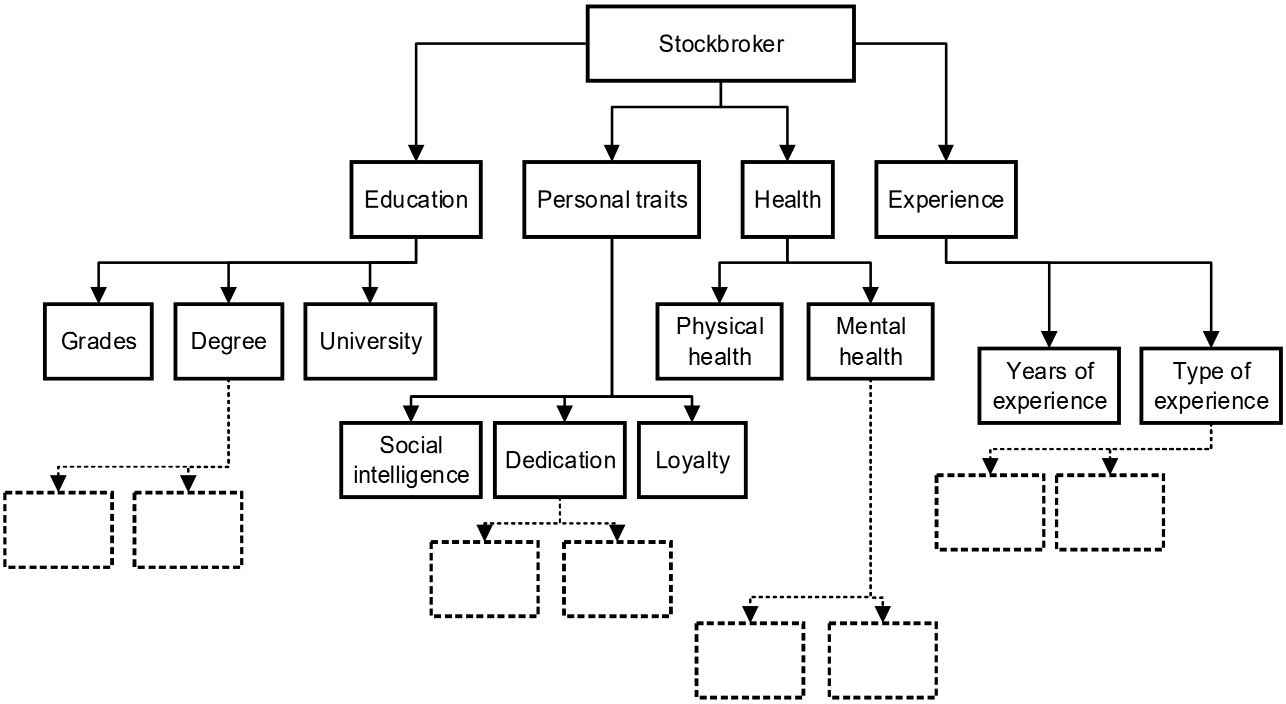


Figure 4-3. Example of a hierarchical approach used by a fictitious company evaluating candidates for a stockbroker position.

4.3 Component Weights

As touched upon in Section 4.1, the varying components must be weighted in accordance with their respective importance to the policy. Yoon and Hwang (1995) suggest that the decision maker must provide information on the components weight. In the area of fire safety, Stollard (1984), among others, recommends consulting an expert panel to perform the weighting of the components (see Section 4.3.1). There are several methods available that the expert panel could use, for example cardinal scales may be utilised when assessing the components weight (Yoon & Hwang, 1995). Within the area of fire safety, a common method is using a Likert scale (e.g. Shields and Silcock (1986) and Budnick et al. (1997)). A Likert scale is a 5 to 10 point ordinal scale, which are used to transform subjective opinions into quantitative data (Joshi, Kale, Chandel, & Pal, 2015). The expert panel that is undertaking the weighting assigns a value according to the defined Likert scale (Budnick et al. 1997) (an example of component weights to a single strategy is provided in Table 4-3). Every value of the Likert scale is defined according to the context, an example of a Likert scale is displayed in Table 4-2.

Table 4-2. Example of a 6 points Likert scale.

Importance or weight	Interpretation
0	No relation
1	Not important
2	Low importance
3	Moderate importance
4	Important
5	Very important

Table 4-3. Example of results from weighting of components.

Components	Strategy: Provide safe egress
Sprinkler system	1
Fire load	2
Signage	4
Internal linings	0
Fire service	2
Compartmentation	2
Detection system	2
Travel distances	4
Escape routes	5

To arrive at the weight of the components in relation to the policy, each component must be weighted in relation to every strategy; in turn, each strategy must be weighted in relation to each objective, and finally, the objectives must be weighted in relation to the policy (Stollard, 1984). Exactly how to calculate the final component weights after the weighting has been undertaken is outlined in Section 4.4.

To facilitate further handling of the data on component weights, it is recommended that the component weights be normalised so that the weights (normalised weights denoted w_i and y_i representing the weighting according to the Likert scale) sum up to 1.0 (Formula 6 and 7). As an example, the normalised weights of Table 4-3Table 4-4 are presented in Table 4-4. The normalised weights have been multiplied with a factor 1,000 to facilitate component comparisons.

$$w_i = \frac{y_i}{\sum_{i=1}^{n} y_i}$$ Formula 6

$$\sum_{i=1}^{n} w_i = 1$$ Formula 7

Table 4-4. Example of component weights in relation to the strategy of providing safe egress according to the Likert scale and corresponding normalised weights.

Components	Strategy: Provide safe egress (Likert scale weights)	Normalised weights
Sprinkler system	1	45
Fire load	2	91
Signage	4	182
Internal linings	0	0
Fire service	2	91
Compartmentation	2	91
Detection system	2	91
Travel distances	4	182
Escape routes	5	227

4.3.1 Expert Panels

As mentioned, a common method for assigning weights to components is to consult an expert panel. The Delphi process is a frequently used, systemised way of undertaking such expert consultations. The method is referred to as an informal method by Schiebe, Scutsch, and Schofer (1975) and was developed in the 1950s in the US by Olaf Helmer and Norman C. Dalkey at the RAND corporation (Elsbernd, 1974). The original purpose was to assess possible targets and damage from a Soviet nuclear strike, but has spread to a number of applications outside the defence industry (Rowe & Wright, 1999).

Rowe and Wright (1999) specify four characteristics of the Delphi process: anonymity, iteration, controlled feedback, and the statistical aggregation of group response. The members of the panel answer anonymously the questions posed by a panel leader (Rowe & Wright, 1999). The members are then provided with the anonymous answers from the other panel members, and may alter their answers based the other members answers (Rowe & Wright, 1999). Frantzich (2000) argues that benefits of the method includes that the anonymity reduces the impact of dominant members of the panel. Shields, Silcock, Donegan, and Bell (1987) discuss some methodical problems related to the Delphi method, mostly related to the expert selection and phrasing of questionnaires.

According to Thorne (1993), group discussions can produce generally good results. Although it should be noted that Thorne (1993) applied group discussions to issues relating to the nuclear industry and that several meetings were required. Frantzich (2000, 2005, 2018) utilises an extended group discussion technique, where two separate groups are enquired to perform the same task. Frantzich's (2000, 2005, 2018) reason for using two separate group is to limit the impact of dominant panel members on the end result.

4.3.2 Analytical Hierarchy Process (AHP)

The analytical hierarchy process introduced by Saaty (1980) is another method that should be mentioned in the context of weighting components. The method is built on pairwise comparisons between components within the same level of the hierarchy (Saaty, 2008). This result can be summarised in a matrix that describes the relations between the components (Saaty, 2008). The matrix is then utilised to establish the relations between each component and the strategies (as described, other labels also exist) of the next level in the hierarchy (Saaty, 1977). Tzeng and Huang (2011) and Saaty (1977) describes a number of methods that can be used to undertake this weighting, such as the geometric mean method, the linear programming method, and the lambda-max method, but the method often described as the most stable is the Eigenvalue method proposed by Saaty (1977).

According to Watts (1997) the AHP is not suitable for situations where the number of components exceeds seven due to the time and effort required to perform the pair vice comparisons.

4.4 Calculating the Component Weights

The first step is to assign weights to each component in relation to each strategy, then each strategy weighted in relation to each objective, and finally each objective weighted in relation to the policy (Stollard, 1984). Frantzich (2000) concludes that when using the method of group discussions to perform the weight assessment, a methodology that yields good results is to weight all the components in relation to a single strategy, then precede to the next strategy and use the same methodology. In Frantzich's (2000) method, the same modus was also applied to remaining levels upwards the hierarchy.

After finalising the weighting, the result can be summarised in matrixes in accordance with Figure 4-4, depending on the number of included objectives, strategies and components. To arrive at the final component weights in relation to the policy, the multiplication described in Figure 4-4 is to be performed. The calculation results in a vector, in the case described in the figure, a 20 × 1 matrix, entailing the final weights in relation to the policy.

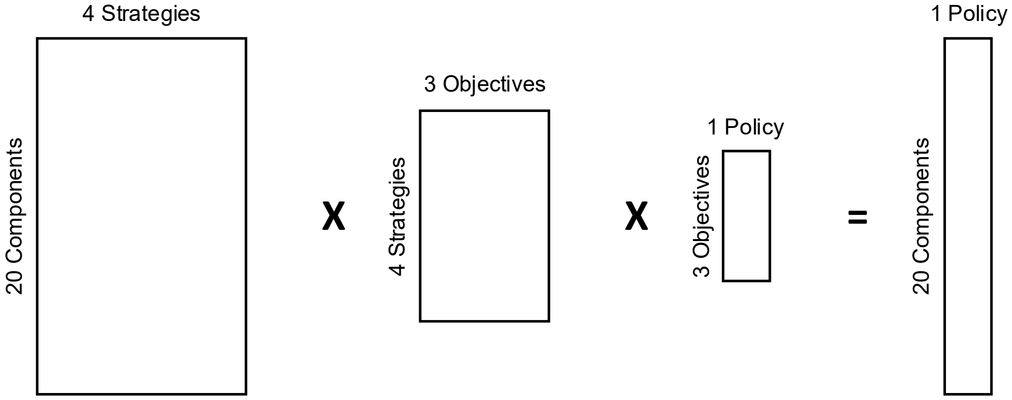


Figure 4-4. The matrix multiplications utilised to calculate the final components weights in relation to the policy (based on Watts (2008, p. 5-137)).

An example of the matrix calculation can be given by multiplying a 4 × 3 matrix and a 3 × 1 matrix (the second and the third matrix dimensions that are displayed in Figure 4-4) with arbitrary numbering:

$$\begin{bmatrix} 1 & 2 & 3 \\ 4 & 5 & 6 \\ 7 & 8 & 9 \\ 10 & 11 & 12 \end{bmatrix} \times \begin{bmatrix} 1 \\ 2 \\ 3 \end{bmatrix} = \begin{bmatrix} 14 \\ 32 \\ 50 \\ 68 \end{bmatrix}$$

4.5 Grading of Components

As outlined in Section 4.1 of this chapter, one of the key traits of the MADM methods is to grade the components with respect to the extent to which they are significant (Watts, 2008). Watts (1997, p. 683) describes it thus: "[…] grades are measures of the intensity, level, or degree of danger or security afforded by the attributes [here attributes can refer to objectives, strategies, components or possibly sub-components] in a particular application". An example from the area of fire safety can be an evacuation alarm component, which is graded on the basis of two sub-components; activation and alarm type (Table 4-5) (Frantzich, 2005). The qualitative grading of the two sub-components are transformed to a quantitative value through a decision matrix (Table 4-6). It should be noted that the grading need not to be undertaken based on the sub-components; the grading can also be based on the component directly (e.g. Stollard (1984) and Frantzich (2000, 2005, 2018)).

Table 4-5. Evacuation alarm sub-component grading (based on Frantzich (2005)).

Activation		**Alarm type**	
Automatic activation	A	**Simple acoustic or optical alarm**	AO
Manual activation	M	**Voice alarm**	V

Table 4-6. Evacuation alarm component grading.

Component grading	**Alternatives**			
Activation	A	M	A	M
Alarm type	AO	V	V	AO
Summarised grade	2	1	3	1

Regardless of whether the rating of the components is undertaken utilising the methodology presented in Table 4-5 and Table 4-6 or whether rating values are assigned in for example percentages or monetary terms, the rating values are required to be normalised (Tzeng & Huang, 2011). Watts (1997) supplies the following formulas to undertake a linear normalisation of the component ratings. Formula 8 is to be utilised when the component is of beneficial value to the overall policy, and Formula 9 is to be utilised when the component is of detrimental value (Watts, 1997).

$$x_i = \frac{y_i - y_i^{max}}{y_i^{max} - y_i^{min}} \qquad \text{Formula 8}$$

$$x_i = \frac{y_i^{max} - y_i}{y_i^{max} - y_i^{min}} \qquad \text{Formula 9}$$

4.6 Combining Weights and Grading (Index Calculations)

By combining the weights and grading for each component, it is possible to calculate an index or score that describes the entire system in terms of for example fire safety (Watts, 1997). Several methods (referred to as calculation procedures by Frantzich, Nystedt, and Lundin (2001)) can be used to undertake this final evaluation of the system. Two of these, the simple additive weighting method (SAW) and the weighted product method (WPM), are briefly described below. It should be noted that the earlier described analytical hierarchy process also may be applied to combining weights and grading (Rao, 2007), however it will not be covered further.

4.6.1 Simple Additive Weighting (SAW)

The simple additive weighting method is probably the most frequently used for combining the weights and the grading of the components (Tzeng & Huang, 2011). It is essential that weights grading are expressed in identical units of measure, hence, weighting and grading must be normalised. The calculated product of each component can then be summarised creating a final number, denoted by the index or the score (Rao, 2007; Watts, 1997; Tzeng & Huang, 2011) (Formula 10). This calculation means the same as calculating the scalar product of the vectors $\overline{w_\iota}$ and $\overline{x_\iota}$ (Watts, 1997).

$$Index = \sum_{n} w_i \, x_i \qquad \text{Formula 10}$$

4.6.2 Weighted Product Method (WPM)

According to Miller and Starr (1969) the weighted product method (WPM) is similar to the SAW method. The main difference they identify is that the weights and grading are multiplied instead of added which is the case in the SAW method. The same requirements regarding normalisation apply to this method as well. The multiplication calculation (Watts, 1997) is presented in Formula 11.

$$Index = \prod_{n} {x_i}^{w^i} \qquad \text{Formula 11}$$

5 Generation of Fire Safety Hierarchy

The purpose of this chapter is to generate a fire safety hierarchy that will be used as part of the expert panel components weighting in Chapter 6. The chosen policy, objectives, strategies and components for retail buildings and retail buildings with high rack storage that will be included in the fire safety hierarchy will be described and explained. The same fire safety hierarchy will be defined for both retail and retail with high rack storage due to their inherent similarities. However, notes are made for some components to reflect how the components apply differently to the building types. The complete fire safety hierarchy is presented in Figure 5-2.

5.1 Policy

The policy is chosen intuitively and is to provide an acceptable fire safety level for buildings conducting retail and to ensure business continuance. Business continuance is included due to the severe economic damage a company can suffer from a fire incident.

5.2 Objectives

This section outlines the objectives that are chosen to comply with the defined policy. The three objectives together encompasses the objectives that are to be achieved to show compliance with the policy.

5.2.1 Provide Life Safety

The objective to provide life safety is included in most MADM methods within the field of fire safety (e.g. Karlsson (2000), Frantzich (2018), Shields and Silcock (1986), Magnusson and Rantatalo (1986) and Watts (1997)). In this decision analysis, the objective of life safety should be interpreted as providing life safety to all occupants residing in the compartment of fire origin, in the rest of the building and in adjacent buildings.

5.2.2 Provide Property Protection

The objective to provide property protection is chosen due to the – often considerable – values of retail space and buildings, including both the values of the building itself, and of goods. According to Frantzich (2018), support for including property protection as an objective can be found in the Swedish National Board of Housing, Building and Planning regulations (Boverket, 2018). Further, as with the objective of providing life safety, the objective of providing property protection is a common occurrence within multi attribute decision methods utilised in the field of fire safety. Within this decision model, property protection may be defined as the limitation of damage to property in the event of fire.

5.2.3 Provide Business Continuance

For a method to assess fire safety in health care facilities, Stollard (1984) includes "mission continuity" as an objective. He defines this objective as "maintenance of the supply of health care with minimal disruption" (p. 147). It is intuitively easy to understand the value of mission continuity in health care facilities, and when considering the costs of interruptions to retail businesses, it easily follows that an objective aimed at business continuance should be included.

Another argument for including business continuance is given by Gaughan (2009), who emphasises that business interruption comes at a significant cost to the company. Not only does the interruption hinder the business's ability to provide their products or services, but it can also, according to Torpey, Lentz, and Barret (2004) lead to adverse publicity, which can have more long term consequences than the temporary interruption itself. A limitation of business interruption in the event of a fire, is how providing business continuance should be interpreted as part of this thesis.

5.3 Strategies

The NFPA 550 Guide to the Fire Safety Concepts Tree (NFPA, 2017) (Figure 5-1) has been used as a basis to identify strategies for fire safety. The NFPA (2017) suggests the strategies "prevent fire ignition" and "manage fire impact" to achieve fire safety objectives. Both of these strategies are divided further, and the strategy of managing fire has sub-strategies that cover the egress and protection of occupants' perspective. It is important to note that the NFPA concept tree solely aims to map fire safety strategies that have an impact on the objectives, in contrast to a hierarchical approach, which also entails a component level.

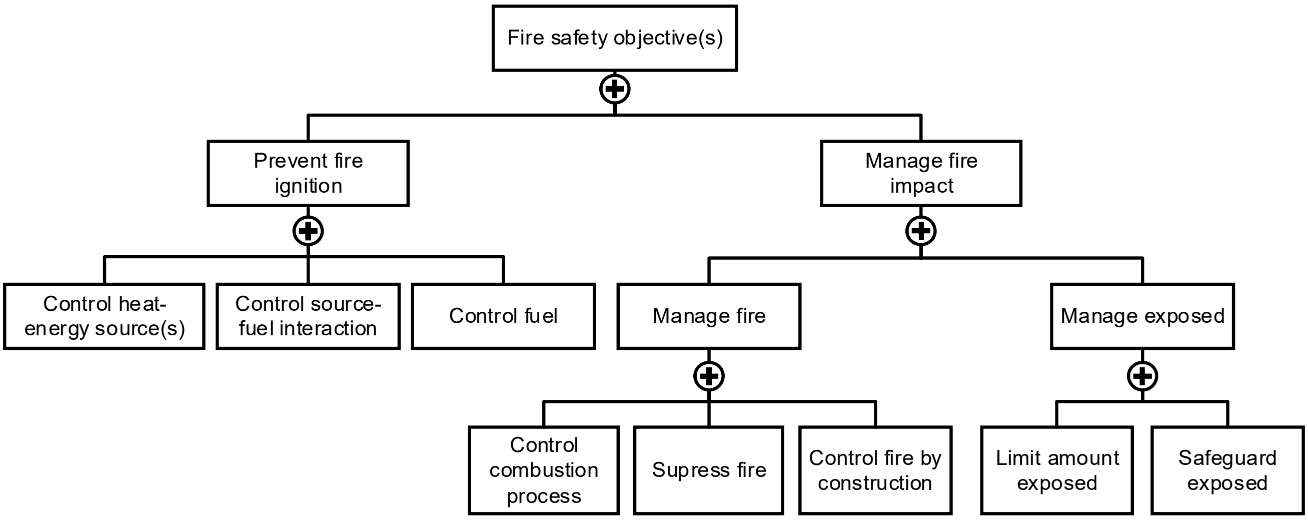


Figure 5-1. Part of NFPA fire safety concept tree. (Reproduced with permission from NFPA 550-2017, Guide to the Fire Safety Concepts Tree, Copyright© 2016, National Fire Protection Association. This reprinted material is not the complete and official position of the NFPA on the referenced subject, which is represented only by the standard in its entirety which can be obtained through the NFPA web site at www.nfpa.org.)

Stollard and Abrahams (2002) suggest the following strategies to achieve the objectives of life safety and property protection: prevention, communication, escape, containment, and extinguishment. Stollard and Abrahams (2002) define the communication strategy as the communication of information about a fire location in the case of a fire occurrence. Stollard and Abrahams (2002) specify that this communication can take place between a person or a system, the people residing within the affected building as well as the fire service. They further shed light on the importance of communication in relation to various components and features relating to fire safety. The value of including communication as a strategy is obvious so that the relations between different components and the strategy of communication in that way can be considered.

Another approach, undertaken by Shields and Silcock (1986) in relation to dwellings, is to include the communication aspect as a component instead of a strategy. This way, the communication perspective is considered while at the same time limiting the comprehensiveness of the hierarchy tree and the number of judgements required of the panel. This, of course, comes at the cost of not considering the components' relations to communication – as a strategy. To summarise, to achieve the objectives outlined above, four strategies are identified: prevent ignition, limit fire and smoke spread, provide safe egress and extinction of fire.

These strategies are also represented in the NFPA fire safety concept tree, however labelled differently (Figure 5-1) as sub-strategies to the strategy "manage fire impact".

5.3.1 Prevent Ignition

The strategy of preventing ignition is defined by Stollard (1984, p. 147) as "preventing the initiation of destructive burning"; naturally, this strategy is the most efficient one to avoid fire occurrences. Going back to the fundamentals of fire science, there are three vital elements required for an ignition to occur: a source of ignition, fuel and sufficient levels of oxygen. As levels of oxygen is not a plausible element to affect in a building containing people, it follows that there are two elements, source of ignition and fuel, that need to be considered when preventing ignition from occurring.

5.3.2 Limit Fire and Smoke Spread

The strategy of limiting fire and smoke spread aims at limiting the effect on the occupants and the structure of the buildings where the fire originated as well as adjacent buildings Stollard and Abrahams (2002). This can be ensured via passive and active fire safety measures (Stollard and Abrahams, 2002). Examples of passive fire safety measures are compartmentation and fire rated cladding, and examples of active measures are sprinklers and smoke evacuation. Limiting fire and smoke spread is a basic requirement set by the European Union in regulation No 305/2011 (Regulation (EU) No 305/2011, 2011).

5.3.3 Provide Safe Egress

Stollard (1984, p. 147) specifies providing safe egress as "continuous path of travel from any point in a building to the outside at ground level". Karlsson (2000) suggests a number of components that will have an effect on this strategy: detection systems, signal systems, design of escape routes and education and training for occupants. Stollard and Abrahams (2002) also mentions preventing fire spread, this leading to the obvious conclusion that components may have an impact on several strategies. This strategy can also be found in the regulation No 305/2011 (Regulation (EU) No 305/2011, 2011).

5.3.4 Extinction of Fire

The strategy of fire extinction has a strong relationship to the objectives of property protection and business continuance. Even if the occupants have egressed safely, the fire need to be extinguished in order to limit property damage and allow for quick recovery and for business to resume. To refer back to the strategy of preventing ignition, it was concluded that the elements of fuel and ignition were required to be considered. Since the fire extinction strategy refers to an ongoing fire event, the fuel is the primary element under consideration. Stollard and Abrahams (2002) describe various extinguishing agents such as water, foam and powder. These agents should be the ones in focus considering that the use of more advanced agents such as halon are not commonly utilised in retail buildings. Stollard and Abrahams (2002) further outline various fire safety features related to these extinguishing agents such as sprinklers and fire extinguishers. Equipment that facilitates fire service operations also affects this strategy (Stollard & Abrahams, 2002).

5.4 Components

In this section, the components identified by the literature review process are listed and described. The selection of the components has been undertaken based on reviews of predominantly fire risk indexing methods such as those of Magnusson and Rantatalo (1998), Shields and Sillcock (1986), Stollard and Abrahams (2002) and Watts (1997), this since they often include a multi-attribute approach. Furthermore, other references – not within the area of fire risk indexing – such as CFPA Europe (2017) and Malhotra (1993) have been reviewed in the selection process. Existing fire safety regulations for a selection of countries, outlined under Section 1.10, have also formed part of the basis for the selection of components. The fire statistics presented in Section 1.9 relating to leading causes for fire occurrences have also been considered.

5.4.1 Sprinkler System

A sprinkler system is a fire suppression system used to extinguish fire or limit fire development. These systems can be wet pipe or dry pipe types of systems depending on the area of use (Lake, 2010). A dry pipe system is useful in compartments where freezing can occur (Lake, 2010), though these are not common within retail buildings. Today most sprinkler systems are activated by the rupture of a glass bulb that keeps a pipe cap in place, which prevents water from flowing through the sprinkler head, whereas before, a fusible link filled the same purpose. Both types of activation are dependent on the ambient temperature.

Sprinkler systems are, if properly designed and maintained (see Section 5.4.8), very effective in fire extinguishment and the prevention of fire development, and offer a high level of reliability. According to NFSN (2017) the operational reliability of sprinklers in the U.K during the four-year period 2011-2015, was over 90 % in retail buildings, and the success rate, meaning extinguishment or containment of the fire, was 100 %. It should be noted that a sprinkler system might have more benefit in retail buildings with high rack storage than in retail buildings. Special in-rack sprinklers are sometimes provided in order to reach a fire inside a storage rack not reachable from a regular ceiling sprinkler (Gluckman & Stavish, 2011).

5.4.2 Fire Detection System

A fire detection system can be defined as a system or equipment for detecting fires (Karlsson, 2000). The purpose of a fire detection system is to notify the fire service in the occurrence of a fire. For the purpose of this thesis, the affected personnel are assumed to be notified as well. Products from fire are identified by various kinds of detectors such as smoke detectors, heat detectors, flame detectors and combination detectors (Stollard & Abrahams, 2002). Fire detection systems can also be manual, meaning that fire is not detected automatically. Instead, it is to be detected by occupants within the building. Fire detection equipment are required to be serviced, tested and maintained according to existing standards (CFPA Europe, 2017).

5.4.3 Evacuation Alarm

An evacuation alarm is a device that produces some kind of signal with the purpose of alerting customers and personnel in the event of fire (Stollard & Abrahams, 2002). This signal can be in the form of a bell producing a ringing noise or a siren; in public buildings where occupants with hearing disabilities can be expected, a flashing light signal may be required (Stollard & Abrahams, 2002). A spoken message alarm is sometimes used, notifying occupants to evacuate the building (Stollard & Abrahams, 2002). The activation of the fire evacuation alarm can be triggered by the activation of the detection system or a sprinkler system (Frantzich, 2005).

5.4.4 Customers

A number of factors are included in the customer component. These include occupancy, mobility of the customers and the customers' familiarity of the premises (Stollard & Abrahams, 2002). Regarding occupancy, it is assumed that occupancy is generally lower in retail with high rack storage than retail. Considering the customer component, customers in buildings conducting retail can be assumed to possess little knowledge about escape routes and emergency exits. Personnel assistance during a fire event is covered under the personnel component (Section 5.4.5). Further, the presence of customers with disabilities is likely.

5.4.5 Personnel

Personnel can affect the overall fire safety level of retail buildings in various ways; they can play a part in fire prevention and assistance during a fire event, both in extinguishment of the fire and in assistance during the evacuation process. According to Stollard and Abrahams (2002), fire safety training for the personnel regarding handling of fire safety equipment, egress assistance and handling of material related to fire risks is crucial for successful courses of action to be undertaken in a fire event. All the aforementioned actions should be considered as elements of the personnel component.

5.4.6 Internal Linings

The component internal linings include linings on walls and ceilings. The internal linings have an effect on the spread of fire and smoke, but may also have a preventing effect on ignition (Frantzich, 2005).

5.4.7 Fire Service

The fire service component include both a preventive and an operative perspective. The preventive perspective entails the provision of information and guidance in fire safety matters. Assistance with fire safety training for the personnel is also included. The operative perspective refers to the fire service ability to fulfil its purpose in the event of a fire. Size of work force, staffing levels, equipment, knowledge level and deployment time all have an impact on fire service performance (Flynn, 2009).

5.4.8 Inspection, Testing & Maintenance (ITM)

Inspection, testing and maintenance (ITM) are mentioned throughout several countries' fire safety regulations in relation to various fire safety systems (Section 1.10), these including sprinklers, fire detection systems, emergency lighting, guiding signage, smoke evacuation, and evacuation alarm etc. Further, ITM of escape routes and doors to escape routes are included.

5.4.9 Escape Routes

Escape routes can be exit doors leading directly to the outside or routes inside a building which lead to the outside. Exit doors to the outside can also lead to an external escape staircase. Escape routes can be designed and dimensioned in various ways depending on the factors such as occupancy. Escape routes can be protected with a fire rating or be unprotected. Further, the distances to escape routes are considered part of this component.

Doors leading to an escape route are generally required to be easily openable. If the escape route is fire rated, the doors must generally achieve the same fire rating. Doors to escape routes must be equipped with an automatic door closer to prevent fire and smoke spreading into the escape routes, the door closer being connected the fire detection system or to an adjacent detector independent from the central system.

5.4.10 Building Geometry

The building geometry component refers to a buildings' layout, referring to whether, for example, the building has a lot of open floor area or if the building has many rooms and corridors. Height differences, including number of floor levels, form part of this component as well.

5.4.11 Emergency Lighting

Emergency lighting provides guidance should a power outage occur during a fire event which requires safe egress. The lights can be powered by batteries or by an emergency power system which activates when a power outage occurs.

5.4.12 Smoke Evacuation

Evacuation of smoke can be undertaken using natural ventilation facilitated by openings in the roof or walls in the form of hatches. Mechanical smoke evacuation can be utilised when natural smoke evacuation is not applicable. Smoke evacuation systems usually activate upon detector activation.

5.4.13 Fire Extinguishing Equipment

The component of fire extinguishing equipment refers to equipment intended to be used by personnel and customers in the event of fire. This include handheld fire extinguishers, fire blankets and fire hose reels. Training the personnel in the use of the fire extinguishing equipment is not included in this component. This is however included in the personnel component (Section 5.4.5).

5.4.14 Guiding Signage

Guiding signage involves signs that indicate the nearest escape route to the occupants. This component also includes signage that aids personnel and customers to locate fire safety equipment in the event of fire.

5.4.15 Ventilation System

The ventilation system component refers to the design of the ventilation system as well as the fire safety equipment aimed at preventing fire and smoke spread throughout the ventilation system. A ventilation system can be designed in a way that one system serves several fire compartments, or each compartments can have its own isolated ventilation system. The equipment mentioned includes smoke ducts, fire dampers and smoke dampers.

5.4.16 Compartmentation

The compartmentation component refers to the degree to which a building is divided into separate fire compartments. The fire compartments are required to achieve a specific fire resistance rating depending on the circumstances. The fire resistance rating is covered under the "structure – separating component" (Section 5.4.18).

5.4.17 Structure – Load Bearing

The structure – load bearing component refers to the structural stability of a building in the event of a fire. In other words, the structure's load bearing capacity when exposed to fire.

5.4.18 Structure – Separating

Separation of structure includes fire resistance ratings of fire compartments, the latter in addition to walls and ceiling includes doors, windows, and penetrations through fire rated structures.

5.4.19 Fire Load

The fire load component refers to combustible material in the building. In both retail buildings and retail buildings with high rack storage, this include merchandise, shelves, and other interior features.

5.4.20 Electrical installations

Electrical installations refer to all electrical equipment in the building under consideration, such as lighting- and heating related devices.

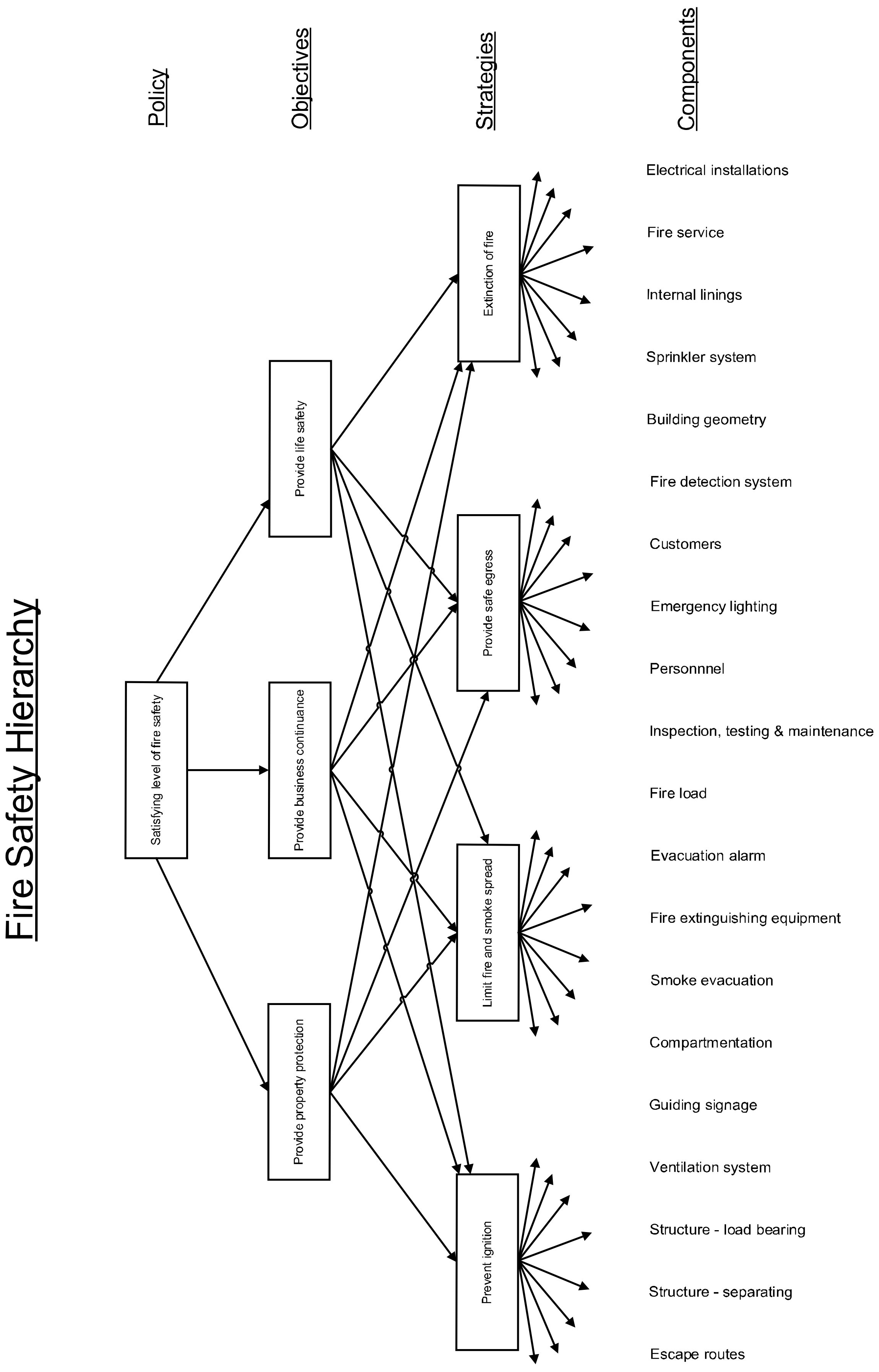


Figure 5-2. The generated fire safety hierarchy based on Chapter 5.

6 Component Weights

This chapter provides a description of the weighting process leading up to the final component weights for retail buildings and retail buildings with high rack storage. The chapter begins with a description of the component weighting undertaken by the expert panel. The final processed weights are presented followed by a results analysis.

6.1 Expert Panel Component Weighting

The expert panel were instructed to undertake the weight assessment using the methodology applied by Frantzich (2000) (described in Section 4.3.1). In accordance with Frantzich's methodology, the panel were instructed to begin with assigning weights to every component in relation to a single strategy, and then to precede to the next strategy and assign weights to every component in same manner. When the component level was finalised, the panel were instructed to precede to the strategy level and apply the same modus in relation to the objectives and finally the same modus to the objectives in relation to the policy. The weights were to be assigned according to a six points Likert scale. The scale, with definitions for every value, were included on the two sheets whereon the panel members were to assign the weights. One sheet was dedicated to retail while the other to retail with high rack storage. These sheets are included in Appendix A. Besides these sheets, the panel members were also provided with the fire safety hierarchy presented in Figure 5-2. The fire safety hierarchy were provided with the purpose of facilitating an overall perspective.

To facilitate the weighting process for the panel members, the panel members were advised to relate a change in the performance of the components with respect to each strategy. The author considered this a pedagogical way of explaining a way of thinking throughout the weighting process. The sprinkler component in relation to the strategy of providing life safety may be utilised as an example: How much does the strategy of life safety benefit or suffers from an increase in sprinkler coverage in relation to a decrease in sprinkler coverage? If the strategy of life safety benefits greatly from a higher sprinkler coverage, and respectively suffers greatly from a lower sprinkler coverage, the sprinkler component should probably by assigned with a high number, meaning a large weight and vice versa. A graphical description of this way of thinking about each weighting is presented in Figure 6-1.

It is important to note that this way of thinking does not deviate from how component weighting is described by Yoon and Hwang (1995). According to Yoon and Hwang (1995), the different components are required to be weighted in accordance with their respective importance to the policy. In other words, the way of thinking summarised in Figure 6-1 provides the weights in accordance with how Yoon and Hwang (1995) describes component weights.

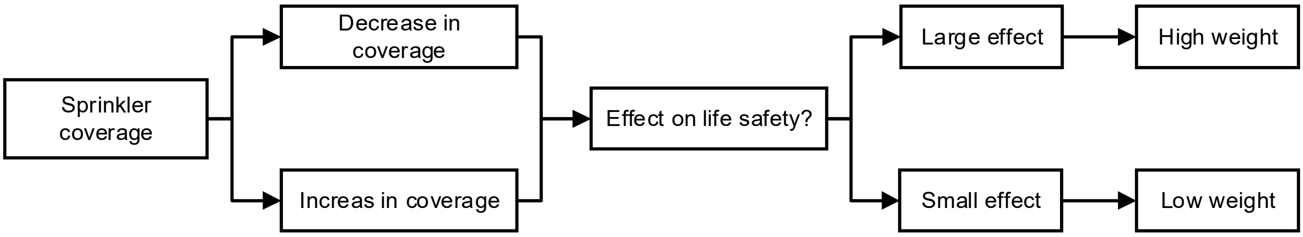


Figure 6-1. Graphical description of a way of thinking during the component weighting process.

The panel members were instructed to assign all the weights independently, and when finalised, were to discuss the weights upon which the panel member´s opinions differed.

6.2 Results from the Expert Panel Weighting

The results from the expert panel weighting are presented in Appendix B. Matrix calculations in accordance with Section 4.4 and Figure 4-4 has been performed, arriving at the component weights in relation to the strategies, objectives and the policy (see Appendix B). The results from the matrix calculations have been normalised (Formula

6 and 7) and multiplied with a factor 1,000 to facilitate comparisons among the weights. The final results from the weightings followed by the described calculations are presented in this section. The five largest component weights in relation to the policy are in bold.

6.2.1 Retail

In this section, the normalised results for retail buildings are presented.

Table 6-1. Component weights in relation to the policy.

	Policy
Components	**Satisfying level of fire safety**
Sprinkler system	**102**
Fire detection system	**88**
Customers	71
Personnel	**85**
Guiding signage	29
Fire load	65
Compartmentation	22
Fire service	51
Evacuation alarm	36
Internal linings	30
Emergency lighting	29
Inspection, testing & maintenance	**110**
Smoke evacuation	37
Escape routes	36
Structure – load bearing	29
Structure – separating	15
Ventilation system	15
Building geometry	**73**
Fire extinguishing equipment	44
Electrical installations	33

Table 6-2. Component weights in relation to each objective.

	Objectives		
Components	**Provide life Safety**	**Provide property protection**	**Provide business continuance**
Sprinkler system	94	111	107
Fire detection system	92	81	86
Customers	75	66	70
Personnel	82	91	86
Guiding signage	42	10	25
Fire load	59	73	68
Compartmentation	27	18	18
Fire service	36	68	59
Evacuation alarm	52	13	31
Internal linings	27	35	29
Emergency lighting	42	10	25
Inspection, testing & maintenance	106	118	112
Smoke evacuation	29	48	39
Escape routes	52	13	31
Structure – load bearing	17	40	37
Structure – separating	17	15	12
Ventilation system	17	15	12
Building geometry	71	76	74
Fire extinguishing equipment	31	61	49
Electrical installations	31	38	31

Table 6-3. Component weights in relation to each strategy.

	Strategies			
Components	**Prevent ignition**	**Limit fire and Smoke spread**	**Provide safe egress**	**Extinction of fire**
Sprinkler system	0	119	87	139
Fire detection system	0	95	109	83
Customers	138	48	87	56
Personnel	207	71	65	83
Guiding signage	0	0	87	0
Fire load	69	71	43	83
Compartmentation	0	48	22	0
Fire service	0	48	22	111
Evacuation alarm	0	0	109	0
Internal linings	0	71	0	28
Emergency lighting	0	0	87	0
Inspection, testing & maintenance	241	95	87	111
Smoke evacuation	0	71	0	56
Escape routes	0	0	109	0
Structure – load bearing	0	0	22	83
Structure – separating	0	48	0	0
Ventilation system	0	48	0	0
Building geometry	0	95	65	83
Fire extinguishing equipment	0	71	0	83
Electrical installations	345	0	0	0

6.2.2 Retail with High Rack Storage

In this section, the normalised results for retail buildings with high rack storage are presented.

Table 6-4. Component weights in relation to the policy.

	Policy
Components	**Satisfying level of fire safety**
Sprinkler system	**120**
Fire detection system	**68**
Customers	65
Personnel	66
Guiding signage	33
Fire load	**94**
Compartmentation	27
Fire service	34
Evacuation alarm	41
Internal linings	27
Emergency lighting	33
Inspection, testing & maintenance	**128**
Smoke evacuation	35
Escape routes	41
Structure – load bearing	24
Structure – separating	19
Ventilation system	9
Building geometry	**68**
Fire extinguishing equipment	35
Electrical installations	37

Table 6-5. Component weights in relation to each objective.

Components	Objectives		
	Provide life safety	Provide property protection	Provide business continuance
Sprinkler system	109	136	125
Fire detection system	79	50	63
Customers	70	56	63
Personnel	70	62	63
Guiding signage	44	12	29
Fire load	81	115	99
Compartmentation	33	22	22
Fire service	26	43	39
Evacuation alarm	55	16	36
Internal linings	24	34	27
Emergency lighting	44	12	29
Inspection, testing & maintenance	119	144	131
Smoke evacuation	26	50	39
Escape routes	55	16	36
Structure – load bearing	15	34	31
Structure – separating	22	19	14
Ventilation system	11	9	7
Building geometry	61	74	72
Fire extinguishing equipment	26	50	39
Electrical installations	33	47	36

Table 6-6. Component weights in relation to each strategy.

Components	Strategies			
	Prevent ignition	Limit fire and smoke spread	Provide safe egress	Extinction of fire
Sprinkler system	0	156	87	179
Fire detection system	0	63	109	36
Customers	148	31	87	36
Personnel	148	63	65	36
Guiding signage	0	0	87	0
Fire load	74	125	43	143
Compartmentation	0	63	22	0
Fire service	0	31	22	71
Evacuation alarm	0	0	109	0
Internal linings	0	63	0	36
Emergency lighting	0	0	87	0
Inspection, testing & maintenance	259	125	87	143
Smoke evacuation	0	63	0	71
Escape routes	0	0	109	0
Structure – load bearing	0	0	22	71
Structure – separating	0	63	0	0
Ventilation system	0	31	0	0
Building geometry	0	63	65	107
Fire extinguishing equipment	0	63	0	71
Electrical installations	370	0	0	0

6.3 Comments on the Expert Panel Meeting

The weight assessment of the members where all in all quite consistent, but there were a few assessments which rendered further discussion. Initially there were also discussions about the selection of the components. Early in the assessment process, the panel highlighted the need for a component that covered electrical installations. Their argument for this was based on the fire risk that is related to more or less permanent installations such as heat and lighting, but also temporary electrical equipment such as construction power tools. As a result of these arguments, it was mutually decided to include the component "electrical installations". The component is briefly described in Section 5.4.20.

Further, a panel member raised the question whether the component "internal linings" should be divided into the two components "wall linings" and "ceiling linings". His opinion was that the "ceiling linings" component should have much higher weight than "wall linings" in relation to some of the strategies. It was mutually agreed to make the distinction between "wall linings" and "ceiling linings" to consider this difference. However, not all panel members followed the new division of the component due to a communicative misunderstanding, hence the two components could not be included in the result. The initial component "internal linings" was however assessed, and therefore was included in the result.

Regarding the weighting assessment itself, the personnel and fire load components rendered some discussion. There were some different opinions regarding the ability of the personnel to limit fire and smoke spread, where opinions varied between the weights of two (low importance) and four (important). A compromise was made to assign the weight of three (moderate importance) to the personnel component in relation to the strategy limit fire and smoke spread. The fire load component rendered a discussion about whether the risk of potential blockage of egress routes should be considered in relation to the strategy of providing safe egress. The discussion resulted in a consensus that this factor should be included in the component, and this was taken into account by the panel.

The weighting of the strategies in relation to the objectives generated a number of discussions. Regarding the strategy of preventing ignition in relation to the objective of providing property protection, the panel concluded that it was not reasonable to assign a value higher than three. The primary argument was that it is not feasible to prevent all occurrences of fire and should therefore be assigned a weight accordingly. The strategy of providing safe egress was initially assigned the value zero (no relation), but a member raised the question of the prioritisation of the fire service. The argument was that the fire service would not initiate fire extinguishing measures before the occupants, if possible, have been evacuated from the building. The strategy of providing safe egress in relation to the objective of providing property protection was therefore assigned the value two. The strategy of providing safe egress in relation to the objective of providing business continuance did also render in discussion. A conclusion were made that the strategy should be assigned the value three since casualties may have an impact on a business ability for business continuance.

The discussions did not vary much between the assessment of retail buildings and retail building with high racks storage, except for the component "Structure – load bearing" in relation to the strategy of extinguishing fire. In the latter, one opinion was that the component should be assigned a low value since the fire service would have small possibilities to affect the fire outcome if a retail building with high rack storage was on fire. Another perspective was that the component should be assign a high value since the importance of the load bearing structure should be of greater importance with an increased fire load, which may be the case in the case with the high racks storage. From this discussion a value of three was assigned to the component.

6.4 Result Summary

The results of the weightings and the matrix calculations show that the components that have the largest weight in relation to the policy in the retail building case are (ranked from highest to lowest weight): inspection, testing and maintenance; sprinkler system; fire detection system; personnel; and building geometry. Worth noting is that the results show that the ventilation system component and separating structures component have the lowest weight (15 and 15) in relation to the policy.

In the case of retail buildings with high rack storage, the top five components differed on just one component. The personnel component in the retail building case (fourth highest weight) was replaced by the fire load component. The components with the lowest weight were similarly the ventilation system and separating structures. The five components with the highest weight for the two building types are summarised in Table 6-7.

Table 6-7. The five components with the highest weight for retail buildings and retail buildings with high rack storage.

Order of importance	Retail buildings	Retail buildings with high rack storage
1	Inspection, testing and maintenance	Inspection, testing and maintenance
2	Sprinkler system	Sprinkler system
3	Fire detection system	Fire detection system
4	Personnel	Fire load
5	Building geometry	Building geometry

7 Development of Indicators

In this chapter, indicators will be developed based on the components of highest importance in terms of fire safety for retail buildings and retail buildings with high rack storage respectively. As the three most important components are the same for the two building types, these will be included in this chapter. The fourth most important components for the building types are personnel and fire load, respectively. The personnel component is considered to be the most suitable component to develop indicators upon as it is assumed to be less demanding in terms of data collection.

Each component is analysed with the purpose of identifying component features that have high relevance in context of fire safety. More specifically, the indicators should meet the criteria outlined in Section 3.12. For clarity, the criteria includes:

- Feasibility
- Sensitivity to change in the conditions in question
- Consistency and comparability over time and space
- Easily understood and applied by potential users
- Timeliness
- Valid and meaningful
- Relatable to other indicators where appropriate
- Acceptability
- Safe
- Avoid duplication
- Quantifiability

7.1 Sprinkler System

7.1.1 Component Description

Sprinkler systems aim to extinguish small fires or control larger fires via the application of water (or sometimes foam). The water is distributed on the fire through one or more sprinkler heads, which are activated by an elevation in the immediate surrounding temperature (Stollard & Abrahams, 2002). The activation temperature varies depending on the sprinkler head type, where the two most common head types are bulb sprinkler heads and fuse sprinkler heads (Ferguson & Janicak, 2005). The activation mechanism of the bulb type consists of a bulb filled with a liquid and an air bubble, which prevents the water from flowing through the sprinkler head (Ferguson & Janicak, 2005). When the surrounding temperature increases, the liquid expands which decreases the size of the bubble, and causes the bulb to fracture, which releases the water flow through the sprinkler head (Ferguson & Janicak, 2005). The sprinkler activation temperature depends on the size of the air bubble and the amount of fluid contained within the bulb (Burke, 2007). The bulbs are colour coded in accordance with their activation temperature, where the most common colour is red, representing an activation temperature of 68 °C (Stollard & Abrahams, 2002).

The fuse sprinkler head has, instead of a bulb, a metal fuse that prevents water from flowing though the sprinkler head. The sprinkler head activates when the surrounding temperature reach a certain level, which causes the metal fuse to melt, and thereby activating the water flow (Ferguson & Janicak, 2005).

Sprinkler heads can also be of quick response type or standard response type (Stollard & Abrahams, 2002). This distinction is made upon the sprinkler heads Response Time Index (RTI). The RTI value is calculated by multiplying a time constant (τ_e) by the square root of the velocity of the hot gases surrounding the sprinkler head (V_g) (Formula 12) (Sze, 2009). The time constant represents the time required to raise the temperature of the bulb to its activation temperature, and is calculated with Formula 13 (Sze, 2009). Sprinkler heads are, according to Lake (2010), defined as standard response sprinklers if the RTI is 80 $\sqrt{\text{ms}}$ or more and defined as quick response sprinkler heads if the RTI is less than 50 $\sqrt{\text{ms}}$.

$$RTI = \tau_e \times \sqrt{V_g} \qquad \text{Formula 12}$$

$$\tau_e = -\frac{t_a}{ln\left(\frac{1 - T_a - T_0}{T_g - T_0}\right)} \qquad \text{Formula 13}$$

Where T_a is the activation temperature of the sprinkler head, T_0 is the initial temperature of the bulb, T_g is the temperature of the ambient gas, and t_a is the activation time.

Sprinkler systems can be divided into four main groups: wet pipe systems, dry pipe systems, deluge systems and preaction systems (Fleming, 2008). The wet pipe system is the system most frequently utilised, and consists of a system of pressurised, water-filled piping (Fleming, 2008). The piping in a dry pipe system is filled with pressurised air or nitrogen (Ferguson & Janicak, 2005; Flemming, 2008). Pressurised gas keep the valves in a closed state, which in turn prevents water from flowing through the system. When a sprinkler activates, the pressure inside the piping drops which has the effect of opening the valve and allowing water to flow through the piping and through the activated sprinkler head (Ferguson & Janicak, 2005; Flemming, 2008). Dry pipe sprinkler systems, as they are not filled with water, are commonly utilised within areas where freezing may occur. The other two systems, deluge systems and preaction systems, are predominantly utilised in high-risk environments and in areas where accidental activation is of special concern (e.g. valuable computer labs), hence these system types will not be covered further.

7.1.2 Development of Sprinkler System Indicators

An intuitive initial approach to developing sprinkler system indicators is to pose the following question: what properties of a sprinkler system have the most significant effect on the sprinkler systems' role in overall fire safety? A suggestion is that this question is answered giving regard to both the operation of the sprinkler system and features relating to its design. The reason for taking this dual perspective on the sprinkler system component is to allow for a broad perspective; it also allows for comparison and interpretation of the relationship between operation and design features.

Sprinkler system indicator 1 – Operation perspective

The operation perspective refers to the operation of the sprinkler system in the occurrence of fire. In the light of the purpose of a sprinkler system, to contain or extinguish fire, an intuitive approach is to base an indicator on this core task of the sprinkler system – to activate in the occurrence of fire. The most evident basis for an indicator aiming to accommodate sprinkler system activation in occurrence of fire, is simply the number of sprinkler activations. The development of an indicator based on the number of sprinkler activations will hence be discussed further.

An issue in relation to using the number of sprinkler activations as the basis for an indicator is that the heat release rate of the fire that induces the sprinkler activations is not reflected in any way. However, by defining a "sprinkler activation" as the activations of an individual sprinkler head, and not to the "sprinkler activation occurrence" some information about fire size is considered in the indicator. This is because the number of activated sprinkler heads should increase linearly with the heat release rate of the fire, given that the buildings have similar layout. Nonetheless, it will only be possible to take advantage of this information if the indicator is viewed graphically for a single building or a limited number of buildings. If the indicator is aggregated to encompass dozens or maybe hundreds of buildings, the underlying data has to be reviewed in order to attain information on the fire size for individual fire occurrence.

According to Hall Jr (2010), over the four-year period 2003-2007, the average number of sprinkler activations induced by fire in public assembly, stores and office buildings in the US was 2,390. Hall Jr (2010) states that the number of non-fire induced sprinkler activation during the year of 2003 for the same property uses was 15,900. This serves to show that less than one in six sprinkler activations were induced by fire. These statistics raise the question of the importance of only including sprinkler activations induced by fire in data utilised as the basis for a sprinkler activations indicator. If the statistics had shown that the number of non-fire induced activations ("non-fire activations") formed a low proportion of the fire-induced activations ("fire activations"), it may not have been necessary to clean the data from non-fire activations. This is pointed out because not cleaning the data would have a positive effect in terms of the feasibility criteria outlined by the Health Information and Quality Authority (2010), Mainz (2003) and von Schirnding (2002). To summarise, data forming the basis of a sprinkler activations indicator must be cleaned from non-fire activations. However, should new research show that the proportion of none-fire activations decreases, it might be justifiable to include all sprinkler activations in a sprinkler activations indicator in order to facilitate the feasibility criteria. It should however be noted that there is no reason why the number of non-fire activations could not form the basis of an additional complementary indicator.

Identification of denominator

Just by collecting data on sprinkler activations enables a company to monitor the number of sprinkler activations over time. This number by itself does not however provide much information. This is because the number of activations cannot be compared between buildings, given that they have different floor areas. Further, it cannot be compared to a generally defined benchmark. As outlined in Section 3.7, an indicator can be constructed to include a denominator. The Health Information and Quality Authority (2010) states that this is required to allow comparisons between organisations and trends.

Two different candidate denominators that could be utilised have been identified: total insurable value (TIV) of the building and building area. The former is usually calculated by summarising the value of the property, the value of inventories and potential income loss in the occurrence of business discontinuance caused by property damage (Total Insurable Value, n.d.). To highlight how these indicator can be applied, and to derive the most suitable denominator, two examples are provided.

Example 1. A company has two retail buildings with the building areas of 200 m^2 (Building 1) and 400 m^2 (Building 2). Ten sprinkler activations have occurred in each building within the last year. These retail buildings follows the company concept, which in this case means that they are structured in the same way, they provide the same type of goods and the layout is similar. If these two buildings are viewed in light of the TIV definition, a reasonable assumption is that the property value, the value of inventories and the potential income loss are approximately proportional to the building area. Assuming that this is a reasonable estimation, and that the TIV of Building 1 is \$100, the TIV of Building 2 should be approximately \$200. Examples of indicators utilising building area and TIV as denominators are provided below.

Denominator: Building area

$$Indicator_{Building\ 1} = \frac{Number\ of\ sprinkler\ activations}{Building\ area} = \frac{10\ activations}{200\ m^2} = 0.05\ activations/m^2$$

$$Indicator_{Building\ 2} = \frac{Number\ of\ sprinkler\ activations}{Building\ area} = \frac{10\ activations}{400\ m^2} = 0.025\ activations/m^2$$

Denominator: Total insured value

$$Indicator_{Building\ 1} = \frac{Number\ of\ sprinkler\ activations}{Total\ insurable\ value} = \frac{10\ activations}{\$100} = 0.1\ activations/dollar$$

$$Indicator_{Building\ 2} = \frac{Number\ of\ sprinkler\ activations}{Total\ insurable\ value} = \frac{10\ activations}{\$200} = 0.05\ activations/dollar$$

Since the proportionality constant for the relationship between building area and TIV in the example is 2, the proportionality constant for the relationship between the indicators is also 2. As a result of the indicator examples, it can be concluded that it would be of little benefit to apply indicators that are based on both building area and TIV. If a company still wants to monitor sprinkler activations in relation to TIV, the indicator based on building area can simply be multiplied by the quotient of the building area and the TIV.

The best alternative would in this case be to choose one of the denominators. The denominator that generally is the most suitable – and generally applicable to a higher degree – is highlighted by example two.

Example 2. In this example, a company has two retail buildings with the building area of 100 m^2 each. As in the previous example, both buildings follows the company concept, but one of the buildings provides goods that are more valuable (building two). The goods are of the same type as in the first example but have a higher value. According to the definition of TIV, the building with the more valuable goods have a higher TIV. In this example, the building with the higher valued goods (Building 2) has a TIV of $100 and the other $80 (Building 1). Ten sprinkler activations in the last year have occurred in each building. Examples of indicators utilising building area and TIV as denominators are provided below.

Denominator: Building area

$$Indicator_{Building\ 1} = \frac{Number\ of\ sprinkler\ activations}{Building\ area} = \frac{10\ activations}{100\ m^2} = 0.1\ activations/m^2$$

$$Indicator_{Building\ 2} = \frac{Number\ of\ sprinkler\ activations}{Building\ area} = \frac{10\ activations}{100\ m^2} = 0.1\ activations/m^2$$

Denominator: Total insurable value

$$Indicator_{Building\ 1} = \frac{Number\ of\ sprinkler\ activations}{Total\ insurable\ value} = \frac{10\ activations}{\$80} = 0.125\ activations/dollar$$

$$Indicator_{Building\ 2} = \frac{Number\ of\ sprinkler\ activations}{Total\ insurable\ value} = \frac{10\ activations}{\$100} = 0.1\ activations/dollar$$

In this example, applying both denominators provides more information than in the previous example. The indicator with the TIV denominator provides information that is not caught by the indicator with the building area as denominator. As demonstrated by the former indicator, the value is lower for building two, the building with the higher TIV. A question that could be posed is what the value of this information is; should the value of the goods have an effect on the sprinkler activation indicator value? As outlined in the example, the only difference between the two buildings is the value of the goods, which is the origin of the differing TIVs. The case could however be that there is an indirect link between the TIV and the number of sprinkler activations. A difference in TIV between two buildings can be derived in part from the buildings' areas (property sizes) and type of goods. However, in the example provided, there were no difference in building area and no difference in type of goods, except for its value. A conclusion that could be made based on this reasoning is that TIV is not necessarily correlated to the number of sprinkler activations. By consequence, the value of comparisons of indicators with a TIV denominator for different buildings are limited.

The building area denominator has a more intuitive relationship to the number of sprinkler activations. A sprinkler-protected corner-shop and a sprinkler-protected warehouse is a clear example, where the number of sprinkler activations naturally will be higher in the warehouse. In this example, the difference in building area is obvious, whereas the difference in TIV is not. Although it is likely that the TIV for the warehouse is significantly higher, it is not a certainty.

It might also be worth highlighting the fact that TIV is dependent on a number of underlying variables. As previously discussed, the indicator value changes when one or more variables comprising the TIV changes. This therefore makes comparison more difficult and less reliable. This can be contrasted to the building area denominator, which is a fundamental unit, and do not depend on any underlying variables.

Based on this theoretical reasoning, it is concluded that the best indicator to describe the operation perspective of a sprinkler system is:

$$\boldsymbol{Indicator}_{\boldsymbol{Sprinkler}} = \frac{\boldsymbol{Number\ of\ sprinkler\ activations}}{\boldsymbol{Building\ area}} \qquad \text{Indicator S.1}$$

To aid the monitoring of the indicator and comparisons between individual retail buildings or between regions or countries, the building area should be expressed in appropriate units. Million square metres is suitable in many cases.

Further discussion on the suggested indicator

Some of the criteria listed in the introduction to this chapter have already been covered indirectly, such as feasibility, consistency and comparability over time and space, and valid and meaningful. Further, it is clear that the indicator meets the majority of the criteria not already discussed, but the timeliness criterion is required to be addressed further. As outlined in Section 3.12, the timeliness criterion states that the data that the indicator is built upon should be made available within a reasonable time. If this criterion is viewed in light of the sprinkler activations per building area indicator, it is clear that the core issue is the reporting process related to sprinkler activations. The sprinkler activations have to be reported at the frequency defined in the specific case, other vice the indicator may not be meaningful. A reasonable conclusion however is that the reporting of sprinkler activations cannot be considered a process that have the prerequisites that could be deemed required to not meeting the timeliness criteria.

Lastly, the issue of how this proposed sprinkler indicator can be monitored must be addressed. The indicator can be monitored on a monthly or yearly basis depending on the buildings or company to which the indicator is applied. If for example a monthly basis is identified as the best time interval, the indicator can be graphically presented with each data point representing the number of sprinkler activations per area unit for each month. Another way of monitoring the indicator is to monitor each sprinkler activation. This can be graphically presented by accumulating each sprinkler activation per area unit over time. Examples of these forms of indicator presentation are provided in Section 8.1.

A question that may have arisen at this point in the chapter is why one would measure sprinkler activations instead of fire occurrences directly. Indeed, it is possible that both measurements – number of sprinkler activations and number of fire occurrences – depending on how “fire occurrences” is defined, would express the same information. The answer is that data on sprinkler activations, given that the data only includes fire-induced activations, is a clear and concise measurement of fire occasions. If the number of fire occasions would be measured instead, a great responsibility is assigned to the reporting structure. What fires qualify as “fire occurrences”? Does for example smoke production from the content of a smouldering cigarette receptacle qualify as a fire occurrence? Are flames required? These questions do not have to be regarded if sprinkler activations are utilised as the basis for the indicator.

Sprinkler system indicator 2 – Design perspective

It was suggested in the beginning of this section that the sprinkler component be viewed from two perspectives: the operation of the sprinkler system and the features relating to its design. The remainder of this section focuses on the design features perspective, and the development of an indicator to reflect this perspective.

Risk scoring methods

Two methods have been identified that could be used to incorporate sprinkler design features in an indicator. The first type of method has its origin in the insurance industry and is utilised to evaluate the fire risk level of buildings. The basic idea of these methods (henceforth referred to as risk scoring methods) is that fire safety related components such as fire detection, heating, personnel fire safety training and maintenance procedures are rated on the basis of how the respective component deviates from a set standard. The global furniture retailer IKEA utilises a system called IKEA Blue, in which each fire safety components are assigned values in accordance with a four-step scale. The steps are colour coded, and when a component fully complies with the internal standards of IKEA, the component coded as blue. The red colour represents the other end of the scale and is assigned to a component that demonstrates critical deviations from the IKEA standard. For the main part of the components, the IKEA Blue system includes clear definitions for each degree of deviation from the standard.

The global insurance company Zurich uses a similar method for evaluating building risk levels, whereby each component is rated and contributes to an overall fire risk rating for the building. Zurich's standards of comparison for each component are based on international fire safety standards such as those of NFPA (2010, 2013). It should be noted that the methodologies utilised by both IKEA and Zurich have many similarities with the fire risk index method Fire Safety Evaluation System (NFPA 101M) that was discussed in Section 2.4.3.

Fire risk representatives from IKEA advocate that a method such as IKEA Blue should be utilised to attend to the design features of sprinkler systems as well as to other fire safety components identified as part of this thesis. The case could however be made that the utilisation of such a method would have a negative effect on the applicability of the indicator. For a global company such as IKEA, which has well defined internal standards with regards to fire safety components, a risk scoring method would undoubtedly be the most suitable. The same would apply to any company that has well defined internal standards, to which each retail building within the company has to comply.

If a sprinkler features indicator is based on the fire safety regulations of one or more countries, there is an obvious possibility that companies in some countries, where these fire safety regulations do not apply, do not see the benefit of incorporating such an indicator. A solution to this issue could be to develop the indicator in accordance with the fire safety regulations of each country in which the indicator is intended to be applied. Put into the context of IKEA Blue, this would mean that every deviation step would be defined differently depending on the fire safety regulation of the country in which the indicator is to be applied. This would however disable comparisons of the indicator between different countries. For example a component deviation in one country would not necessary be assessed in the same way in another country, this because the indictor is based on two separate fire safety regulations. The incomparability that would be built into the indicator would further violate the consistency and comparability over time and space criteria.

The risk scoring methods discussed should also be compared to the usability criteria. Regardless of what fire safety regulations the deviation steps are derived from, an assessment of the respective indicator has to be undertaken on the basis of the deviation steps. This assessment may not be possible to undertake for a person with no fire safety training or experience; an internal or external fire safety resource may therefore be required.

The grading method

The other type of method that can be applied has its origin in MADM. It has been applied as part of risk indexing methods by for example Frantzich (2000, 2005, 2018) and Karlsson (2000), where it was referred to as grading.

The essence of this type of method is that a numerical value is assigned to each component, based on the design of the component and potential subcomponents. This type of method has been covered in Section 4.5 as part of the MADM chapter, and will not be described further here. These grading methods have several advantages in terms of comparability and usability compared to the risk scoring methods. Since the grading methods entails describing the components themselves and not how they deviate from a set standard, indicators built on these methods will be more generally applicable and comparable across countries.

Further, the grading methods are probably easier to utilise and to incorporate in various companies. Those who use the indicator are required only to describe the components with respect to the fire safety features included in the method. Based on this reasoning concerning the two different type of methods, the grading methods are concluded to be the best suitable.

Frantzich (2000, 2005) includes sprinkler head type and sprinkler coverage as the features (referred to as sub-components by Frantzich (2000, 2005)) upon which the summarised sprinkler component grade should be based. These suggestions are made as part of risk indexing methods for hospital wards, dance studios and schools. Because of the invariable applicability of these sprinkler features across different building types, as demonstrated by Frantzich's risk indexing methods, the features are considered to be suitable for retail buildings as well. The following variations to the sprinkler system features, as suggested by Frantzich (2000, 2005), will be adopted, in line with the purpose of adhering to the design feature perspective to sprinkler indicator development. These are set out in Table 7-1.

Table 7-1. Sprinkler system features.

Sprinkler coverage		**Sprinkler head type**	
Full sprinkler coverage	F	**Quick response sprinkler (RTI $< 50 \sqrt{m \times s}$)**	QR
Partial sprinkler coverage	P	**Standard response sprinkler (RTI $> 50 \sqrt{m \times s}$)**	SR

Frantzich (2000, 2005) further proposes the following grading matrix as a tool to transform the sprinkler features to a summarised sprinkler design grade (Table 7-2). Each combination of sprinkler head type and sprinkler coverage is assigned a value based on the respective designs. The summarised grade for each combination of sprinkler head type and sprinkler coverage should be viewed as an example of grades rather than the optimal grading of sprinkler feature combinations that can be applied without further review.

Table 7-2. Sprinkler system grading matrix.

Sprinkler system features	**Alternatives**			
Sprinkler head type	QR	SR	QR	SR
Sprinkler coverage	P	P	F	F
Summarised grade	0	0	3	1

The summarised grade of the sprinkler component, the indicator (see Indicator S.2), has the form of a single numerical value. Revisiting the indicator theory chapter, this indicator form is expressed as an absolute value or absolute figure indicator.

$$\boldsymbol{Indicator}_{\boldsymbol{Sprinkler}} = \boldsymbol{Summarised\ grade\ of\ the\ sprinkler\ system\ features} \qquad \text{Indicator S.2}$$

This type of summarised grade indicator can be applied alongside the sprinkler activations (operational) indicator to individual buildings, but it is not suitable to aggregate the indicator for a number of buildings. The only case where it is possible to aggregate the indicator is if the purpose is to compare an equal number of buildings (e.g. when comparing ten buildings with another ten other buildings). If the purpose is to compare an unequal number of buildings, the indicator has to be averaged over the number of included buildings. This is further discussed in Section 7.5.

7.2 Fire Detection System

7.2.1 Component Description

A fire detection system identifies the presence of fire. It is however not the fire itself that a detection system identifies, but its products: smoke, heat, and light (Stollard & Abrahams, 2002). Fire can be detected automatically by a detector or manually by a person, however, manual detection will not be covered further as this is included in the personnel component. Automatic detectors can be divided into three general groups; smoke detectors, heat detectors, and flame detectors (Ferguson & Janicak, 2005).

Smoke detectors are the most common detector type. They detect fire by identifying particles in smoke (Stollard & Abrahams, 2002). The heat detector identifies temperature elevation in its immediate surroundings; the temperature threshold for detector activation depends on the heat detector type (Ferguson & Janicak, 2005). Flame detectors are activated by the presence of radiant energy from flames in its immediate surroundings (Stollard & Abrahams, 2002). According to Ferguson and Janicak (2005) heat detectors are the detector type least likely to cause false alarms, but have the longest response time. (Response time is measured from time of ignition to activation). The smoke detector is more likely to cause false alarm but has a shorter response time, while the flame detector is the most likely to cause false alarm but has the shortest response time (Ferguson and Janicak, 2005).

According NFPA 72 (NFPA, 2010) detectors should cover the entire building, this including closets and other non-occupied spaces. If a building has such coverage, the NFPA 72 refers to the building as having total complete coverage (in this thesis referred to as full coverage).

The fire detection system can be connected to the fire service, meaning that the fire service is notified upon detector activation (Fitzgerald, 2002). There are four main types of systems for fire service notification: proprietary supervising station system, central station, remote supervising station, and auxiliary system (Fitzgerald, 2002). For the first type, a supervisory station in the building gets notified when a detector activates, wherefrom the station personnel notifies the fire service (Fitzgerald, 2002). The second and third types involve a central station or remote supervising station – not located on the building – being notified and them notifying the fire service (Fitzgerald, 2002). For the last system type, the fire service is notified directly without a middleman (Fitzgerald, 2002). All the fire service connection types except for direct connection are associated with an average delay of 15-60 seconds (Fitzgerald, 2002).

7.2.2 Development of Fire Detection System Indicators

For the development of sprinkler indicators, a dual perspective approach – relating both to sprinkler operation and design – was adopted for comprehensiveness. The same approach is chosen in the development of fire detection indicators.

Fire detection system indicator 1 – Operation perspective

The reasoning behind using building area as the denominator for the sprinkler activations (operational) indicator can in general be applied to the development of an operational indicator for the fire detection system component. Hence, the first step in the development of indicators for fire detection systems is to propose the indicator "number of detector activations divided by the building area":

$$\boldsymbol{Indicator}_{\boldsymbol{Detection}} = \frac{\boldsymbol{Number\ of\ detector\ activations}}{\boldsymbol{Building\ area}} \qquad \text{Indicator D.1}$$

Fire detection system indicator 2 – Design perspective

There are natural similarities between fire detection and sprinkler system components in terms of developing indicators from the design features perspective. Both are technical fire safety systems consisting of various devices that enable the system to operate effectively. It is hence suggested that the reasoning behind the choice of method for developing the sprinkler system features indicator (Indicator S.2) be applied to that for fire detection system features indicator as well. Given that the same reasoning applies, it is suggested that a grading methodology is also utilised.

The first step in developing the design-based indicator is to identify the relevant fire detection system features. As part of the fire risk indexing methods used by Frantzich (2000, 2005) and Karlsson (2000) (referred to in Section 7.1) a number of fire detection system features are suggested to be included in their respective methods. Karlsson's (2000) method, applied in the context of multi-storey apartment buildings, included detector coverage, detector type and detector power supply as the sub-components or features that underpin the detection system component grading. Frantzich's methods (2000, 2005) included detector coverage, detector type and fire service connection in the context of health care facilities, dance studios and schools. The fire detection system features identified by Karlsson (2000) and Frantzich (2000, 2005) are considered to be relevant for the development of a fire detection system features indicator. However, in consideration of the usability criteria, it is arguably necessary to limit the number of included features.

As the features "detection coverage" and "detector type" are included in the methods of both Karlsson (2000) and Frantzich (2000, 2005) – e.g. for apartment buildings, schools, dance studios and hospital wards – it is clear that these features are relevant for a wide range of building types. Hence, it is reasonable to include these features in an indicator applied to retail buildings and retail buildings with high racks storage.

The fire detection features that differs between the methods of Karlsson (2000) and Frantzich (2000, 2005) are "detector power supply" and "fire service connection". Karlsson (2000) does not elaborate on his inclusion of the "detector power supply" feature. It does, however, appear logical that the relevance of detector power supply is higher for apartment buildings than for the building types included in Frantzich's (2000, 2005) method. This is due to the possibility that detectors in individual apartments of apartment buildings are not tested at the same frequency as detectors in more public buildings such as schools and dance studios included in Frantzich's (2000, 2005) methods. Assuming that this reasoning is accurate, and as retail buildings are comparable to schools and dance studios in this sense, a detector power supply feature would not be sufficiently relevant for inclusion in a fire detection system features indicator for retail buildings.

Frantzich's (2000, 2005) includes "fire service connection" in his methods. The reasons for this may include the importance of limiting the time for fire service engagement, given that dance studios and schools have a lesser degree of compartmentation than apartment buildings. Other reasons may be that dance studios and schools usually are unoccupied during night time and that the occupational density can be relatively high. These circumstances have naturally a high degree of similarity to retail buildings. It is therefore concluded that the fire service connection feature should be included in the fire detection system features indicator.

In the methods of Frantzich (2000, 2005) and Karlsson (2000), the alternatives for the detector coverage feature include a selection of specified areas that are covered by detectors, such as corridors, egress routes and storage areas. In consideration of the usability criteria, and to allow for the indicator to be applicable across a broad range of retail buildings, the same alternatives that were included in the sprinkler system features indicator will be utilised as part of the fire detection system feature indicator. The definition of the "full detector coverage" component has been addressed in Section 7.2.1; if a building does not comply with this definition, the building should be viewed as having partial detector coverage. As the detector type feature entails the alternatives "smoke detectors" and "heat detectors" in all the methods by Frantzich (2000, 2005) and Karlsson (2000), these alternatives will be included as part of the fire detection system features indicator as well. The word "predominantly" is added to the alternatives to accommodate buildings with both smoke detection and heat detection.

The alternatives of the "fire service connection" feature included in Frantzich's (2000, 2005) methods are: direct connection to the fire service (no delayed alarm), direct connection to the fire service (delayed alarm with documented procedure), direct connection to the fire service (delayed alarm without documented procedure), phone connection, and no connection. With the exception of the second direct connection alternative ("documented procedure"), Frantzich's (2000, 2005) alternatives are consistent with the fire service connection types defined by Fitzgerald (2002). The alternatives of Fitzgerald (2002) can be considered slightly more general than Frantzich's (2000, 2005) and hence are the most suitable alternatives to be incorporated into the fire detection system features indicator. The identified fire detection features are summarised in Table 7-3.

Table 7-3. Fire detection system features.

Fire service connection		**Detector type**		**Detector coverage**	
Direct connection	DC	**Predominantly smoke detectors**	SD	**Full detector coverage**	F
Connection via third party	TPC	**Predominantly heat detectors**	HD	**Partial detector coverage**	P
Phone connection	PC				
No connection	NC				

Based on the grades assigned by Frantzich (2000, 2005) and Karlsson (2000), and Fitzgerald's (2002) description of fire service connection, the following grades are assigned to each combination of fire detection features (Table 7-4):

Table 7-4. Fire detection system grading matrix.

Detection system features	**Alternatives**							
Fire service connection	DC	TPC	PC	NC	DC	TPC	PC	NC
Detector type	SD	SD	SD	SD	HD	HD	HD	HD
Detector coverage	F	F	F	F	P	P	P	P
Summarised grade	5	4	3	1	2	1	0	0

The summarised grade for each combination of the fire detection system features should be viewed as an example of grading rather than the optimal grading than can be applied without further review. The indicator is formalised as the following:

$$\boldsymbol{Indicator_{Detection} = Summarised\ grade\ for\ the\ detection\ system\ fetaures}$$

Indicator D.2

7.3 Personnel

7.3.1 Component Description

The personnel component is multi-faceted to its nature. Literature within the field of fire safety in general and fire safety management in particular describe a number of responsibilities that can, or should, be assigned to personnel in various types of businesses. These responsibilities include fire extinguishment, egress assistance and in some situations fire detection (Ball, 2001; Stollard & Abrahams, 2002). In order to be able to shoulder these responsibilities, fire safety training for the personnel is required. Ball (2001), and Stollard and Abrahams (2002) suggest that fire safety training is closely related to the outcome of an emergency occurrence. Ball (2011) advocates that fire safety training for personnel should encompass elements of fire extinguishment and fire hazards related to the materials and processes around them. Demers and Jones (2011) add that an element of emergency egress should be included in the fire safety training.

According to Stollard and Abrahams (2002), personnel in warehouses and other large buildings are sometimes able to contribute to early fire detection, for example, observing a fire before any activation from a technical detection system. An earlier fire detection may advance a potentially necessary emergency egress, providing a larger time margin before critical conditions occur.

The training aspect to the personnel component can also be found in fire safety regulations. The NFPA Life Safety Code (NFPA, 2018a) states that both practical and theoretical training specific to the duties assigned to the staff in the buildings emergency plan shall be undertaken periodically. It is further stated that the training shall involve training on the use of portable fire extinguishers and that all training shall be undertaken with such a frequency that the training is established as a routine.

England and Wales' primary fire safety regulation document, the Regulatory Reform (Fire Safety) Order 2005 (Department for Communities and Local Government, 2007, p. 22) states that "the responsible person must ensure that his employees are provided with adequate safety training and record this where he employs five or more people" (the English/Welsh legislation structure is covered in Section 1.10). The supporting documents for undertaking the fire risk assessment for factories and warehouses (Department for Communities and Local Government, 2006b) and offices/shops (Department for Communities and Local Government, 2006d) highlight the importance of an emergency plan that outlines how the personnel should act should a fire occur. The Department for Communities and Local Government (2006b; 2006d) further lists several elements that the fire safety training should encompass. These elements can be summarised as fire extinguishment training (including the use of fire extinguishing equipment) and training related to providing assistance in the emergency egress process.

7.3.2 Development of Personnel Indicators

It has been made clear that fire safety training is an important aspect of the personnel component; hence, it appears logical that one or more personnel indicators should be based on fire safety training. However, before proceeding to the issue of fire safety training, the personnel component should be viewed from a more fundamental perspective.

Personnel indicator 1

For the personnel to be practically able to undertake the responsibilities discussed in Section 7.3.1, there must be a sufficient number of personnel present in the building. Naturally, data exclusively including the number of personnel provides no information on the abilities of the personnel to fulfil their responsibilities. For this information to be meaningful, the data has to be complemented with information on the conditions of the building. As for the previous indicators, building area appears to be the denominator that is most suited to developing a meaningful personnel indicator. Keeping in mind the possible responsibilities of personnel, the number of personnel in relation to the size of the building they occupy is intuitively related to their ability to undertake said responsibilities.

The case could be made that the use of TIV as denominator, in this case, would even less suitable than for the sprinkler activations indicator. The reason for this is that the TIV value can be considered to be less related to the number of personnel than the number of sprinkler activations. For example, the value of inventory is intuitively not highly correlated to the number of personnel, even though some correlation probably exist.

There may be a risk related to how an indicator with number of personnel and building area is perceived. Take for example a building that has a personnel density of 0.1 personnel/m^2. When viewing this indicator, a risk might be that it is perceived as the personnel is evenly distributed throughout the building. Although the case can be that 90 % of the personnel, at certain times, are located in auxiliary areas and not in the vicinity of the customers. A reasonable assumption to make, in relation to the distribution of personnel in retail buildings, is that the personnel density in customer areas is naturally higher than in auxiliary personnel areas. Hence, although it is a theoretical risk that 90 % or even 100 % of the personnel at certain times are located in non-customer spaces, the indicator can still be considered meaningful. An important note to be made is that uneven distribution is only an issue if the indicator is more or less viewed in real time. If the data for the indicator is collected for example daily or weekly, uneven distribution will not be an issue. Based on this reasoning, the following indicator is suggested:

$$\boldsymbol{Indicator}_{\boldsymbol{Personnel}} = \frac{\boldsymbol{Number\ of\ personnel}}{\boldsymbol{Building\ area}} \qquad \text{Indicator P.1}$$

As this indicator has a simple structure, it is easy to understand and it can be assumed that the data that the indicator is built upon is already being recorded in most companies. It also offers comparability between buildings or companies and is consistent over time and space. To summarise, the indicator criteria are easily met and should not require further discussions.

If the potential responsibilities of the personnel (Section 7.3.1) are compared to this indicator, it becomes clear that the indicator should be closely related to the ability of the personnel to detect and extinguish fire. However, this personnel indicator provides no information relating to the ability of the personnel to assist during an emergency evacuation. Naturally, the number of customers will also have a significant impact on this responsibility of the personnel.

Personnel indicator 2

Nelson and Shibe (1978) emphasise the importance of the ratio between attendants and patients in healthcare facilities. They demonstrate that the attendants have a critical role in emergency evacuation and that the attendant to patient ratio is intrinsically related to the rescue of patients during a fire occurrence. Of course, the role of personnel in retail buildings and the role of attendants in health care facilities are different. However, the element of assistance during emergency evacuation is a responsibility that both retail personnel and health care attendants often have, even though an attendant-patient ratio and a personnel-customer ratio, for obvious reasons, would be interpreted differently and have different requirements and benchmarks.

A personnel to customer ratio indicator has inherently the same problems attached to it as with the personnel per building area indicator. The same arguments that were presented in relation to the personnel per building area indicator can be applied to the number of personnel part of a personnel to customer ratio indicator (the numerator); i.e. the distribution of personnel.

Regarding the customer part, there is a possibility that the main body of the customers are located in a small area of a building, even if they are located in customer areas. Regarding the personnel, there is an obvious benefit of the personnel being evenly distributed throughout the customer areas of a retail building, but the case could be made that an even distribution of customers is not solely beneficial in relation the number of personnel. If the customers are concentrated in a limited part of the building, the case could be made that this is beneficial for the personnel when it comes to assisting customers during an emergency egress. If the customers were evenly distributed, there might be more challenging for the personnel to find and assist customers during a fire occurrence. To summarise, temporarily unevenly distributed customers in a building does not necessarily make a personnel to customer ratio indicator less meaningful. As for the indicator personnel per building area, it should be noted that uneven distribution only is an issue of the indicator is monitored on real time. Based on this reasoning the following indicator is suggested:

$$\boldsymbol{Indicator}_{\boldsymbol{Personnel}} = \frac{\boldsymbol{Number\ of\ personnel}}{\boldsymbol{Number\ of\ customers}} \qquad \text{Indicator P.2}$$

Personnel indicator 3

The fundamentals regarding personnel have been discussed for the two previous suggested indicators. The remainder of the personnel section will cover the issue of fire safety training. As has been outlined in Section 7.3.1, fire safety training has a significant impact on the ability of the personnel to undertake their potential responsibilities. Intuitively, the elements of fire safety training – together with the frequency with which it is undertaken – should decide the value of fire safety training. As discussed in Section 7.3.2, these are elements which are regulated by various fire safety regulations.

Before proceeding to the issue of training frequency, the issue of defining fire safety training has to be addressed. It must be made clear what constitutes fire safety training in order to measure the frequency by which it is undertaken. Defining fire safety training in the context of basing an indicator off these fire safety training sessions is however a complicated task. If a fire safety training indicator was based solely on the definitions made by various fire safety regulations, there is the obvious risk that fire safety training not undertaken in exact accordance with the fire safety regulation definitions would fail to be accounted for.

A solution to this problem might be to weigh each training session in accordance with what it entails. If, for example, a training session entails both practical and theoretical elements, the training session could be assigned a high weight and if it solely entails theoretical elements, it could be assigned a low weight. If this weight was included in a fire safety training indicator, the content of each training session would have an impact directly on the indicator. However, the case could be made that the implementation of such a system, where each training session is weighted in accordance with its content, is not consistent with the feasibility criterion. An alternative approach would be to have an indicator for each type of fire safety training, but for the indicators to be able to cover all, or most, types of training, a number of indicators may be required which could be complicated to monitor. Hence, it is concluded that some sort of weighting system is the best solution. This solution allows for the most important features of fire safety training to be represented in one single indicator.

A way of structuring this weighting of fire safety training features is to utilise MADM methodology in a similar way as in Chapter 4. A hierarchy tree depicting the features of fire safety training that has been identified as the most important is presented in Figure 7-1.

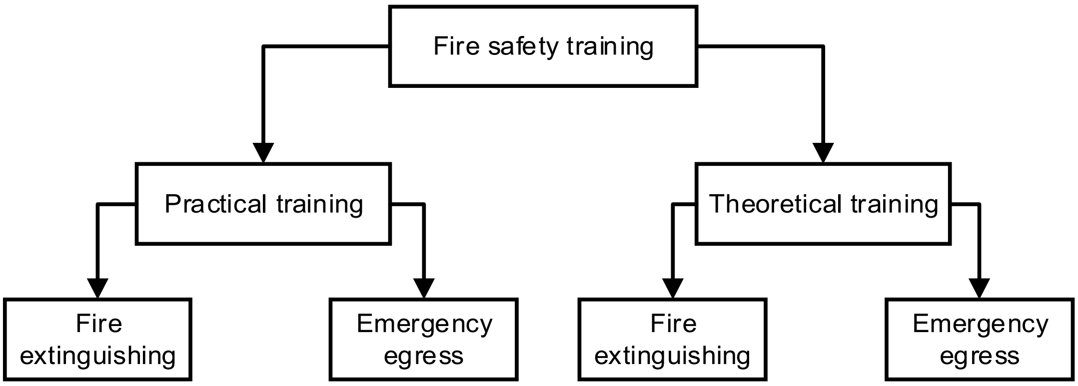


Figure 7-1. Fire safety training hierarchy.

In this fire safety training hierarchy, practical training and theoretical training have been identified as suitable components, based on the fire safety regulations discussed in Section 1.10. These should be seen as examples and are unlikely to be the optimal selection of components. Emergency egress and fire extinguishing have been chosen as sub-components. If enough time and resources were available, the preferable methodology for weighting these components and sub-components would be to consult an expert panel in a similar way as described in Section 4.3.1 and 6.1. As this is not possible, the author assigns weights in a subjective manner, hence the weighting of the fire safety components and sub-components that are presented below (Table 7-5) should be seen as an example of the methodology rather than a result that can be implemented without a comprehensive review. An important note is that if a fire safety training session entails neither the elements of fire extinguishing training nor emergency egress training, the training session should be assigned the value zero.

Table 7-5. Fire safety training component and sub-component weights.

	Components			**Policy**
Sub-components	**Practical training**	**Theoretical training**	**Components**	**Fire safety training**
Fire extinguishing	0.6	0.5	**Practical training**	0.7
Emergency egress	0.4	0.5	**Theoretical training**	0.3

As the weights of the sub-components are assessed individually for the respective components, matrix multiplication in accordance with Section 4.4 produces the following weights for each sub-component in relation to the components (Table 7-6):

Table 7-6. Summarised weights for the sub-components in relation to the components of fire safety training.

	Components	
Sub-components	**Practical training**	**Theoretical training**
Fire extinguishing	0.42	0.15
Emergency egress	0.28	0.15

Going forward, the weight for each training session will be denoted w_{pt}, a weight factor, where w stands for weight and pt for personnel training.

Revisiting the issue of training frequency, the w_{pt} factor enables for each training session to be assigned a weight in accordance with the characteristics of the training session. If for example, a training session entails fire extinguishing training and emergency egress training, with both theoretical and practical elements, the training session should be assigned the weight of one (w_{pt} = 0.42 + 0.28 + 0.15 + 0.15 = 1). If the training session solely entails theoretical training on fire extinguishing, the session should be assigned the weight w_{pt} = 0.15 (see Table 7-6). Naturally, the next step is to define a fire safety training indicator including the w_{pt} factor.

Since the w_{pt} factor allows for the inclusion of every fire safety training session (given that at least one of the two training elements, fire extinguishing or emergency egress, is included), an indicator that measures the training frequency can simply be built upon the number of weighted training sessions. An indicator that considers the content of each training session is presented below.

$$Indicator_{\,Personnel} = \sum_{i}^{N} w_{pt_i}$$

The summation notation is included as the weighted training sessions need to be summarised over the time period for which the indicator aims to measure.

This indicator provides information about the fire safety training undertaken in one or more retail buildings. Although a significant weakness with this indicator is that it does not provide any information on the level of personnel participation in each training session. To consider personnel participation, this has to be included in the indicator. If solely the number of participants is included, the indicator cannot be compared between different buildings. An alternative approach may be to utilise a factor constructed by the quotient of the participating personnel in each training session and the total number of personnel, creating a percentage of personnel participation. This quota must be multiplied with the weight of each training session, since the personnel participation – in the same manner as the weight – may vary from training session to training session. By including this quotient in the indicator in the manner described, the following indicator takes form:

$$\boldsymbol{Indicator}_{\boldsymbol{Personnel}} = \sum_{i}^{N} \left(\boldsymbol{w_{pt}} \times \frac{\boldsymbol{Participating\ personnel}}{\boldsymbol{Total\ number\ of\ personnel}} \right)_i \qquad \text{Indicator P.3}$$

This indicator allows each undertaken training session to be included in the indicator; even introductory fire safety training for one or two newly hired personnel will be accounted for. If these one or two newly hired only constitute a few percent of the total number of personnel, this session will naturally have little impact on the indicator. Another training session may include 100 % of the personnel, which instead should have a large effect on the indicator. These variations in personnel participation is attended to by the inclusion of the personnel participation quotient in the indicator.

An intuitive issue with this indicator is the effect of w_{pt} (content of training session) and personnel participation on the indicator. The case could be made that these factors should be weighted in relation to each other to account for respective importance of w_{pt} and personnel participation. The case could be that personnel participation is more important than training content, and should therefore have a larger impact on the indicator. This could be facilitated by introducing two weight constants that regulates the impact the respective factor has on the indicator. If these constants are denoted a for training session content and b for personnel participation, the indicator could be formalised as followed:

$$Indicator_{Personnel} = \sum_{\mathrm{i}}^{N} \left(aw_{pt} \times b \frac{Participating\ personnel}{Total\ number\ of\ personnel} \right)_i$$

What numbers the constants a and b should be, or if they even serve a purpose in this indicator, will not be investigated further as part of this thesis. The reasoning behind these constants are included in this thesis to make the reader aware of their possible existence. In the context of how training session content and personnel participation affect the indicator value, the point should be made that the indicator always can be analysed further than just monitoring the indicator value. If the indicator is monitored over time and there is a spike in the indicator value the underlying data of the indicator can always be analysed in order to identify the origin of the indicator behaviour.

The proposed indicator can be monitored in the same way as the sprinkler activation and detection system activation indicators. The difference is that the personnel training indicator requires a calculation to be performed for each training session, whereas the sprinkler system and detection system indicators allows for each activation to be summarised directly over the preferred time period. As long as the required calculation is performed, the personnel training indicator can be graphically presented in the same manner as the other indicators. Examples of a graphical presentations of the personnel training indicator is presented in Section 8.3.

The case could be made that the proposed indicator violates the usability criteria. As the indicator is dependent on accurate reporting regarding training session content and personnel participation, a large responsibility is placed on managers, for instance, to report the training sessions in accordance with how the indicator is designed. The concern that the level of detail of the content may impact the reliability of reporting has been considered for the training session content selected (fire extinguishing training and emergency egress training). The cost of including only two features is that the training session content factor w_{pt}, can be considered somewhat blunt. However, while including five features would have rendered a more precise w_{pt} factor, the content as selected is considered a reasonable balance between usability and level of detail.

7.4 Inspection, Testing & Maintenance (ITM)

7.4.1 Component Description

The ITM component refers to the inspection, testing and maintenance of fire safety-related components or systems. In the NFPA 25 standard (NFPA, 2014, p. 10), the inspection element of ITM is defined as "a visual examination of a system or portion thereof to verify that it appears to be in operating condition and is free of physical damage". The testing element is further defined as "[a] procedure used to determine the operational status of a component or system by conducting periodic physical checks […]" (NFPA, 2014, p. 11). Finally, the NFPA 72 (NFPA, 2010, p. 26) defines maintenance as "work, including, but not limited to, repair, replacement, and service, performed to ensure that equipment operates properly". The standards from which these definitions are reproduced provide detailed descriptions on how each fire safety-related system should be inspected, tested and maintained, including the allowable time intervals between the undertaking of each separate element of ITM. For example sprinkler systems are to be inspected annually; the inspection should entail the replacement of sprinklers that shows sign of corrosion, leakage, physical damage, loss of fluid in the glass bulb heat-responsive element, loading or painting unless painted by the sprinkler manufacturer (NFPA, 2014).

The fire risk assessment guidance document for the English and Welsh fire safety regulations (Department for Communities and Local Government, 2006d) provides detailed examples of checklists that can be utilised to undertake the required ITM. These checklists have a similar structure as the NFPA regulations discussed in the previous paragraph. The checklists provide descriptions of the fire safety-related components that are to be inspected, tested and maintained, and the frequency with which this is to be done.

7.4.2 Development of ITM Indicators

The ITM component is – due to its nature – a challenging basis on which to develop indicators; the wide range of fire safety components that requires ITM, together with the diversity of what ITM may entail poses a number of difficulties. There are similarities with the development of indicators for personnel fire safety training. To account for each training occurrence each training session was weighted with a factor that described the content of each session. Theoretically a similar approach could be utilised for the ITM component, meaning that each ITM occurrence is weighted in accordance with the content of that specific ITM occurrence. Applying this approach to the ITM component would however pose a number of problems. The first one being that the weighting factor for ITM would probably need to be far more comprehensive than the personnel weighting factor. The ITM weighting factor would need to include a number of variables in order to cover the most significant variations of ITM, where examples of variables include: the element or elements of ITM that is/are performed, the content of each element and the fire safety-related components included in the ITM.

Another problem is the range of alternatives by which the two latter variables (the content of each element and the fire safety-related components included in the ITM) can be described. To include possible alternatives, or at least the most significant would require that each alternative be weighted in relation to each other in the same manner as in the development of the personnel training weighting factor, meaning in the same manner as the weighting of practical and theoretical training and egress- and fire extinguishment training. If this weighting would be undertaken, the ITM weighting factor would allow for a high value even if some fire safety-related components may not have been attended to in any way. The factor could for example achieve a high value if all components are attended to except the sprinkler system. This approach is hence not considered applicable to the development of ITM indicators.

An alternative approach may be to handle the elements of inspection, testing and maintenance separately, meaning to develop an indicator for each element. This would however not avoid the problems related to developing just the one indicator for the entire ITM component. Based on this reasoning, it is concluded that taking a similar approach as to the development of the personnel training indicator, is not feasible.

Karlsson (2000) includes a "maintenance and information" component in his fire risk indexing method for multi-story apartment buildings. To represent the maintenance part of the component, Karlsson (2000) includes the sub-components "maintenance of fire safety systems" and "inspection of escape routes". As part of the method, the sub-components are graded with respect to the frequency by witch each activity is undertaken. The case could be made that this method has similar problems attached to it as the weighted factor methodology previously discussed in this section, especially with regards to the fact that it is not possible to consider the actual content of each maintenance occurrence.

Based on this discussion, the case could be made that developing an ITM indicator based on the content of each ITM occurrence, and the frequency by with it is undertaken is very difficult or even impossible. A reasonable decision may be to accept that the ITM component is not suitable to base indicators upon. However, the result from the expert panel weighting indicated that the ITM component has the largest weight in relation to the policy, for retail buildings as well as retail building with high rack storage. Hence, an indicator might still be of value, even if it is required that the indicator has a simpler structure than those previous. A way forward may therefore be to develop an indicator that has a different outset than ITM content and frequency.

Another angle of approach may be to focus on the existence of defined routines for ITM for the building or company. This approach could be undertaken with a risk scoring method such as IKEA Blue (see Section 7.1.2), i.e. assigning a value to the component based on its deviation from an internal standard. In the case of the ITM component, a value could be assigned based on the degree to which the undertaken ITM deviates from a set internal ITM standard. However, the same problem that was discussed as part of the sprinkler indicator development will have the same impact on the development of an ITM indicator. As the internal ITM standards naturally vary between companies, depending on their size, area of business and geographical location etc., a risk scoring approach would not enable comparisons of the indicator between companies or buildings given that the internal standards are not identical.

A number of approaches to indicator development based on the ITM component have been discussed. No approach has enabled the development of a meaningful indicator. The author is convinced that there exist approaches that could produce various indicators for the ITM component; however, keeping in mind that the ITM component was identified as having the largest weight in relation to the policy, particular care should be taken in the development process. If too general an indicator is developed – which probably is the only reasonable way forward – there comes the obvious risk that it would draw disproportionate attention because of the attractive combination of generality and high importance.

Based on the discussion in this section, it is concluded to not develop any indicators based on the ITM component.

7.5 Aggregation of Indicators

The indicators of ratio and proportion type can easily be aggregated to include any number of buildings. These indicators may be added in accordance with Formula 14:

$$Aggregated = \sum_{i=1}^{N} Indicator\ value \qquad \text{Formula 14}$$

where N is the number of aggregated indicators.

As mentioned in Section 7.1.2, this is not possible for absolute value indicators (the summarised grade indicators). If absolute value indicators are to be aggregated, the best solution is to average the indicators over the number of buildings that for which the indicator is aggregated. The average indicator is given by Formula 15:

$$Average\ indicator = \frac{\sum_{i=1}^{N} Indicator\ value}{N} \qquad \text{Formula 15}$$

This approach will naturally have the effect that the source of potential changes in the indicator values of individual buildings will not be identifiable in the averaged indicator. Neither will the averaged value provide any information on the dispersion of the underlying indicators. However, the complementation of the averaged indicator with a measure of dispersion – for example variance (Formula 16) or standard deviation (Formula 17) (Evans & Rosenthal, 2009) – alleviates this issue.

$$\sigma^2 = \frac{1}{N}\sum_{i=1}^{N}(x_i - \mu)^2 \qquad \text{Formula 16}$$

$$\sigma = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i - \mu)^2} \qquad \text{Formula 17}$$

where N is the included number of absolute indicators, x_i is the individual indicator value and μ is the mean value of the indicators.

Examples of graphical representations of aggregated indicators as well as averaged indicators are provided in Chapter 8.

7.6 Summary of Developed Indicators

The following section summarises the developed indicators for each component.

7.6.1 Sprinkler System

$$Indicator_{\ Sprinkler} = \frac{Number\ of\ sprinkler\ activations}{Building\ area} \qquad \text{Indicator S.1}$$

$$Indicator_{\ Sprinkler} = Summarised\ grade\ of\ the\ spinkler\ system\ features \qquad \text{Indicator S.2}$$

7.6.2 Fire detection System

$$Indicator_{\ Detection} = \frac{Number\ of\ detector\ activations}{Building\ area} \qquad \text{Indicator D.1}$$

$$Indicator_{\ Detection} = Summarised\ grade\ of\ the\ detection\ system\ features$$ Indicator D.2

7.6.3 Personnel

$$Indicator_{\ Personnel} = \frac{Number\ of\ personnel}{Building\ area}$$ Indicator P.1

$$Indicator_{\ Personnel} = \frac{Number\ of\ personnel}{Number\ of\ customers}$$ Indicator P.2

$$Indicator_{\ Personnel} = \sum_{i}^{N}(\,w_{pt}\ \times \frac{Participating\ personnel}{Total\ number\ of\ personnel})_i$$ Indicator P.3

8 Examples of Graphically Presented Indicators

In this chapter, a selection of graphs representing various developed indicators are provided. The input data regarding building areas is loosely built upon IKEA Group's warehouses in Sweden. The rest of the data is wholly fictitious. The input data is included in Appendix C.

8.1 Sprinkler System Indicators

Figure 8-1 represents the number of sprinkler activations per 1,000,000 m^2 (Indicator S.1) between the years 2009 and 2019 for two groups of buildings. Building Group 1 has a total building area of 200,000 m^2 and Building Group 2 a total building area of 125,000 m^2. The groups intend to represent the building area encompassing a number of retail buildings, the average area of which is 20,000 m^2.

The number of sprinkler activations are summarised for each year and divided by the total building area. A benchmark of 50 sprinkler activations per 1,000,000 m^2 yearly has been included in the figure.

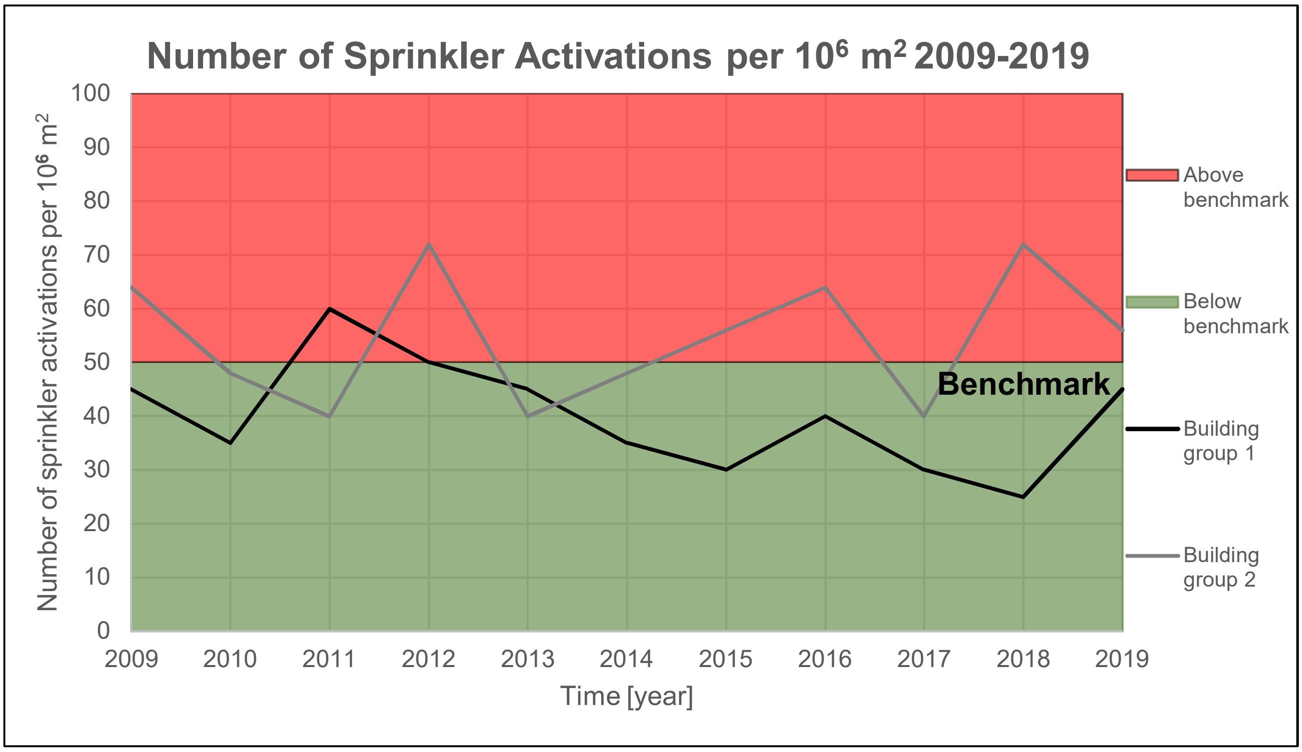


Figure 8-1. Number of sprinkler activations per 1,000,000 m^2 for two groups of buildings during the years 2009-2019.

Figure 8-2 represents the accumulated number of sprinkler activations per 1,000,000 m^2 (Indicator S.1) for two building groups during the year of 2019. Building Group 1 has a combined building area of 634,590 m^2 and Building Group 2 a combined area of 211,530 m^2. Each step in the figure represents one sprinkler activation, and the number of sprinkler activations are accumulated throughout the year. A benchmark of 10 sprinkler activations per 1,000,000 m^2 for the year 2019 has been included in the figure. It could be argued that the benchmark should be accumulated in the same manner as the sprinkler activation data. This type of benchmark would introduce a preference with regards to when the sprinkler activations occur throughout the year, in terms of the time interval between each sprinkler activation. The benchmark included in Figure 8-2 can be considered to be more general as it only considers the total number of sprinkler activations during the year. Which of these alternatives is the most suitable will not be discussed further, but it is highlighted to make the reader aware of the different benchmark approaches. The same argument is also applicable to Figure 8-8.

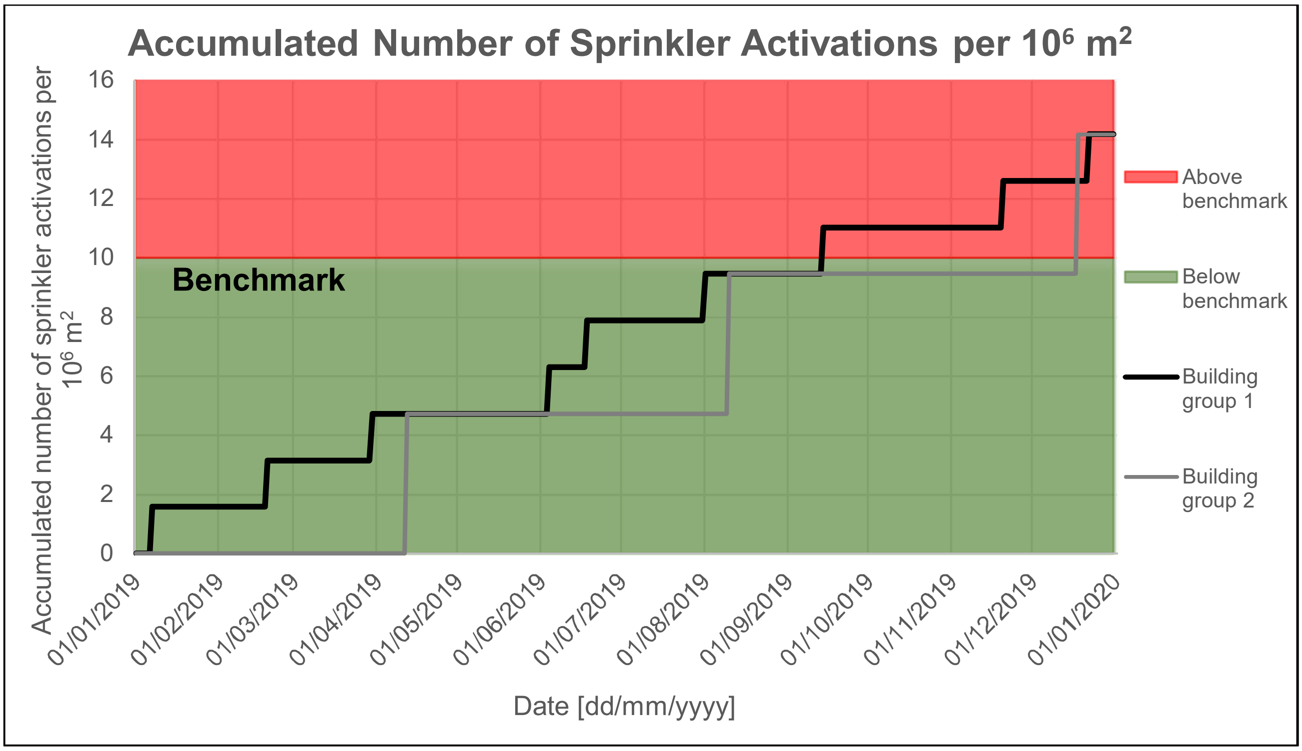


Figure 8-2. Accumulated number of sprinkler activations per 1,000,000 m² for the year 2019.

8.2 Fire Detection System Indicators

Figure 8-3 represents the summarised grade indicator for fire detection systems (Indicator D.2). Each data point represents the average absolute value of the fire detection systems indicator for a total of 10 different buildings between the years 2009 and 2019. The positive and negative standard deviation are included for each year.

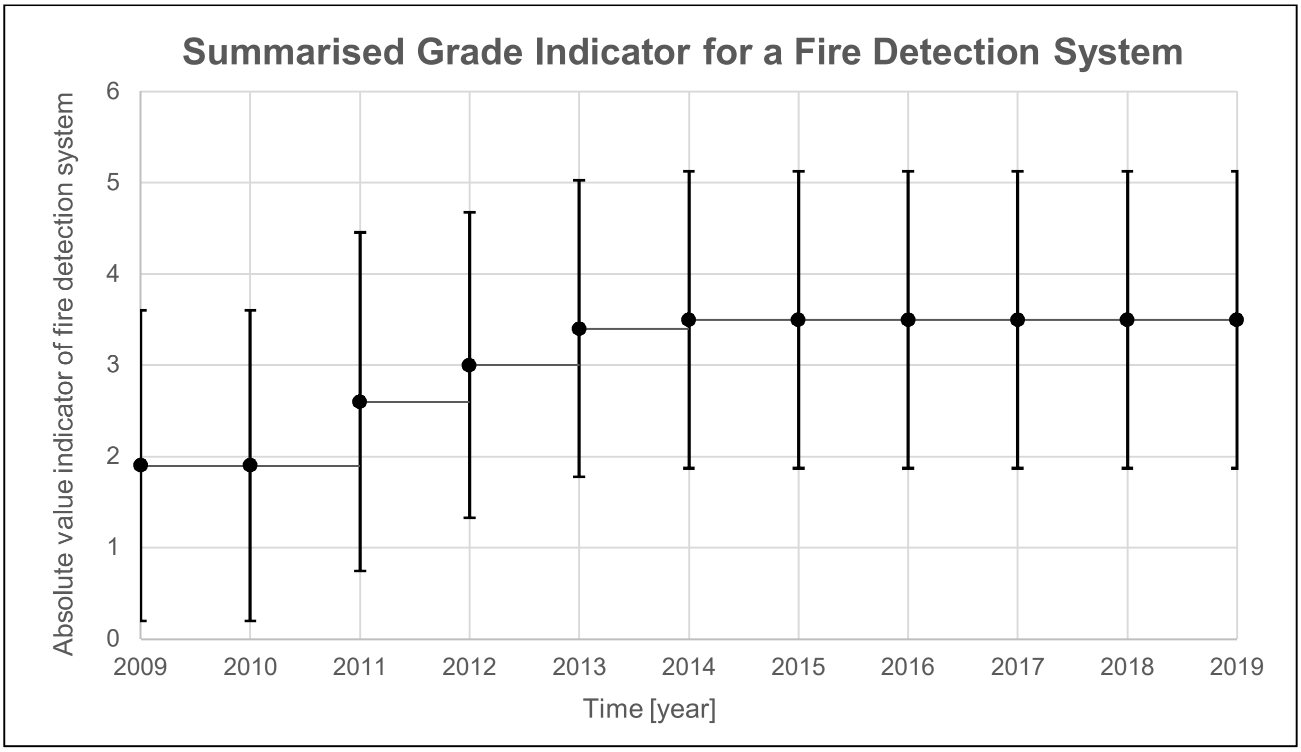


Figure 8-3. Summarised grade indicator for fire detection systems for the years 2009-2019. The positive and negative standard deviation is included.

The underlying indicator values of the 2009 data points in Figure 8-3 are presented in Table 8-1.

Table 8-1. Indicators values of the year 2009 for the ten buildings included in Figure 8-3.

	Indicator values											
Year	**Bldg. 1**	**Bldg. 2**	**Bldg . 3**	**Bldg . 4**	**Bldg . 5**	**Bldg . 6**	**Bldg . 7**	**Bldg . 8**	**Bldg . 9**	**Bldg . 10**	**Mean**	**Std.**
2009	1	2	5	1	0	4	0	3	3	0	1.9	+/- 1.7

8.3 Personnel Indicators

Figure 8-4 and Figure 8-5 represent the number of personnel per 1,000 m^2 (Indicator P.1) for two buildings. Building 1 has an area of 12,000 m^2 and Building 2 has an area of 18,000 m^2. Both figures use the same input data; however, Figure 8-4 represents daily measurements of the number of personnel while Figure 8-5 represents weekly measurements of the number of personnel. A benchmark of 5.0 personnel per 1,000 m^2 daily for the year 2019 has been included in the figure.

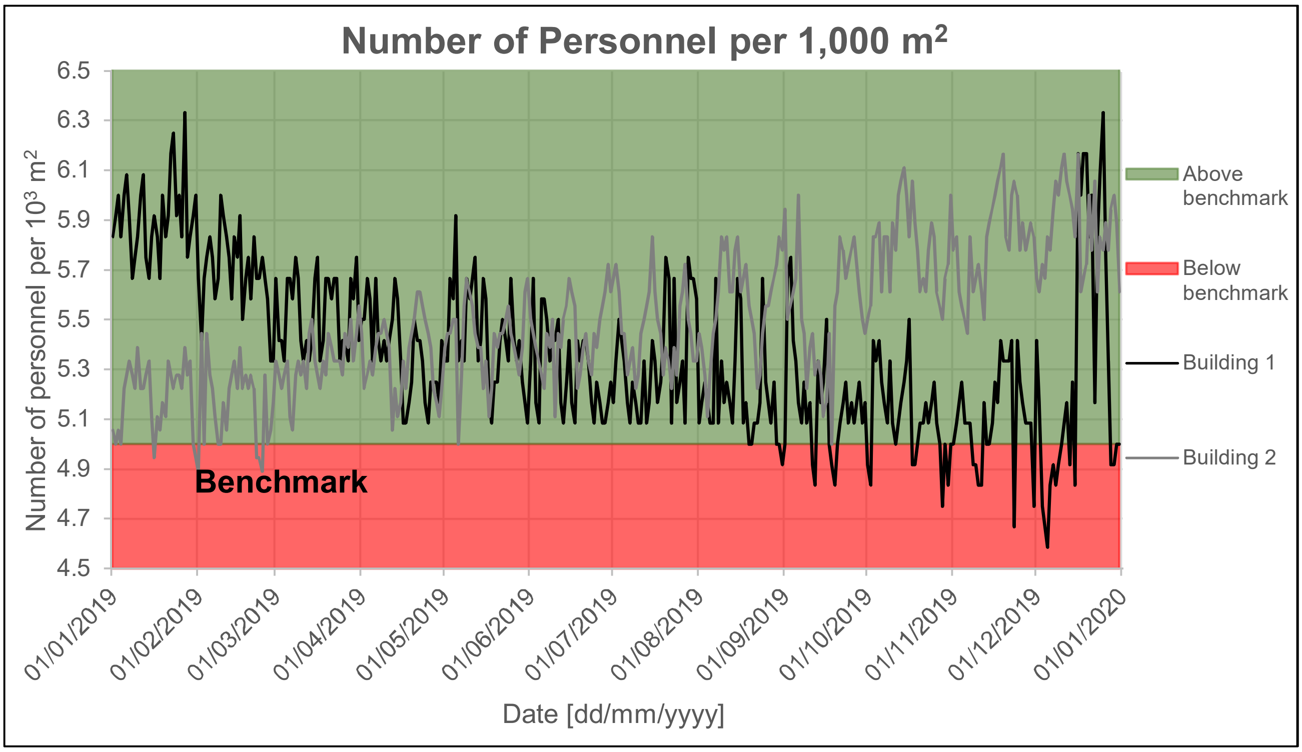


Figure 8-4. Number of personnel per 1,000 m^2 for the year of 2019.

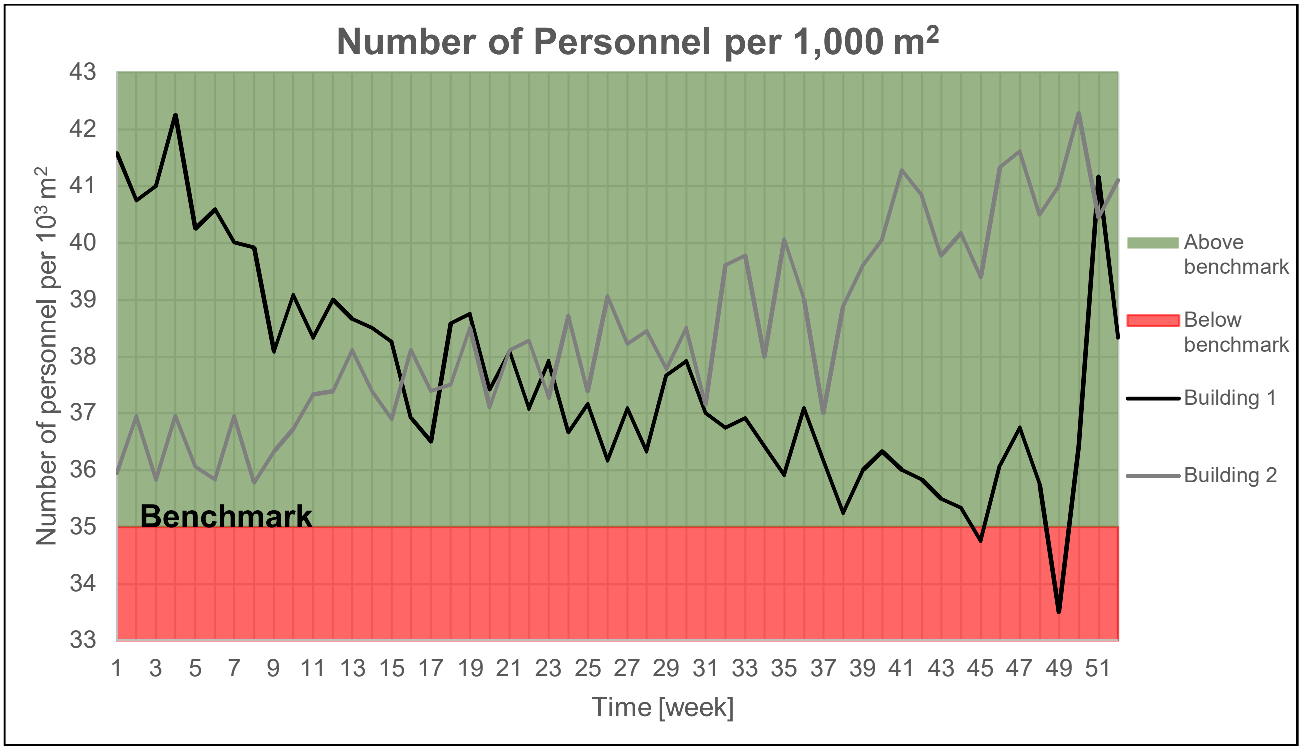


Figure 8-5. Number of personnel per 1,000 m² for the year of 2019.

Figure 8-6 and Figure 8-7 represent the number of personnel to 100 customers ratio (Indicator P.2) for two buildings during the year of 2019. Building 1 has an average of 64.4 personnel to 5,176 customers per day, while Building 2 has an average of 32.5 personnel to 2,996 customers per day. A benchmark of 1.1 personnel per 100 customers on a daily basis for the year of 2019 has been included in each figure. Both figures use the same input data, however, Figure 8-6 represents daily measurements of the number of personnel per 100 customers and Figure 8-7 represents weekly measurements of the number of personnel per 100 customers.

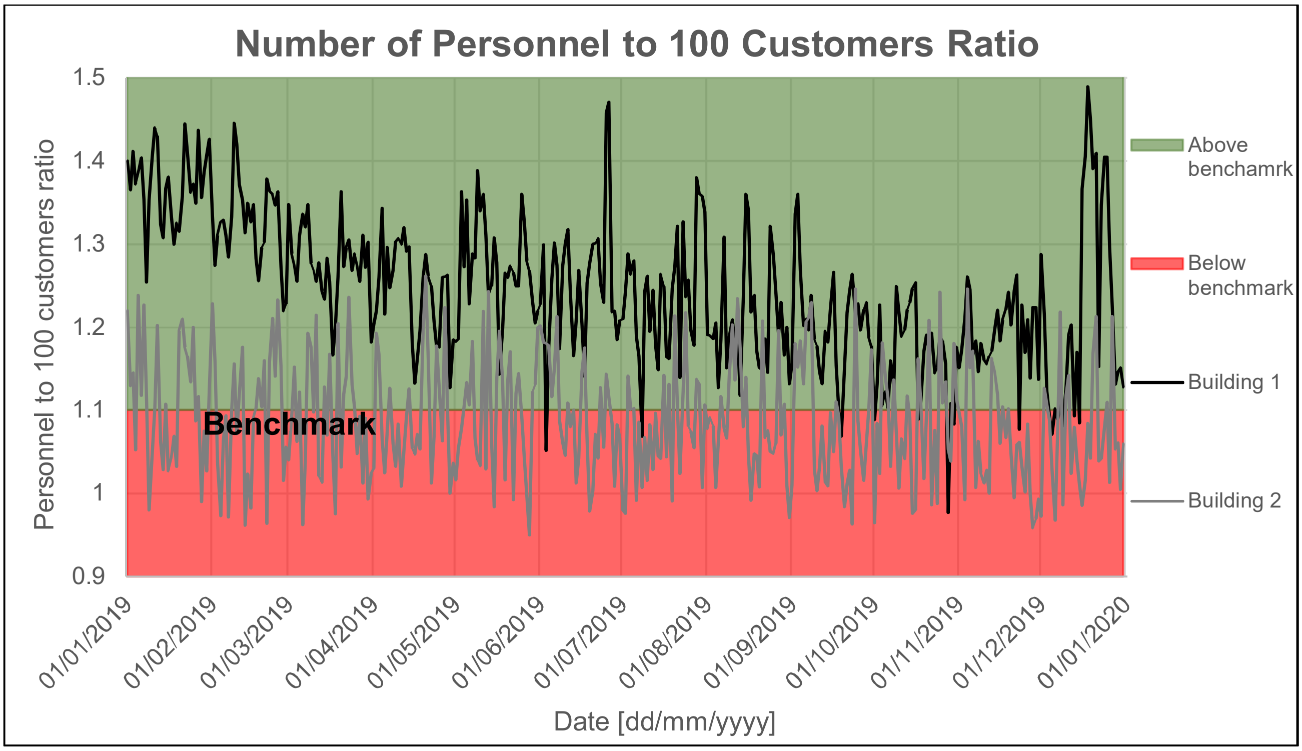


Figure 8-6. Number of personnel per 100 customers ratio for the year of 2019.

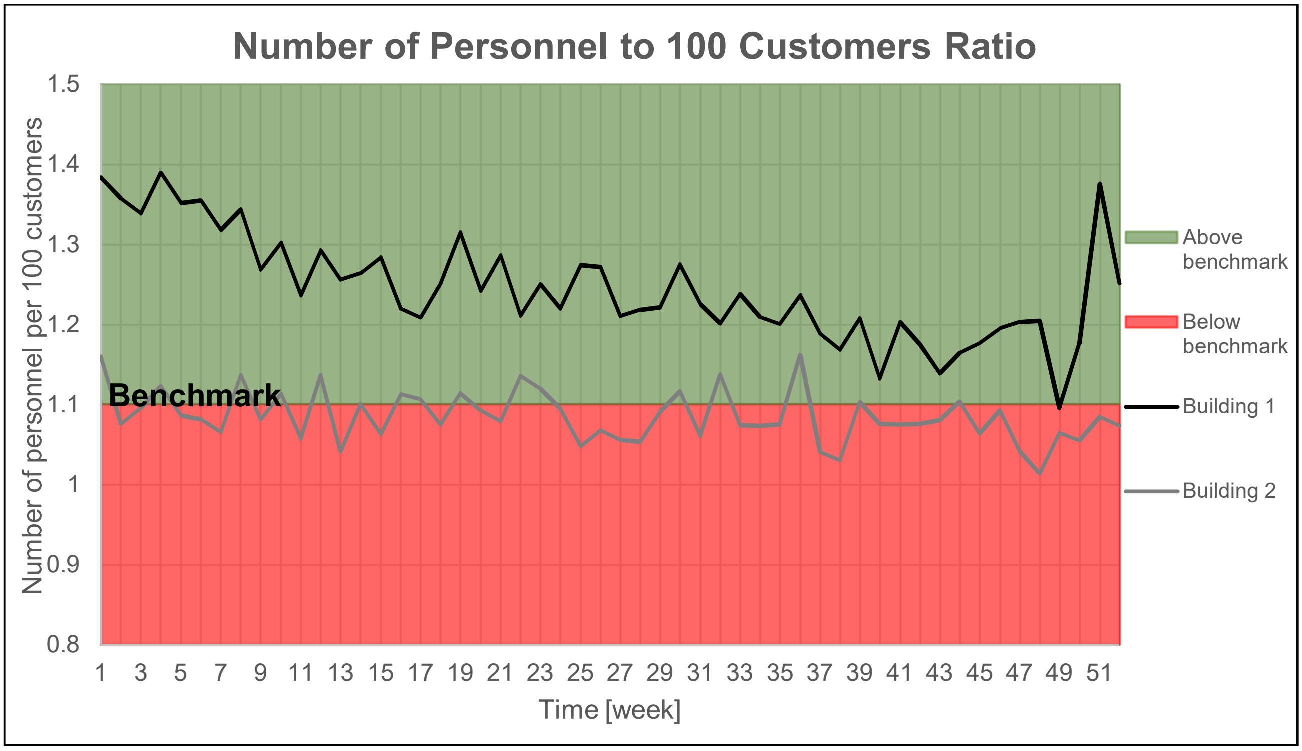


Figure 8-7. Number of personnel per 100 customers ratio for the year of 2019.

Figure 8-8 represents the accumulated number of weighted fire safety training sessions (Indicator P.3) for two buildings during the year of 2019. Building 1 has a total of 180 personnel while Building 2 has 110 personnel. A benchmark of three fire safety training sessions for the year 2019 has been included in the figure.

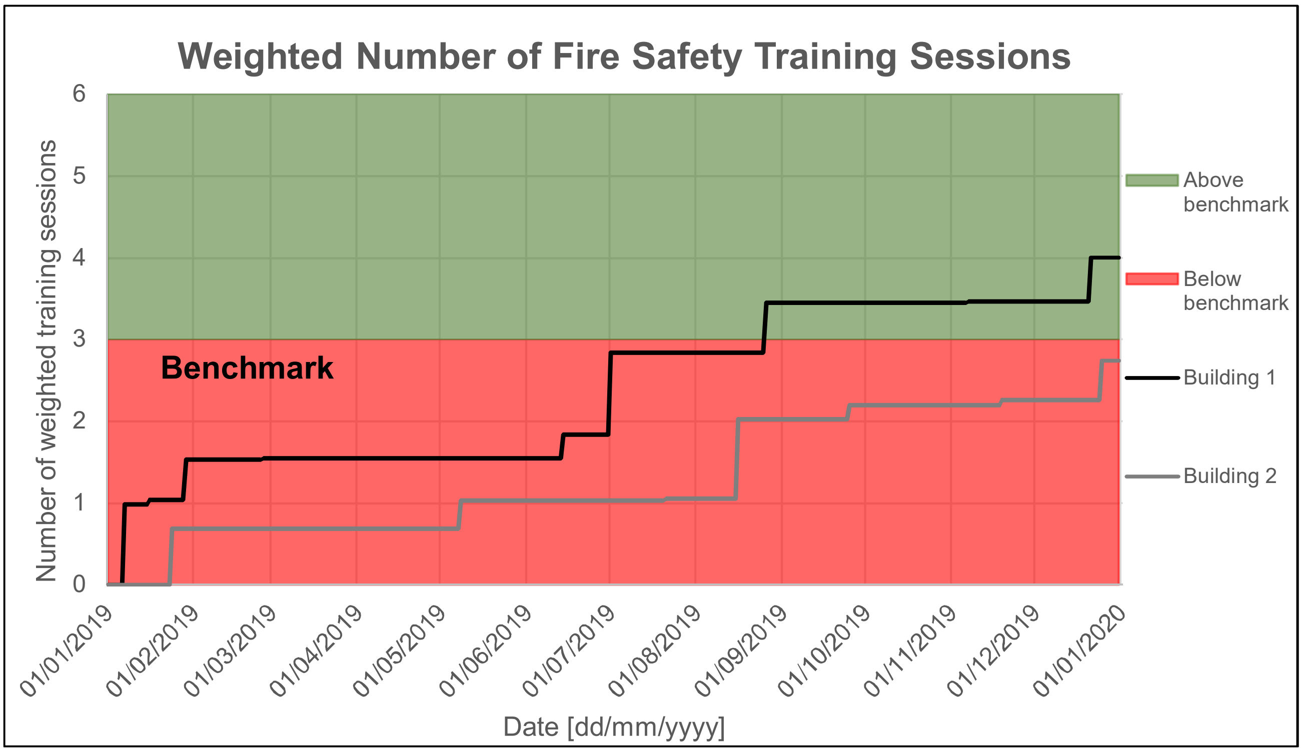


Figure 8-8. Weighted number of fire safety training sessions for the year of 2019.

Figure 8-9 represents the weighted number of fire safety training sessions for two buildings from the year 2009 to 2019. A benchmark of three fire safety training sessions for per year has been included in the figure.

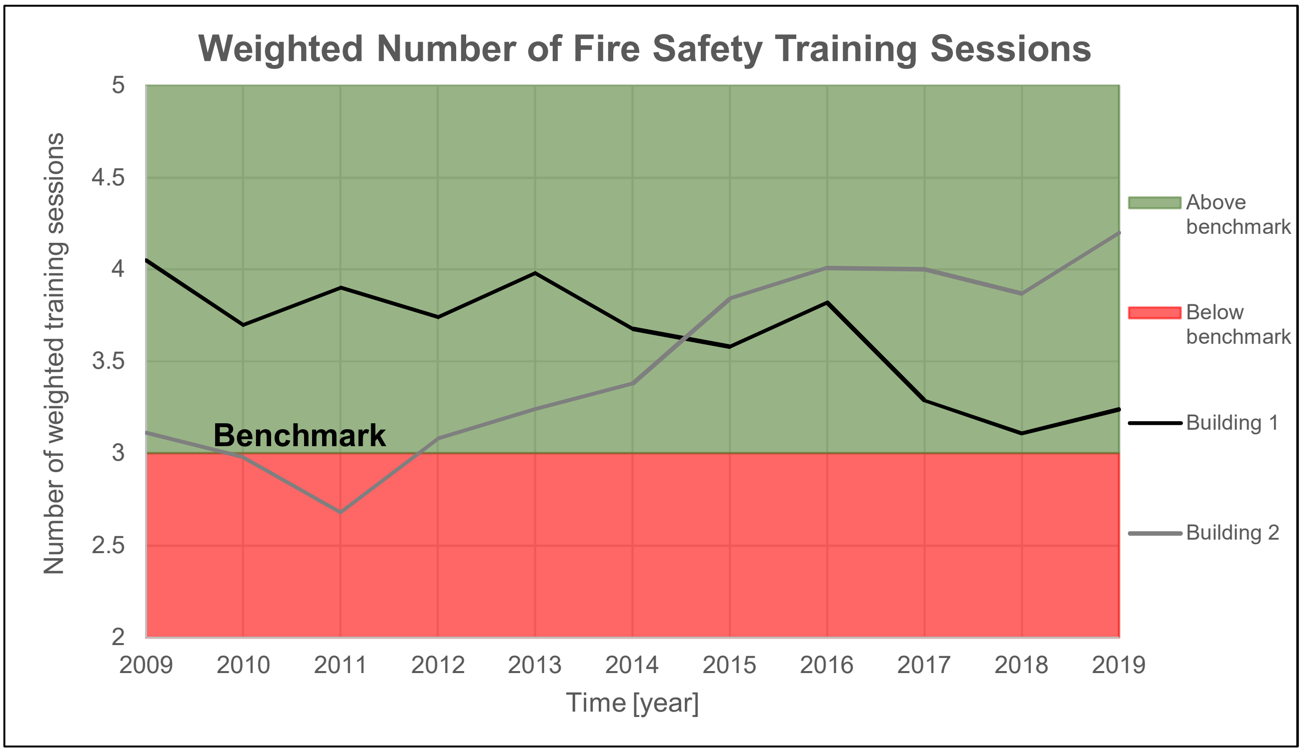


Figure 8-9. Weighted number of fire safety training sessions for the years 2009-2019.

8.4 Dashboard Example

Dashboards (briefly described in Section 3.9) are a visual and holistic way of presenting and monitoring indicators. There a numerous computer programs that can be used to develop dashboards. These programs often have a broad variation of technical features that allow indicators to be connected to external systems for automatic updates. In Figure 8-10, an example of an indicator dashboard is provided. The example is presented to demonstrate how indicators utilised within the area of fire safety can be presented. A map has been included in the example to demonstrate the value of dashboards in making comprehensive data easily monitorable. The dashboard example is developed in the computer program Microsoft Power BI.

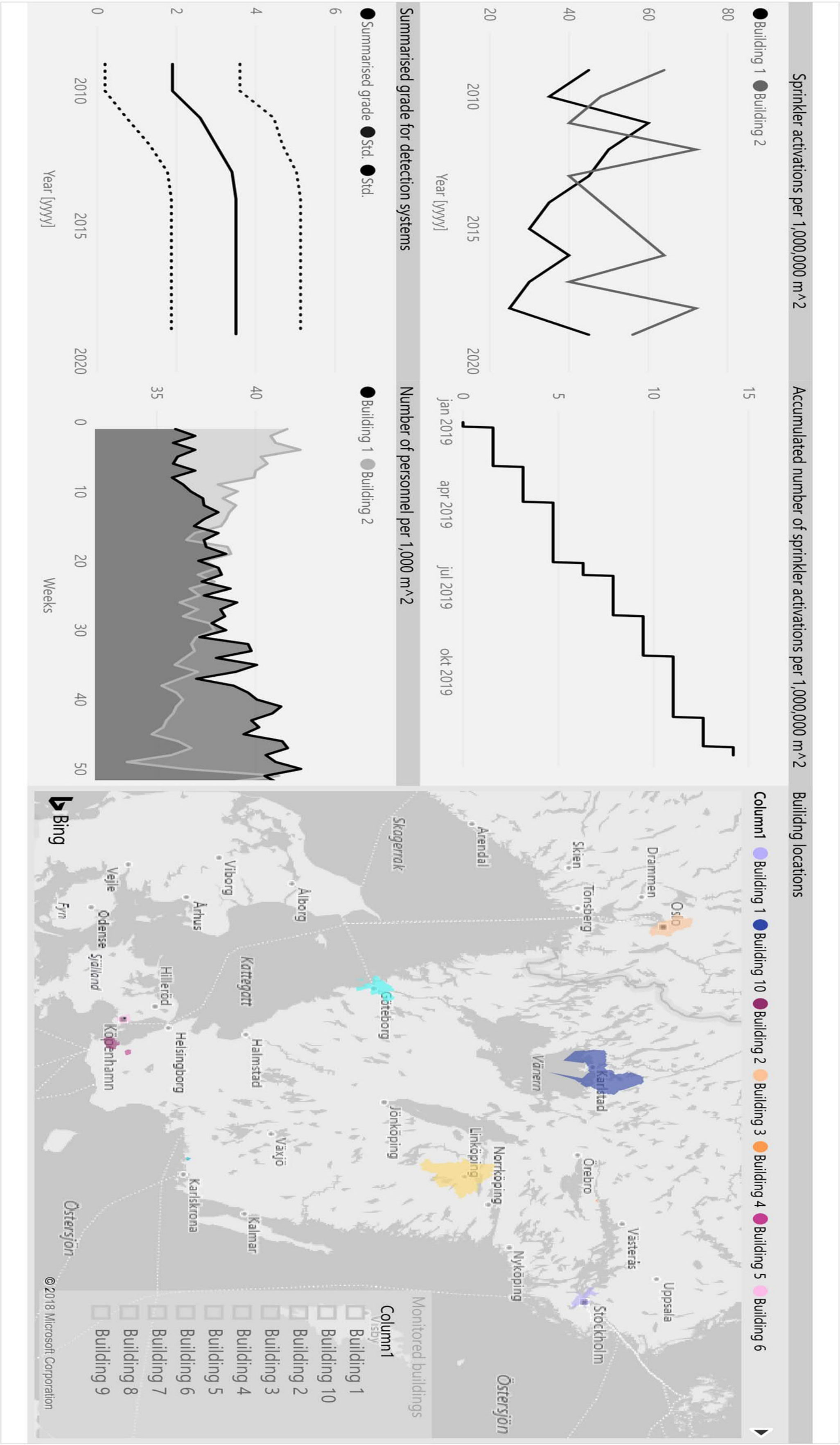


Figure 8-10. Example of a KFSI dashboard.

9 Discussion

9.1 Naming Indicators Utilised within the Area of Fire Safety

Throughout the chapters of "developing indicators" (Chapter 7) and "examples of graphically presented indicators" (Chapter 8), indicators within the area of fire safety have been referred to simply as "indicators". The purpose of this section is to derive a suitable name for these indicators based on the theory review of different types of indicators outlined in Chapter 3. Reviewing the various indicator types discussed in Chapter 3, it is clear that there exists no universal standard for how various indicator types utilised in different fields should be named.

The word "indicator" is often preceded by a word aiming to describe what the indicator intends to measure. Examples mentioned in the indicator theory chapter include qualifiers such as "result", "performance", "quality", "risk" and "safety". The words "result" and "performance" are almost exclusively utilised to describe indicators in the context of organisational results and performance, in financial as well as non-financial applications. According to Parameter (2012), an example of an indicator that can be referred to as a "result indicator" or a "performance indicator", is the number of staff trained to use certain systems. Naturally, this can serve as an argument for qualifying the indicators developed for fire safety training in much the same way. These words, however, would not be suitable for the indicators developed to describe features of fire safety systems (i.e. summarised grade indicators). This is because these indicators are not describing performance or result, but rather the design of the systems themselves.

The indicators developed as part of this thesis could of course be assigned different names depending on what they measure. However, considering the limited proportion the fire safety indicators would constitute of all the organisational indicators of a large company, it can be expected that it would not be beneficial to have several sub groups of indicators within the fire safety field. Based on this reasoning, it would be beneficial to identify a name for the indicators that are applicable to all indicators within the field of fire safety.

The remaining words commonly utilised to describe indicators are "quality", "risk" and "safety". "Quality" is almost exclusively utilised for indicators within the area of health care, measuring for example the effect of various treatments. In order to ensure the name for indicators within the area of fire safety is consistent with the larger context, the word "quality" is not considered suitable. "Risk" and "safety" appear to be interchangeably utilised to describe indicators measuring activities relating to risk and safety. Considering that all the developed indicators in this thesis are built upon components that have the largest effect on the level of fire safety, the word "safety" appears as a suitable word to describe these indicators. To distinguish the indicators within the field of fire safety from other safety indicators, it is suggested that the word "fire" is added to the indicator name.

The word "key" is usually utilised to describe indicators that measure the most significant activities or occurrences in an organisation. As discussed previously, the developed indicators are based upon the most important components. It is therefore logical that the word "key" should be added to the indicator name as well. This discussion around naming the indicators within the area of fire safety leads to the following name:

"Key Fire Safety Indicators (KFSIs)"

9.2 Key Fire Safety Indicators as Measures of Fire Safety

The developed indicators are based on the components that have the highest importance in relation to the policy – a satisfying level of fire safety. The connection between the identified components and the policy is therefore clear. Notwithstanding, the connection between the developed indicators and the level of fire safety is a subject that has been unaddressed until this point, largely for the reason that this connection is hard to define.

The weighting of the three components (sprinkler system, fire detection system and personnel) provided a numerical value representing the importance of each component in relation to the fire safety policy. These weights or rankings cannot, however, be transferred to the indicators, the bases of which are formed by the components. No relation can be established between the developed indicators and the component weights; in other words, the performance of an indicator is entirely independent of the ranked importance of each constituent component to that indicator. A question that has to be posed is therefore; how should movements in the respective indicator be interpreted in terms of the changes in the level of fire safety? The simple answer to this question is that it is an issue that is not addressed as part of this thesis, it is, however, a very important issue that should be addressed if further work is undertaken on KFSIs (see Chapter 11).

Even if the developed indicators do not provide explicit information on the level of fire safety of a building or buildings (in other words, a change in an indicator value does not render a definite change in the fire safety level), it can be argued that the indicators are directly related to whether the level of fire safety increases or decreases. For example, if the personnel per customer indicator increases over time, it can be assumed that the life safety of customers, and thereby the overall fire safety, increases. Nevertheless, this need not necessarily be the case: a certain increase in the personnel per customer indicator does not necessarily correspond to a certain increase in the level of fire safety.

The incorporation of all developed KFSIs in a company or for a building raises the issue of how, or perhaps whether, movements in the respective indicator value should be interpreted in terms of a change in the level of fire safety. Suppose that the three personnel indicators show positive movements in their respective values, but the sprinkler activation and the fire detection activation indicators show an increase in activations. This situation is even more complicated than when only a single indicator is monitored. The issue in this situation is how the movements in the indicator's values, together, affect the level of fire safety. In this situation, it might not even be possible to determine whether the respective indicator value movement amount to an overall increase or decrease in the level of fire safety.

As mentioned in the beginning of this section, the connection between the developed indicators and the level of fire of fire safety has not been the focus of this thesis. The focus has instead been to enable comparison between buildings, companies and countries as well as to defined benchmarks, this being brought about by the utilisation of KFSIs. When comparing indicators to each other and to benchmarks, there is no need for viewing indicator movements of all indicators together. Instead, each individual indicator is compared to its respective benchmark and to other individual indicators. These comparisons would not focus on what change in level of fire safety each indicator movement infers, instead the focus would be on the relationship between the respective indicator and their respective benchmarks. To summarise, it is clear that further work is required with regard to the interpretation of indicator movements, however, it could be argued that the developed indicators are nevertheless useful for the purpose of comparison.

9.3 Benchmarking

The discussion in the previous section about the unclear connection between indicator movements and their effect on the level of fire safety raises the question on how benchmarks should be chosen. If future work on KFSIs identifies relationships between indicator movements and level of fire safety, it might enable benchmarks for the respective indicator to be derived from the level of fire safety. This methodology would probably be the best way to identify suitable benchmarks as they would be related to the level of fire risk itself. However, as this methodology is not possible to undertake at this point, other alternative methods will be discussed.

The Health Information and Quality Authority (2010) suggests that benchmarks should be defined by widely accepted industry standards or best practises. This view on defining benchmarks could be transferred to KFSIs, but this should be considered in the context of the fact that the KFSIs have been developed with the expressed purpose of being as generally applicable as possible. This meaning that the KFSIs should be applicable anywhere in the world and to various types of retail buildings. It could be argued that general benchmarks, defined by some sort of international standard or regulation, would counter the general applicability of the KFSIs. As fire safety regulations and the required level of fire safety of buildings differ between countries and regions, a reasonable assumption might be that the benchmarks to which companies compare their KFSIs should differ as well. It should be noted that differing benchmarks between countries and regions does not interfere with KFSI's comparability. Providing that the KFSIs have been designed and incorporated in the same way, the KFSIs can still be compared between companies that utilise differing benchmarks.

Given this reasoning, the next issue that has to be discussed is how the country or region specific benchmarks should be set. Gillen (2017) suggests that benchmarks should be defined in accordance with the "best-in-class" examples in the branch wherein the benchmarks are to be defined. The "best-in-class" benchmark should be seen more as a desirable goal than a value that the indicator should stay over or under in order to be in acceptable territory. Viewing Gillen's (2017) benchmark suggestion in the context of KFSIs, a question that arises is on what basis the "best-in-class" benchmarks should be identified. It seems that Gillen (2017) means that the "best-in-class" benchmarks simply are the applied indicators that demonstrates the highest (or lowest) values in that specific branch. If that is the case, Gillen's (2017) method to define benchmarks requires that the considered indicators are, and have been, incorporated in a reasonable number of companies (buildings) for a reasonable time period so that the indicator data can be deemed credible.

9.4 Indicators in the Risk Management Process

In this section, the case will be made that the developed KFSIs can have a natural role in every step of the risk management process (the risk management process covered in Chapter 2). The KFSIs are not something that are developed as part of the risk management process, rather, they should be viewed as an aiding tool that can be included in each step of the process. Examples will be provided to highlight the potential utility of the developed KFSIs. A graphical representation of the risk management process is reproduced from Chapter 2 for clarity (end of section).

9.4.1 Establishing the context

Establishing the context is the first step of the risk management process. One of the elements of this step is to define risk criteria to which the later identified risk will be compared. A suggestion is that KFSI benchmarks could form part of the risk criteria. Specifying a risk criteria as a benchmark, however not in the context of indicators, is also mentioned in NFPA 551 (NFPA, 2019). Benchmarks of sprinkler activations and detector activations per building area, for example, may provide a suitable risk criterion for the risk of fire in a certain building or part of building. Further, a benchmark for the personnel fire safety training indicator may be utilised as a risk criteria for risks relating to emergency egress.

9.4.2 Risk identification

It could be argued the risk identification step of the risk management process is where KFSIs have the greatest potential for contribution. The case can be made that KFSIs can be utilised as a screening tool in the risk identification process. If the indicators demonstrate any irregular, or unexpected behaviour, further review of the underlying data can be undertaken to establish its origin. For example, this could apply to the sprinkler activation indicator and the fire detector activation indicator. When it comes to the personnel indicators, it can be argued that these indicators demonstrate risks directly without further review of the underlying data. If the personnel training indicator demonstrates a low number of personnel training sessions, it can be argued that this information by itself constitutes an identifiable risk.

This reasoning may paint the picture of the risk management process as a chronological process, and that the indicators could be initially introduced to the risk management process in the identification step. However, in practice, it would seem logical that the KFSIs could be the initiator of the process, that an irregular indicator behaviour or an indicator falling below or exceeding a benchmark initiates further analysis of the origin behind the movements. This approach is also suggested by the International Nuclear Safety Advisory Group (INSAG) (1999), in the context of nuclear power plant safety.

9.4.3 Risk analysis

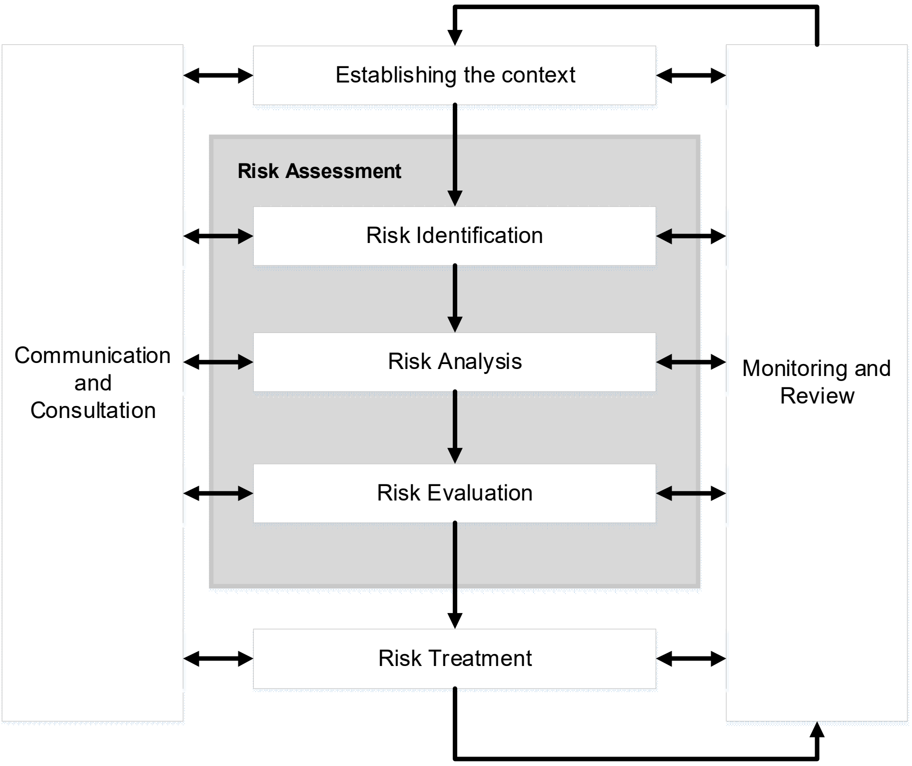
It could be argued that KFSIs can be utilised as a tool to establish the frequency for fire occurrences within a certain building as part of the risk analysis step. A combination of the sprinkler activation indicator and the fire detection indicator would seem suitable for such a purpose. However, the discussion in this section will be focusing on the possibility of incorporating KFSIs in recognised semi-quantitative fire risk indexing methods originating from MADM theory.

These risk analysis methods share the characteristic of producing a final measure that describes the fire risk level of a building or buildings. Additionally, each is required to be repeated if changes occur in the underlying data upon which the final measure is derived. A suggestion is that the KFSIs may provide an opportunity to allow the final measure to be updated automatically when changes occur in the underlying data. The Gretener method (covered in Section 2.4.3) includes the parameters "risk for fire occurrence" and "counter measures" which are constituted by the standard measures, special measures and the fire resistance of the building. It could be argued that the sprinkler activation and the fire detection indicator could be included in the "risk for fire occurrence" parameter to enable the parameter to be updated on a continual basis. The "counter measures" parameters could incorporate the personnel indicator as well as the summarised grade indicator for sprinkler systems and fire detection systems. Naturally, a method would have to be developed for how to enable the inclusion of these indicators in the respective parameters, and this will not be covered further here.

A similar reasoning can be applied to the fire risk indexing methods developed by Karlsson (2000) and Frantzich (2000, 2005, 2018). A suggestion for these methods is that the KFSIs could be included as part of the component scoring. A conceivable approach may be to let certain intervals of the respective indicator be translated into a certain number in the same manner as the components themselves are scored within these methods. This approach would enable the risk index to vary depending on the variations in each indicator. For the components upon which the summarised grade indicators has been based, the use of KFSIs in the way described may exclude the need for grading the components that originally were included as part of these methods, this since the grading may already be included in the indicator. This reasoning can also be applied to the Fire Safety Evaluation System (NFPA 101M) (covered in Section 2.4.3).

9.4.4 Monitoring and review

The same reasoning that was applied to the risk identification step can in many regards be applied to the monitoring and review step as well. As discussed in Section 9.2, changes in indicator values, whether in an individual or a group of indicators, do not provide any information on the change in the overall level of fire safety. Each indicator value movement does however indicate whether the level of fire safety increases or decreases. It could be argued that this makes the KFSIs suitable tool to incorporate in the monitoring and review step.



Reproduction of Figure 2-1 from Chapter 2.

9.5 Indicator Correlations and Indicator Interpretation

This section will aim to discuss possible correlations between the developed KFSIs. Since the limitations of this thesis do not allow for the KFSIs to be applied to existing building and real data, this discussion has to be of a hypothetical character. The discussion will focus on the KFSIs that vary over time, in contrast to the summarised grade indicators that by nature should involve less fluctuations.

Initially, the sprinkler activations indicator (Indicator S.1) and the fire detector activation indicator (Indicator D.1) will be discussed on the basis of a couple of different indicator behaviours. In the first case, an increase in detector activations can be identified during time period of ten years (Figure 9-1), while the number of sprinkler activations is constant (Figure 9-2).

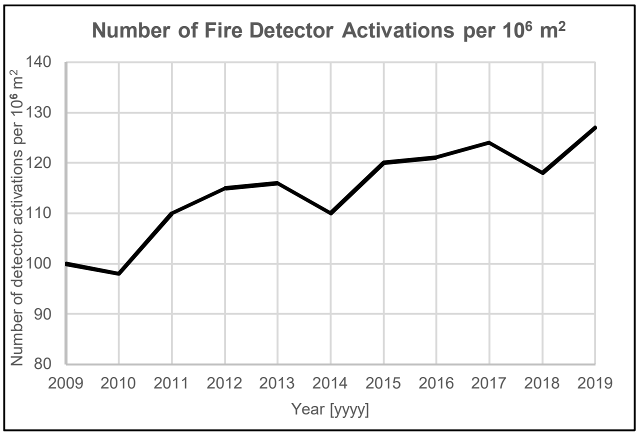


Figure 9-1. Number of detector activations per 10^6 m².

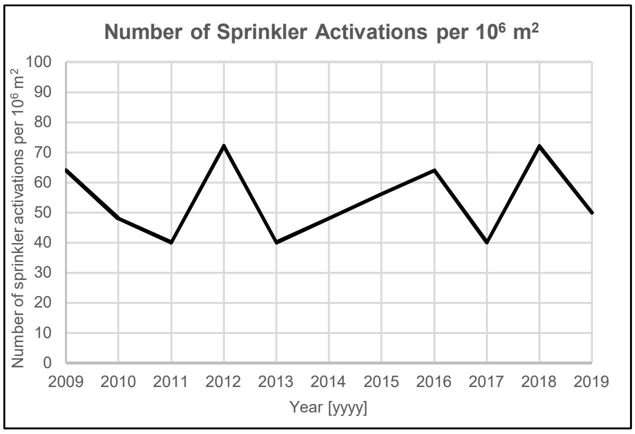


Figure 9-2. Number of sprinkler activations per 10^6 m².

Providing that the indicators represent accurate data with only fire induced fire detector activations and sprinkler activations respectively, it could be argued that the indicators indicate that there have been an increase in fire by what could be labelled as small fires. This observation is based on the fact that a sprinkler heads require a certain temperature to activate whereas smoke detectors are activated by the presence of smoke particles. Naturally this reasoning does not apply to buildings with a combination of smoke and heat detector or exclusively heat detectors. In another case, the number of detector activations and the number of sprinkler activations increases more or less linearly over the same time period. In this case, it could be argued that there has been an increase in the number of more substantial fires, producing heat sufficient for sprinkler head activation.

Secondly, the relationship between the personnel indicators and the fire safety system indicators will be discussed. Suppose that a more or less linear decrease in fire detector activations as well as sprinkler activations can be viewed during the same time period as in Figure 9-1 and Figure 9-2. This coincides with a steady increase in the weighted number for fire safety training sessions as well as the number of personnel per building area unit. Obviously, a correlation need not necessarily be drawn here. There may exist numerous other circumstances than the number of fire safety training sessions that have caused a decrease in the number of fire safety system activations. Although, it could be argued that correlations such as this one, and others, may help companies to develop a better understanding on the relations that may exist between various fire safety components, and in turn help companies incorporate the most effective fire safety measures in their business.

9.6 Determining Level of Aggregation

This section will discuss the determination of level of aggregation, in terms of both time and space. This refers to the concept of adding indicators of the same type to encompass more than one building, and to the reporting frequency of each indicator.

9.6.1 Space

How to undertake the aggregation of indicators over space have been covered throughout Chapter 7, however, how to decide the level of aggregation has not been discussed.

It can be argued that the level of aggregation of indicators over space solely depends on the purpose of the result. If a company or owner operating in an individual building has incorporated KFSIs into their business, no aggregation is necessary nor possible. For larger companies or building owners of more than one building, the aggregation alternatives increase with the number of buildings to which the KFSIs are applied. For a national company, the management team might wish to compare KFSIs between regions, cities or other types of country sub-divisions, all depending on the purpose with the indicator aggregation is. For multi-national or even world-wide companies, there might be a need for aggregating indicators across countries, continents or the entire company.

9.6.2 Time

When it comes to aggregation over time, referring to the reporting frequency, the discussion must be focused on three groups of KFSIs. The first group of KFSIs that will be discussed is the summarised grade indicators (Indicator S.2 and D.2). Since these indicators are solely based on the design of the respective fire safety system, they will demonstrate small changes over time. It could be argued that the reporting frequency for small companies or individual building could be undertaken on a momentary basis, meaning that the indicator would be updated when an alteration in the design of the fire safety systems is made. For a situation where, for example, the coordinating body at a large company's headquarters manages the indicators exclusively, it may not be feasible to update the indicators on a momentary basis. This will be so even if the alterations to fire safety systems are regularly reported to the coordinating body. In these cases the summarised grade indicator may be updated yearly, based on the potential alteration reports.

The case could be made that the reporting frequency for the indicators "number of sprinkler activations per building area" (Indicator S.1), "number of detector activations per building area" (Indicator D.1) and "number of weighted fire safety sessions" (P.3) depends greatly on the number and size of the buildings upon with the indicators are applied. For a single building, or a small company, the benefit of reporting fire safety systems activations and fire safety training sessions on a momentary basis may be limited. This is due to the very few activations and sessions that will occur during a year, for example. The number of activations and training sessions during the limited time of a year or six months will not demonstrate a result upon which any conclusions or decisions will be possible to make. For single building and small companies, the case could be made that activations and training sessions should be reported and the indicator be updated on a yearly basis, allowing the indicator to be monitored from year to year, e.g. demonstrating one data point per year. The indicators could naturally be updated more frequently, but as the number of activations and training sessions can be assumed to be very few during a given year, more frequent reporting and updates of the indicator will not provide any meaningful information.

With the same reasoning applied to larger companies with a higher number of buildings, it is probably beneficial for them to undertake more frequent reporting and updates of the indicators. This as the number of activations and training sessions – accumulated for the buildings – can be assumed to be much higher. The higher number of activations and training sessions means that frequent reporting and indicator updates may be able to provide more meaningful information, this meaning that the indicator demonstrates sufficiently grounded results for conclusions to be made. In Chapter 8, some indicators are presented graphically with various reporting frequencies. Exactly what reporting frequency is suitable for any given situation is impossible to say; this should instead be decided on a case-by-case basis.

9.7 Reporting Systems

Arriving to this point in the thesis, the importance of accurate reporting has been implied on a number of occasions. It has been made clear that all the developed KFSIs are dependent on the reporting and compiling of the data that each KFSI is based on. As for determining the level of aggregation (Section 9.6), the reporting systems depend on the number of buildings to which the KFSIs are applied, as well as on what level within a company the KFSIs are managed. If the KFSIs are applied to a single building, it could be argued that the requirements for reporting systems need not be so extensive.

Naturally the complexity around reporting increases with the size and number of buildings the KFSIs are applied to. In the case of a large company with retail buildings in a number of countries, and the management of the indicators being undertaken by a coordinating body, the case could be made that the structure around reporting must be solid and well defined. Exactly how these systems should be structured will not be discussed, however, it could be argued that routines around exactly what is to be reported, who the responsible persons are for undertaking the reporting and at what frequency the reporting is to be undertaken are all elements of reporting that must be thoroughly defined.

9.8 Leading and Lagging Indicators

As outlined in Section 3.8, the concepts of leading and lagging indicators are defined slightly differently depending on the area of application. Leading and lagging indicators within the field of economics are distinguished solely by time, where leading indicators describes ongoing processes and lagging indicators describe past results. The concepts of leading and lagging indicators when applied to the field of safety, specifically process safety, by contrast, are distinguished by their relationship to accidents. Owing to accidental fire prevention being at the very core of fire safety, these are considered to be the most applicable to the developed KFSIs.

The leading safety indicators are based on accidents (Kongsvik et al., 2017) whereas lagging safety indicators are referred to by Dyreborg (2009) as tools to prevent accidents from happening. The purpose of this section is now to view the respective KFSI in the light of these concepts.

The indicators "number of sprinkler activations per building area" (Indicator S.1) and "number of fire detector activations" (Indicator D.1) can naturally be categorised as lagging indicators. This since these indicators are "triggered" directly by fire occurrences, which as defined by Kongsvik et al. (2017) may be defined as "accidents". All the personnel indicators – "number of personnel per building area" (Indicator P.1), "number of personnel per customers" (Indicator P.1) and "number of weighted fire safety training sessions" (Indicator P.3) – measure features of the personnel component that aims to increase fire safety in terms of limiting the risk for ignition, fire spread and the provision of support during emergency egress. In sum, due to the role of personnel indicators being preventive, personnel KFSIs may typically be categorised as leading indicators.

The summarised grade indicators for the fire safety systems (Indicator S.2 and D.2) can evidently not be labelled as lagging indicators as they are in no way related to fire occurrences themselves. Instead, it could be argued that they could be labelled as leading indicators as they are describing fire safety systems that aim to detect and extinguish fire, and hence are preventive measures. Table 9-1 sets out the summarised division of the KFSIs in terms of lead or lag type.

Table 9-1. Division of KFSIs in terms of lead or lag type.

Leading indicators	Lagging indicators
S.2	S.1
D.2	D.1
P.1	
P.2	
P.3	

As discussed in Section 3.8, researchers within the field of safety has contextualised lagging and leading indicators by applying them to Reason's (Reason, 1997) Swiss cheese model. It has been suggested that the barriers can represent leading indicators and the holes can represent the lagging indicators. Applying the lagging KFSIs to Reason's model, the fire safety system activations indicators are represented by the holes in the safety barriers, while the summarised grade indicators and the personnel indicators are represented by the barriers themselves. The author believes that the Swiss cheese model is a pedagogical way of explaining the role of the developed KFSIs in fire safety.

9.9 Method Validation

The development of indicators chapter (Chapter 7) is to a large extent produced using a reasoned albeit subjective approach. This approach motivates the inclusion of a method validation discussion entailing a critical review of the methodology undertaken.

The undertaking of a reasoned albeit subjective approach to methodology has been justifiable for the purpose of this thesis; as no clear methodology for developing indicators exists, a new approach was essential. Outcomes of such an approach will vary depending on the background and preferences of the researcher; another person could have made different choices as to the development of indicators and produce outcomes of comparable quality. In mitigation against the obvious shortfalls of a subjective approach, however, every effort was made to provide explicit reasoning behind each assumption at each step of the development of the respective indicators in Chapter 7.

To summarise, it cannot be well argued that the outcome of the reasoned but subjective approach as undertaken in Chapter 7 of this thesis is the best way of reflecting the goal of developing indicators within the area of fire safety.

Nevertheless, as no established methodology of indicator development exists, the approach undertaken was deemed the best choice given the scope and limitations of this project.

10 Conclusion

It can be concluded that it is possible to develop meaningful indicators within the field of fire safety. A number of possible areas of application have been discussed and suggested. In terms of areas for future consideration, the effect that changes in individual, or multiple, indicator values have on the overall fire safety of a building or buildings has been discussed; nevertheless, it has been argued that this effect is hard to define and concretise. As part of this thesis, seven Key Fire Safety Indicators (KFSIs) have been developed. These are summarised below:

$$Indicator_{\ Sprinkler} = \frac{Number\ of\ sprinkler\ activations}{Building\ area} \qquad \text{Indicator S.1}$$

$$Indicator_{\ Sprinkler} = Summarised\ grade\ of\ the\ spinkler\ system\ features \qquad \text{Indicator S.2}$$

$$Indicator_{\ Detection} = \frac{Number\ of\ detector\ activations}{Building\ area} \qquad \text{Indicator D.1}$$

$$Indicator_{\ Detection} = Summarised\ grade\ of\ the\ detection\ system\ features \qquad \text{Indicator D.2}$$

$$Indicator_{\ Personnel} = \frac{Number\ of\ personnel}{Building\ area} \qquad \text{Indicator P.1}$$

$$Indicator_{\ Personnel} = \frac{Number\ of\ personnel}{Number\ of\ customers} \qquad \text{Indicator P.2}$$

$$Indicator_{\ Personnel} = \sum_{i}^{N} (\ w_{pt} \times \frac{Participating\ personnel}{Total\ number\ of\ personnel})_i \qquad \text{Indicator P.3}$$

11 Future Research

The MADM methodology undertaken to identify the most important fire safety components for retail buildings and retail buildings with high racks storage as a part of this thesis could easily be applied to other building types. Substantial parts of the reasoning process undertaken to develop the KFSIs based on the identified components in this thesis can hopefully be applied to the most important fire safety components developed for other building types.

In Section 9.4.3 (risk analysis) the potential for incorporating KFSIs as part of fire risk indexing methods were discussed. However, this discussion was speculative; the author believes that a research project aiming to develop a methodology for incorporating KFSIs into risk indexing methods could be of great benefit for future risk analysis methods and risk monitoring methods.

As part of Section 9.29.2, it was discussed how indicator movements affect the overall level of fire safety. A possible future research project could be to establish if, or how, the relation between movements in various KFSIs and the overall level of fire safety for a building or buildings could be described quantitatively.

An area that initially was supposed to be addressed as part of this thesis is defining generally applicable KFSI benchmarks. The time frame did not allow for this to be undertaken as part of this project and is therefore suggested as a future research project.

As part of the method validation discussion in Section 9.9, it was concluded that different persons taking a reasoned but subjective approach to indicator development will probably produce varying outcomes. A possible future area of research could be to take test the report's general findings, and the indicator development chapter (Chapter 7) in particular, by undertaking a peer review process.

References

2010:900. Plan och bygglagen. (2010). Stockholm: Näringsdepartementet.

2011:338. Plan- och byggförordningen. (2011). Stockholm: Näringsdepartementet.

Alverbro, K., Nevhage, B., & Erdeniz, R. (2010). *Methods for Risk Analysis.* Stockholm: Royal Institute of Technology.

Aven, T. (2007). A unified framework for risk and vulnerability analysis and management. *Reliability Engineering and System Safety, 92*, 745-754.

Aven, T. (2011). The risk concept — historical and recent development trends. *Reliability Engineering and System Safety, 99*, 33-44.

Ball, J. L. (2011). Developing a Preparedness Plan. In G. Colonna, *Employee Fire and Life Safety: Developing a Preparedness Plan and Conducting Emergency Evacuation Drills.* Quincy: National Fire Protection Association.

Barry, T. F. (2002). Quantitative Risk Assessment in Chemical Process Industries. In P. J. DiNenno (Ed.), *SFPE Handbook of Fire Protection Engineering.* Quincy: National Fire Protection Association.

BBR, Boverkets byggregler. BFS 2011:6 med ändringar till och med BFS 2018:4. (2018). Boverket.

Berg , H.-P. (2010). Risk Management: Procedures, Methods and Experiences. *Reliability and Risk Analysis: Theory and Applications, 1*(17), 79-95.

Bhutta, K. S., & Huq, F. (1999). Benchmarking - best practices: an integrated approach. *Benchmarking: An International, 6*(3), 254-268.

Borghesi, A., & Gaudenzi, B. (2013). *Risk Management - How to Assess, Transfer and Communicate Critical Risks.* London: Springer-Verlag.

Brindusa, M. P. (2015). Challenges when Developing Performance Indicators. *Journal of Defence Resources Management, 6*(1), 111-114.

Brown, D. (2009). Good Practice Guidelines for Indicator Development and Reporting. *Statistics, Knowledge and Policy: Charting Progress, Building Visions, Improving Life.* Busan: OECD.

Budnick, E. K., McKenna, L. A., & Watts, J. M. (1997). Quantifying Fire Risk for Telecommunications Network Integrity. *Fire Safety Science - Proceedings of the Fifth International Symposium* (pp. 691-700). Melbourne: International Association for Fire Safety Science.

Burke, R. (2007). *Fire Protection Systems and Response.* Boca Raton: CRC Press.

Campbell, R. (2015). *Structure Fires in Stores and Other Mercantile Properties.* Quincy: National Fire Protection Association.

Campbell, R. (2016). *Structure Fires in Warehouse Properties.* Quincy: National Fire Protection Association.

CFPA Europe. (2017). European Guideline CFPA-E No 35:2017 F - Fire Safety in Warehouses. CFPA Europe.

Crowley , M., Bukowski , D., & Baldassarra , C. (2014). *Validation of the Fire Safety Evaluation System (FSES) in the 2013 Edition of NFPA 101A.* Quincy: Fire Protection Research Foundation.

D. Simmons, R. D. (2017). *Qualitative and quantitative approaches to risk assessment.* Luxembourg: Publications Office of the European Union.

Dashboard. (2012, 12 12). Retrieved from https://upload.wikimedia.org/wikipedia/commons/a/a1/Sample_Klipfolio_Dashboard_Dark_Theme.png

DeBusk, G. K., Brown, R. M., & Killough, L. N. (2003). Components and relative weights in utilization of dashboard measurement systems like the Balanced Scorecard. *The British Accounting Review, 35*, 215-231.

Demers, D. P., & Jones, J. C. (2001). Emergency Evacuation Drills. In G. Colonna, *Employee Fire and Life Safety: Developing a Preparedness Plan and Conducting Emergency Evacuation Drills.* Quincy: National Fire Protection Association.

Department for Communities and Local Government. (2006a). *Fire Safety Risk Assessment - Educational Premises.* London: Department for Communities and Local Government Publications.

Department for Communities and Local Government. (2006b). *Fire Risk Assessment - Factories and Warehouses.* London: Department for Communities and Local Government Publications.

Department for Communities and Local Government. (2006c). *Fire Safety Risk Assessment - Large Places of Assembly.* London: Department for Communities and Local Government.

Department for Communities and Local Government. (2006d). *Fire Safety Risk Assessment - Offices and Shops.* London: Department for Communities and Local Government.

Department for Communities and Local Government. (2007). *Regulatory Reform (Fire Safety) Order 2005.* London: Department for Communities and Local Government.

Dyreborg, J. (2009). The causal relation between lead and lag indicators. *Safety Science, 47*, 474-475.

Elsbernd, G. F. (1974). *The use of the Delphi method within the Defence Department.* Alabama: Air University, Maxwell Air Force Base.

Evans, M. J., & Rosenthal, J. S. (2009). *Probability and Statistics - The Science of Uncertainty.* Toronto: University of Toronto.

Ferguson, L. H., & Janicak, C. A. (2005). *Fundamentals of Fire Protection for the Safety Professional.* Oxford: Government Institutes.

Few, S. (2006). *Information Dashboard Design.* Italy: O'Reilly Media, Inc.

Fitzgerald, R. W. (2005). *Building Fire Performance Analysis.* Chichester: John Wiley & Sons Ltd.

Fleming, R. P. (2008). Automatic Sprinkler System Calculations. In P. J. DiNenno, *SFPE Hand book of Fire Protection Engineering, 4th ed* (pp. 4-82 - 4-87). Quincy: National Fire Protection Association.

Flynn, J. D. (2009). *Fire Service Performance Measures.* Quincy: National Fire Protection Association.

Frantzich, H. (1998). Risk analysis and fire safety engineering. *Fire Safety Journal, 31*, 313-329.

Frantzich, H. (1998b). *Uncertainty and Risk Analysis in Fire Safety Engineering.* Lund: Department of Fire Safety Engineering, Lund University.

Frantzich, H. (2000). *Brandskyddsvärdering av vårdavdelningar - Ett riskanalysverktyg.* Karlstad: Räddningsverket.

Frantzich, H. (2005). *Brandskyddsvärdering - Brandskyddsindex för skola och danslokal.* Karlstad: Räddningsverket.

Frantzich, H. (2018). *Brandskyddsvärdering av flerbostadshus BSV-FB: Utveckling av metod för säkerhetsindex.* Lund: Division of Fire Safety Engineering, Lund University.

Frantzich, H., Nystedt, F., & Lundin, J. (2001). Risk Concepts in Fire Safety Design. *International Conference on Safety, Risk and Reliability – Trends in Engineering* (pp. 1001-1006). Malta: International Association for Bridge and Structural Engineering.

Galloway, D. L. (2010). Achieving Accurate Metrics using Balanced Scorecards and Dashboards. *Performance Improvement, 49*(7), 38-45.

Gaughan, P. A. (2009). *Measuring Business Interruption Losses and Other Commercial Damages.* New Jersey: John Wiley & Sons, Inc.

Gillen, D. (2017). Benchmarking and Performance Measurement: The Role in Quality Management. In A. M. Brewer, K. J. Button, & D. A. Henshe, *Handbook of Logistics and Supply-Chain Management (Handbooks in Transport, Volume 2)* (pp. 325-338). Elsevier.

Glossary of statistical terms. (2001, 11 21). Retrieved from OECD: https://stats.oecd.org/glossary/detail.asp?ID=2360

Gluckman, D. H., & Stavish, J. (2011). Warehouse Property Protection. *Strategic Outcomes Practice - Technical Advisory Bulletin.*

Gran, B. (1995). Major Differences in Cardiovascular Risk Indicators by Educational Status. *Scandinavian Journal of Social Medicine, 23*(1), 9-16.

Hall Jr, J. R. (2010). *Experience with Sprinklers and other Automatic Fire Extinguishing Equipment.* Quincy: National Fire Protection Association.

Health and Safety Executive. (2006). *Developing Process Safety Indicators.* United Kingdom: Health and Safety Executive.

Hermann, R. C., Mattke, S., Somekh, D., Silferhielm, H., Goldner, E., Glover, G., . . . Chan, J. A. (2006). Quality indicators for international benchmarking of mental health care. *International Journal for Quality in Health Care, 18*(1), 31-38.

Hirschler, M. M. (2017). Procedures for development and revision of codes and standards associated with fire safety in the USA. *Fire and Materials, 41*, 1058-1071.

Ho, C.-T., & Wu, Y.-S. (2006). Benchmarking performance indicators for banks. *Benchmarking: An International Journal, 13*(1/2), 147-159.

Holmberg, J., Laakso, K., Lehtinen, E., & Johansson, G. (1994). *Safety Evaluation by Living Probabilistic Safety Assessment and Safety Indicators.* Copenhagen: The Nordic Council of Ministers.

Hwang, C.-L., & Yoon, K. P. (1981). *Multi Attribute Decision Making: Methods and Applications.* Berlin/Heidelberg/New York: Springer.

IEC, International Electrotechnical Commission. (1995). *International Standard 60300-3-9, Dependability management - Part 3: Application guide - Section 9: Risk analysis of technological systems.* Geneva.

International Code Council. (2018). 2018 International Building Code. USA.

International Code Council. (2018). 2018 International Fire Code. USA.

International Organization for Standardization. (2009). Risk management — Principles and guidelines ISO 31000.

International Organization for Standardization. (2017). Risk management — Principles and guidelines ISO 31000.

International Safety Advisory Group. (1999). *Management of Operational Safety in Nuclear Power Plants.* Vienna: International Atomic Energy Agency.

Jasch, C. M. (2009). *Environmental and Material Flow Cost Accounting: Principles and Procedures.* Dordrecht: Springer.

Joshi, A., Kale, S., Chandel, S., & Pal, D. K. (2015). Likert Scale: Explored and Explained. *British Journal of Applied Science & Technology, 7*(4), 396-403.

Järvinen, J. (2016). *The Use of Digital Analytics for Measuring and Optimizing Digital Marketing Performance.* Jyväskylä: University Library of Jyväskylä.

Kaiser, J. (1979/1980). Experiences of the Gretener Method. *Fire Safety Journal, 2*, 213-222.

Kaplan, R. S., & Norton, N. P. (1992). The Balanced Scorecard - Measures that Drive Performance. *Harvard Business Review, 70*(1), 71-79.

Kaplan, S., & Garrick, J. B. (1981). On The Quantitative Definition of Risk. *Risk Analysis, 1*(1), 11-27.

Karlsson, B. (2000). *Fire Risk Index Method - Multistorey Apartment Buildings.* Stockholm: Trä-Tek.

Keeney, R. L., & Raiffa, H. (1975). Decision Analysis with Multiple Conflicting Objectives, Preferences and Value Tradeoffs. IIASA Working Paper. Laxenburg: IIASA.

Khalifa, M., & Khalid, P. (2015). Developing Strategic Health Care Key Performance Indicators: A Case Study on a Tertiary Care Hospital. *Procedia Computer Science, 63*, 459–466.

Kibira, D., Brundage, M., Feng, S., & Morris, K. (2017). Procedure for Selecting Key Performance Indicators for Sustainable Manufacturing. *Proceedings of the ASME 2017 12th International Manufacturing Science and Engineering Conference. 140 (1).* Los Angeles: Journal of Manufacturing Science and Engineering.

Kongsvik, T., Bye, R., Almklov, P., & Kleiven, E. (2017). The use of 'big data' in constructing loss-based performance indicators. *Risk, Reliability and Safety: Innovating Theory and Practice* (pp. 105-112). London: CRC Press.

Kotane, I., & Kuzmina-Merlino, I. (2012). Assessment of Financial Indicators for Evaluation of Business Performance. *ISSN 1822–8402 European Integration Studies*(6), 216-224.

Kwak, Y., & Ingall, L. (2007). Exploring Monte Carlo simulation applications for project management. *Risk Management, 9*(1), 44-57.

Lake, J. D. (2010). *Automatic Sprinkler Systems Handbook.* Quincy: National Fire Protection Association.

Leveson, N. (2015). A systems approach to risk management through leading safety indicators. *Reliability Engineering and System Safety, 136*, 17-34.

Lowrance, W. (1976). *Of Acceptable Risk: Science and the Determination of Safety.* Los Altos: William Kaufmann, Inc.

Mack, D. (2014, 03 18). *Swiss cheese model of accident causation.* Retrieved from https://upload.wikimedia.org/wikipedia/commons/e/e8/Swiss_cheese_model_of_accident_causation.png

Magnusson, S.-E., & Rantatalo, T. (1998). *Risk Assessment of Timberframe Multistorey Apartment Buildings – Proposal for a Comprehensive Fire Safety Evaluation Procedure.* Department of Fire Safety Engineering, Lund University, Lund.

Mainz, J. (2003). Defining and classifying clinical indicators for quality improvement. *International Journal for Quality in Health Care, 15*(6), 523–530.

Malhotra, H. (1993). Proposed Code for Fire Safety in Buildings for the State of Sao Paolo.

Marchant, E. (1988). Fire Safety Engineering — A Quantified Analysis. *Fire Prevention, 210*, 34-38.

McGregor, F. (2000). Performance measures, benchmarking and value. *Australian Library and Information Association ALIA 2000 Conference.* Canberra: Australian Library and Information Association.

Meacham, B. (2016). Toward Next Generation Performance-Based Building Regulatory Systems. Worcester: Worcester Polytechnic Institute.

Miller, D. W., & Starr, M. (1969). *Executive Decisions with Operations Research.* Englewood Cliffs: Prentice-Hall Inc.

Ministry of Business, I. a. (2016, 03 15). *Buildings with compliance schedules for specified systems.* Retrieved from Ministry of Business, Innovation and Employment: https://www.building.govt.nz/managing-buildings/managing-your-bwof/specified-systems-and-compliance-schedules/

Ministry of Business, Innovation and Employment. (2014). New Zealand Building Code Handbook. Wellington: Ministry of Business, Innovation and Employment.

Ministry of Business, Innovation and Employment. (2016). C/AS4 - Acceptable Solution for Buildings with Public Access and Educational Facilities (Risk Group CA). Wellington: Ministry of Business, Innovation and Employment.

Ministry of Business, Innovation, and Employment. (2017). Building Act 2004. Wellington: Ministry of Business, Innovation, and Employment.

Mobley, R., & Smith, R. (2008). *Rules of Thumb for Maintenance and Reliability Engineers.* Oxford: Elsevier.

National Fire Protection Association . (2010). *NFPA 72 National Fire Alarm and Signaling Code.* Quincy: National Fire Protection Association .

National Fire Protection Association. (2013). *NFPA 13 Standard for the Installation of Sprinkler Systems .* Quincy: National Fire Protection Association.

National Fire Protection Association. (2014). *NFPA 25 Standard for the Inspection,Testing,and Maintenance of Water-Based Fire Protection Systems.* Quincy: National Fire Protection Association.

National Fire Protection Association. (2017). NFPA 550 Guide to the Fire Safety Concepts Tree. Quincy: National Fire Protection Association.

National Fire Protection Association. (2018a). NFPA 101 Life Safety Code. Quincy: National Fire Protection Association.

National Fire Protection Association. (2018b). NFPA Glossary of Terms. National Fire Protection Association.

National Fire Sprinkler Network. (2017). *Efficiency and Effectiveness of Sprinkler Systems in the United Kingdom: An Analysis from Fire Service Data.* National Fire Sprinkler Network.

Nelson, H. E., & Shibe, A. J. (1978). *A System for Fire Safety Evaluation of Health Care Facilities.* Washington: US Department of Commerce.

Nevalainen, D., Berte, L., Kraft, C., Leigh, E., Picaso, L., & Morgan, T. (2000). Evaluating Laboratory Performance on Quality Indicators With the Six Sigma Scale. *Archives of Pathology & Laboratory Medicine, 124*.

NFPA. (2019). Guide for the Evaluation of Fire Risk Assessments. National Fire Protection Association.

Nguyen, H., Corbett, S., Steele, R., Banta, J., Clark, R., Hayes, S., . . . Wittlake, W. (2007). Implementation of a bundle of quality indicators for the early management of severe sepsis and septic shock is associated with decreased mortality. *Critical Care Medicine, 35*(4).

Niedritis, A., Niedrite, L., & Kozmina, N. (2011). Performance Measurement Framework with Formal Indicator Definitions. In J. Grabis, & M. Kirikova (Ed.), *Perspectives in Business Informatics Research, Lecture Notes in Business Information Processing. 90*, pp. 44-58. Springer.

Nurdiana, A., & Risdiyanto, I. (2015). Indicator determination of forest and land fires vulnerability using Landsat-5 TM data (case study: Jambi Province). *Procedia Environmental Sciences, 24*, 141-151.

OECD. (2005). *Guidance on Safety Performance Indicators.* OECD Publications.

Olsson, F., & Frantzich, H. (1999). *Brandteknisk dimensionering med riskbaserade ekvationer. (LUTVDG/TVBB--3107--SE; Vol. 3107).* Department of Fire Safety Engineering and Systems Safety, Lund University.

Oxford English Dictionary. (n.d.). Retrieved from Oxford English Dictionary: http://www.oed.com/view/Entry/94420?redirectedFrom=indicator#eid

Parameter, D. (2015). *Key performance indicators : developing, implementing, and using winning.* New Jersey: Wiley.

Paulson Gjerde, K. A., & Hughes, S. B. (2007). Tracking Performance: When Less Is More. *Management Accounting Quarterly, 9*(1).

Piñeiro-Otero, T., & Martínez-Rolán, X. (2016). Understanding Digital Marketing—Basics and Actions. In C. Machado, & J. P. Davim, *Theory and Application of Business and Management Principles* (pp. 37-74). Springer.

Pourtaghi, Z. S., Pourghasemi, H. R., Aretano, R., & Semeraro, T. (2016). Investigation of general indicators influencing on forest fire and its susceptibility modeling using different data mining techniques. *Ecological Indicators, 64*, 72-84.

Rao, V. R. (2007). *Decision Making in the Manufacturing Environment.* London: Springer.

Reason, J. (1997). *Managing the Risks of Organizational Accidents.* England: Ashgate Publishing Limited.

Regulation (EU) No 305/2011 of the European Parliament and of the Council of 9 March 2011 laying down harmonised conditions for the marketing of construction products and repealing. (2011). *L88*, 5-43. Official Journal of the European Union.

Robinson, T. R., Greuning, H., Henry, E., & Broihahn, M. A. (2009). *International Financial Statement analysis.* New Jersey: John Wiley & Sons.

Rockwell, T. H. (1959). Safety Performance measurement. *Journal of Industrial Engineering, 10*, 12-16.

Rowe, G., & Wright, G. (1999). The Delphi technique as a forecasting tool: issues and analysis. *15*, 353-375.

Rovins, J., Wilson, T., Hayes, J., Jensen, S. J., & Dohaney, J. M. (2015). *Risk Assessment Handbook.* Massey University.

Saaty, T. L. (1977). A Scaling Method for Priorities in Hierarchical Structures. *Journal of Mathematical Psychology, 15*, 234-281.

Saaty, T. L. (1980). *The Analytic Hierarchy Process.* New York: McGraw Hill.

Saaty, T. L. (2008). Decision making with the analytic hierarchy process. *Int. J. Services Sciences, 1*(1), 83–98.

Sample Klipfolio Dashboard Dark Theme. (2012, 12 12). Retrieved from https://upload.wikimedia.org/wikipedia/commons/a/a1/Sample_Klipfolio_Dashboard_Dark_Theme.png

Saura, J., Palos-Sánchez, P., & Suárez, L. M. (2017). Understanding the Digital Marketing Environment with KPIs andWeb Analytics. *Future Internet, 9*(76).

Schiebe, M., Scutsch, M., & Schofer, J. (1975). Experiments in Delphi Methodology. In H. Lindstone, & M. Turoff, *The Delphi Method: Techniques and Applications* (pp. 262-285). Glenview: Addison-Wesley.

Shields, J., & Silcock, G. (1986). An Application of the Hierarchical Approach to Fire Safety. *Fire Safety Journal, 11*, 235-242.

Shields, T. J., Silcock, G., Donegan, H. A., & Bell, Y. A. (1987). Methodological Problems Associated with the Use of the Delphi Technique. *Fire Technology, 23*(3).

Sim, K. L., & Koh, H. C. (2001). Balanced scorecard: a rising trend in strategic performance measurement. *Measuring Business Excellence, 5*(2), 18-27.

Simon, H. A. (1962). The Architecture of Complexity. *Proceedings of the American Philosophical Society. 106*, pp. 467-482. Philadelphia: American Philosophical Society.

Spetz, J., Donaldson, N., Aydin, C., & Brown, D. S. (2008). How Many Nurses per Patient? Measurements of Nurse Staffing in Health Services Research. *HSR: Health Services Research, 43*(5), 1674–1692.

Stollard, P. (1984). The Development of a Points Scheme to Assess Fire Safety in Hospitals. *Fire Safety Journal, 7*, 145-153.

Stollard, P., & Abrahams, J. (2002). *Fire from First Principles: A Design Guide to International Building Fire Safety.* London and New York: E & FN SPON.

Strelnik, E., & Usanova, D. (2015). Key Performance Indicators in Corporate Finance. *Asian Social Science, 11*(11).

Sze, C. K. (2009). Response Time Index of Sprinklers. *International Journal on Engineering Performance-Based Fire Codes*(1), 1-6.

The Health Information and Quality Authority. (2010). *Guidance on Developing Key Performance Indicators and Minimum Data Sets to Monitor Healthcare Quality.* Dublin: Health Information and Quality Authority.

The International Electrotechnical Commission. (2009). *Risk management — Risk assessment techniques EC/FDIS 31010.*

Thorne , M. C. (1993). The use of expert opinion in formulating conceptual models of underground disposal systems and the treatment of associated bias. *Reliability Engineering and System Safety, 42*, 161-180.

Todinov, M. (2006). *Risk-Based Reliability Analysis and Generic Principles for Risk Reduction.* Elsevier.

Torpey, D. T., Lentz, D. G., & Barret, D. A. (2004). *The Business Interruption Book: Coverage, Claims and Recovery.* National Underwriter Company.

Total Insurable Value. (n.d.). Retrieved from Investopedia: https://www.investopedia.com/terms/t/total-insurable-value.asp

Tzeng, G.-H., & Huang, J.-J. (2011). *Multiple Attribute Decision Making - Methods and applications.* Boca Raton: CRC Press.

U.S. Department of Energy. (2012). *Implementation Guide Aviation Program Performance Indicators (Metrics) for use with Doe Order 440.2B, Aviation Management and Safety.* Washington: U.S. Department of Energy.

Usrey, C. (2016, 03 27). *The Campbell Institute: What are safety leading indicators?* Retrieved from Safety and Health Magazine: https://www.safetyandhealthmagazine.com/articles/print/13821-the-campbell-institute-what-are-safety-leading-indicators

Valis, D., & Koucky, M. (2009). *Selected Overview of Risk Assessment Techniques.* Brno, Czech Republic: University of Defence.

Wang, Y., Zio, E., Fu, S., Zhang, D., & Yan, X. (2017). Some reflections on pre- and post-accident analysis for water transport: A case study of the Eastern Star accident. *Risk, Reliability and Safety: Innovating Theory and Practice* (pp. 127-133). Glasgow: CRS Press.

Watts, J. M. (1991). Criteria for Fire Risk Ranking. *Fire Safety Science - Proceedings 3rd ISFSS*, (pp. 457–466). Edinburgh, Scotland.

Watts, J. M. (1997). Fire Risk Assessment Using Multiattribute Evaluation. *The Fifth International Symposium on Fire Safety Science* (pp. 679-690). Melbourne: International Association for Fire Safety Science.

Watts, J. M. (2008). Fire Risk Indexing. i P. DiNenno, *SFPE Hand Book of Fire Protection Engineering, 4th ed.* Quincy: National Fire Protection Association.

Watts, J. M., & Hall Jr, J. M. (2008). Introduction to Fire Risk Analysis. i P. J. DiNenno (Red.), *SFPE Hand Book of Fire Protection Engineering, 4th ed.* Quincy: National Fire Protection Association.

Verstraeten, J. G., Roelen, A. L., & Speijker, L. J. (2014). *Safety performance indicators for system of organizations in aviation.* Aviation Safety and Certification of new Operations and Systems.

Willis, H. (2007). Guiding resource allocations based on terrorism risk. *Risk Analysis, 27*, 597-606.

Vinnem, J. (2010). Risk indicators for major hazards on offshore installations. *Safety Science, 48*, 770-787.

von Schirnding, Y. (2002). *Health in Sustainable Development Planning: The Role Indicators.* Geneva: World Health Organization.

Yavorskyy, A. (2008). Analysis of Indicators of in Patient Surgical Care at the Health Care Facilities in Ivano-Frankivsk Region for 2005-2015. *Galician Medical Journal, 23*(4).

Yoon, K. P., & Hwang, C.-L. (1995). Multiple Attribute Decision Making - An Introduction. *SAGE University Papers 07-104*.

Øien, K. (2001). *Risk Control of Offshore Installations. A Framework for the Establishment of Risk Indicators.* Trondheim: Department of Production and Quality Engineering, The Norwegian University of Science and Technology.

Øien, K., Utne, I. B., Tinmannsvik, R. K., & Massaiu, S. (2011b). Building Safety indicators: Part 2 – Application, practices and results. *Safety Science, 49*, 162-171.

Øien, K., Utne, I., & Herrera, I. (2011). Building Safety indicators: Part 1 – Theoretical foundation. *Safety Science, 49*, 148-161.

Appendix A – Weighting Forms

Retail

1

Strategies

Components

	Prevent Ignition	Limit Fire and Smoke Spread	Provide Safe Egress	Extinction of Fire
Sprinkler System				
Fire Detection System				
Customers				
Personnel				
Guiding Signage				
Fire Load				
Compartmentation				
Fire Service				
Evacuation Alarm				
Internal Linings				
Emergency Lighting				
Inspection, Testing & Maintenance				
Smoke Evacuation				
Escape Routes				
Structure – Load Bearing				
Structure – Separating				
Ventilation System				
Building Geometry				
Fire Extinguishing Equipment				

2

Objectives

Strategies

	Provide Life Safety	Provide Property Protection	Provide Business Continuance
Prevent Ignition			
Limit Fire and Smoke Spread			
Provide Safe Egress			
Extinction of Fire			

3

Policy

Objectives

	Satisfying Level of Fire Safety
Provide Life Safety	
Provide Property Protection	
Provide Business Continuance	

Weighting

Importance or Weight	Interpretation
0	No Relation
1	Not Important
2	Low Importance
3	Moderate Importance
4	Important
5	Very Important

Retail with High Rack Storage

1

Strategies

Components

	Prevent Ignition	Limit Fire and Smoke Spread	Provide Safe Egress	Extinction of Fire
Sprinkler System				
Fire Detection System				
Customers				
Personnel				
Guiding Signage				
Fire Load				
Compartmentation				
Fire Service				
Evacuation Alarm				
Internal Linings				
Emergency Lighting				
Inspection, Testing & Maintenance				
Smoke Evacuation				
Escape Routes				
Structure – Load Bearing				
Structure – Separating				
Ventilation System				
Building Geometry				
Fire Extinguishing Equipment				

2

Objectives

Strategies

	Provide Life Safety	Provide Property Protection	Provide Business Continuance
Prevent Ignition			
Limit Fire and Smoke Spread			
Provide Safe Egress			
Extinction of Fire			

3

Policy

Objectives

	Satisfying Level of Fire Safety
Provide Life Safety	
Provide Property Protection	
Provide Business Continuance	

Weighting

Importance or Weight	Interpretation
0	**No Relation**
1	**Not Important**
2	**Low Importance**
3	**Moderate Importance**
4	**Important**
5	**Very Important**

Appendix B – Weight Calculations

B.1 Components Weights – Retail

Table B-1. Component weights in relation to each strategy.

	Strategies			
Components	**Prevent ignition**	**Limit fire and smoke spread**	**Provide safe egress**	**Extinction of fire**
Sprinkler system	0	5	4	5
Fire detection system	0	4	5	3
Customers	2	2	4	2
Personnel	3	3	3	3
Guiding signage	0	0	4	0
Fire load	1	3	2	3
Compartmentation	0	2	1	0
Fire service	0	2	1	4
Evacuation alarm	0	0	5	0
Internal linings	0	3	0	1
Emergency lighting	0	0	4	0
Inspection, testing & maintenance	3.5	4	4	4
Smoke evacuation	0	3	0	2
Escape routes	0	0	5	0
Structure – load bearing	0	0	1	3
Structure – separating	0	2	0	0
Ventilation system	0	2	0	0
Building geometry	0	4	3	3
Fire extinguishing equipment	0	3	0	3
Electrical installations	5	0	0	0

Table B-2. Component weights in relation to each objective.

	Objectives		
Strategies	**Provide life safety**	**Provide property protection**	**Provide business continuance**
Prevent ignition	3	3	3
Limit fire and smoke spread	4	3	3
Provide safe egress	5	1	3
Extinction of fire	1	5	5

Table B-3. Component weights in relation to the policy.

	Policy
Objectives	**Satisfying level of fire safety**
Provide life safety	5
Provide property protection	3
Provide business continuance	4

B.1.1 Components Weights in Relation to Each Strategy

$$\begin{bmatrix} 0 & 5 & 4 & 5 \\ 0 & 4 & 5 & 3 \\ 2 & 2 & 4 & 2 \\ 3 & 3 & 3 & 3 \\ 0 & 0 & 4 & 0 \\ 1 & 3 & 2 & 3 \\ 0 & 2 & 1 & 0 \\ 0 & 2 & 1 & 4 \\ 0 & 0 & 5 & 0 \\ 0 & 3 & 0 & 1 \\ 0 & 0 & 4 & 0 \\ 3.5 & 4 & 4 & 4 \\ 0 & 3 & 0 & 2 \\ 0 & 0 & 5 & 0 \\ 0 & 0 & 1 & 3 \\ 0 & 2 & 0 & 0 \\ 0 & 2 & 0 & 0 \\ 0 & 4 & 3 & 3 \\ 0 & 3 & 0 & 3 \\ 5 & 0 & 0 & 0 \end{bmatrix}$$

$$\sum_{i=1}^{20} y_{Prevent\ Ignition\ (column\ 1)} = 14.5$$

$$\sum_{i=1}^{20} y_{Limit\ Fire\ and\ Smoke\ Spread\ (column\ 2)} = 42$$

$$\sum_{i=1}^{20} y_{Provide\ Safe\ Egress\ (column\ 3)} = 46$$

$$\sum_{i=1}^{20} y_{Extinction\ of\ Fire\ (column\ 4)} = 36$$

Each weight in the 20 × 4 matrix is divided by the sum of the respective column, and multiplied by a factor 1,000:

$$\begin{bmatrix} 0 \\ 0 \\ 2 \\ 3 \\ 0 \\ 1 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 3.5 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 5 \end{bmatrix} \times \frac{1{,}000}{14.5} \approx \begin{bmatrix} 0 \\ 0 \\ 138 \\ 207 \\ 0 \\ 69 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 241 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 345 \end{bmatrix}, \begin{bmatrix} 5 \\ 4 \\ 2 \\ 3 \\ 0 \\ 3 \\ 2 \\ 2 \\ 0 \\ 3 \\ 0 \\ 4 \\ 3 \\ 0 \\ 0 \\ 2 \\ 2 \\ 4 \\ 3 \\ 0 \end{bmatrix} \times \frac{1{,}000}{42} \approx \begin{bmatrix} 119 \\ 95 \\ 48 \\ 71 \\ 0 \\ 71 \\ 48 \\ 48 \\ 0 \\ 71 \\ 0 \\ 95 \\ 71 \\ 0 \\ 0 \\ 48 \\ 48 \\ 95 \\ 71 \\ 0 \end{bmatrix}, \begin{bmatrix} 4 \\ 5 \\ 4 \\ 3 \\ 4 \\ 2 \\ 1 \\ 1 \\ 5 \\ 0 \\ 4 \\ 4 \\ 0 \\ 5 \\ 1 \\ 0 \\ 0 \\ 3 \\ 0 \\ 0 \end{bmatrix} \times \frac{1{,}000}{46} = \begin{bmatrix} 87 \\ 109 \\ 87 \\ 65 \\ 87 \\ 43 \\ 22 \\ 22 \\ 109 \\ 0 \\ 87 \\ 87 \\ 0 \\ 109 \\ 22 \\ 0 \\ 0 \\ 65 \\ 0 \\ 0 \end{bmatrix}, \begin{bmatrix} 5 \\ 3 \\ 2 \\ 3 \\ 0 \\ 3 \\ 0 \\ 4 \\ 0 \\ 1 \\ 0 \\ 4 \\ 2 \\ 0 \\ 3 \\ 0 \\ 0 \\ 3 \\ 3 \\ 0 \end{bmatrix} \times \frac{1{,}000}{36} \approx \begin{bmatrix} 139 \\ 83 \\ 56 \\ 83 \\ 0 \\ 83 \\ 0 \\ 111 \\ 0 \\ 28 \\ 0 \\ 111 \\ 56 \\ 0 \\ 83 \\ 0 \\ 0 \\ 83 \\ 83 \\ 0 \end{bmatrix}$$

The normalised matrix can now be written as:

$$\begin{bmatrix} 0 & 119 & 87 & 139 \\ 0 & 95 & 109 & 83 \\ 138 & 48 & 87 & 56 \\ 207 & 71 & 65 & 83 \\ 0 & 0 & 87 & 0 \\ 69 & 71 & 43 & 83 \\ 0 & 48 & 22 & 0 \\ 0 & 48 & 22 & 111 \\ 0 & 0 & 109 & 0 \\ 0 & 71 & 0 & 28 \\ 0 & 0 & 87 & 0 \\ 241 & 95 & 87 & 111 \\ 0 & 71 & 0 & 56 \\ 0 & 0 & 109 & 0 \\ 0 & 0 & 22 & 83 \\ 0 & 48 & 0 & 0 \\ 0 & 48 & 0 & 0 \\ 0 & 95 & 65 & 83 \\ 0 & 71 & 0 & 83 \\ 345 & 0 & 0 & 0 \end{bmatrix}$$

B.1.2 Components Weights in Relation to Each Objective

$$\begin{bmatrix} 0 & 5 & 4 & 5 \\ 0 & 4 & 5 & 3 \\ 2 & 2 & 4 & 2 \\ 3 & 3 & 3 & 3 \\ 0 & 0 & 4 & 0 \\ 1 & 3 & 2 & 3 \\ 0 & 2 & 1 & 0 \\ 0 & 2 & 1 & 4 \\ 0 & 0 & 5 & 0 \\ 0 & 3 & 0 & 1 \\ 0 & 0 & 4 & 0 \\ 3.5 & 4 & 4 & 4 \\ 0 & 3 & 0 & 2 \\ 0 & 0 & 5 & 0 \\ 0 & 0 & 1 & 3 \\ 0 & 2 & 0 & 0 \\ 0 & 2 & 0 & 0 \\ 0 & 4 & 3 & 3 \\ 0 & 3 & 0 & 3 \\ 5 & 0 & 0 & 0 \end{bmatrix} \times \begin{bmatrix} 3 & 3 & 3 \\ 4 & 3 & 3 \\ 5 & 1 & 3 \\ 5 & 3 & 4 \end{bmatrix} = \begin{bmatrix} 45 & 44 & 52 \\ 44 & 32 & 42 \\ 36 & 26 & 34 \\ 39 & 36 & 42 \\ 20 & 4 & 12 \\ 28 & 29 & 33 \\ 13 & 7 & 9 \\ 17 & 27 & 29 \\ 25 & 5 & 15 \\ 13 & 14 & 14 \\ 20 & 4 & 12 \\ 50.5 & 46.5 & 54.5 \\ 14 & 19 & 19 \\ 25 & 5 & 15 \\ 8 & 16 & 18 \\ 8 & 6 & 6 \\ 8 & 6 & 6 \\ 34 & 30 & 36 \\ 15 & 24 & 24 \\ 15 & 15 & 15 \end{bmatrix}$$

$$\sum_{i=1}^{20} y_{Provide\ Life\ Safety\ (column\ 1)} = 477.5$$

$$\sum_{i=1}^{20} y_{Provide\ Property\ Protection\ (column\ 2)} = 395.5$$

$$\sum_{i=1}^{20} y_{Provide\ Business\ Continuance\ (column\ 3)} = 487.5$$

Each weight in the 20 × 3 matrix is divided by the sum of the respective column, and multiplied by a factor 1,000:

$$\begin{bmatrix} 45 \\ 44 \\ 36 \\ 39 \\ 20 \\ 28 \\ 13 \\ 17 \\ 25 \\ 13 \\ 20 \\ 50.5 \\ 14 \\ 25 \\ 8 \\ 8 \\ 8 \\ 34 \\ 15 \\ 15 \end{bmatrix} \times \frac{1{,}000}{477.5} \approx \begin{bmatrix} 94 \\ 92 \\ 75 \\ 82 \\ 42 \\ 59 \\ 27 \\ 36 \\ 52 \\ 27 \\ 42 \\ 106 \\ 29 \\ 52 \\ 17 \\ 17 \\ 17 \\ 71 \\ 31 \\ 31 \end{bmatrix}, \begin{bmatrix} 44 \\ 32 \\ 26 \\ 36 \\ 4 \\ 29 \\ 7 \\ 27 \\ 5 \\ 14 \\ 4 \\ 46.5 \\ 19 \\ 5 \\ 16 \\ 6 \\ 6 \\ 30 \\ 24 \\ 15 \end{bmatrix} \times \frac{1{,}000}{395.5} \approx \begin{bmatrix} 111 \\ 81 \\ 66 \\ 91 \\ 10 \\ 73 \\ 18 \\ 68 \\ 13 \\ 35 \\ 10 \\ 118 \\ 48 \\ 13 \\ 40 \\ 15 \\ 15 \\ 76 \\ 61 \\ 38 \end{bmatrix}, \begin{bmatrix} 52 \\ 42 \\ 34 \\ 42 \\ 12 \\ 33 \\ 9 \\ 29 \\ 15 \\ 14 \\ 12 \\ 54.5 \\ 19 \\ 15 \\ 18 \\ 6 \\ 6 \\ 36 \\ 24 \\ 15 \end{bmatrix} \times \frac{1{,}000}{487.5} \approx \begin{bmatrix} 107 \\ 86 \\ 70 \\ 86 \\ 25 \\ 68 \\ 18 \\ 59 \\ 31 \\ 29 \\ 25 \\ 112 \\ 39 \\ 31 \\ 37 \\ 12 \\ 12 \\ 74 \\ 49 \\ 31 \end{bmatrix}$$

The normalised matrix can now be written as:

$$\begin{bmatrix} 94 & 111 & 107 \\ 92 & 81 & 86 \\ 75 & 66 & 70 \\ 82 & 91 & 86 \\ 42 & 10 & 25 \\ 59 & 73 & 68 \\ 27 & 18 & 18 \\ 36 & 68 & 59 \\ 52 & 13 & 31 \\ 27 & 35 & 29 \\ 42 & 10 & 25 \\ 106 & 118 & 112 \\ 29 & 48 & 39 \\ 52 & 13 & 31 \\ 17 & 40 & 37 \\ 17 & 15 & 12 \\ 17 & 15 & 12 \\ 71 & 76 & 74 \\ 31 & 61 & 49 \\ 31 & 38 & 31 \end{bmatrix}$$

B.1.3 Components Weights in Relation to the Policy

$$\begin{bmatrix} 0 & 5 & 4 & 5 \\ 0 & 4 & 5 & 3 \\ 2 & 2 & 4 & 2 \\ 3 & 3 & 3 & 3 \\ 0 & 0 & 4 & 0 \\ 1 & 3 & 2 & 3 \\ 0 & 2 & 1 & 0 \\ 0 & 2 & 1 & 4 \\ 0 & 0 & 5 & 0 \\ 0 & 3 & 0 & 1 \\ 0 & 0 & 4 & 0 \\ 3.5 & 4 & 4 & 4 \\ 0 & 3 & 0 & 2 \\ 0 & 0 & 5 & 0 \\ 0 & 0 & 1 & 3 \\ 0 & 2 & 0 & 0 \\ 0 & 2 & 0 & 0 \\ 0 & 4 & 3 & 3 \\ 0 & 3 & 0 & 3 \\ 5 & 0 & 0 & 0 \end{bmatrix} \times \begin{bmatrix} 3 & 3 & 3 \\ 4 & 3 & 3 \\ 5 & 1 & 3 \\ 5 & 3 & 4 \end{bmatrix} \times \begin{bmatrix} 5 \\ 3 \\ 4 \end{bmatrix} = \begin{bmatrix} 565 \\ 484 \\ 394 \\ 471 \\ 160 \\ 359 \\ 122 \\ 282 \\ 200 \\ 163 \\ 160 \\ 610 \\ 203 \\ 200 \\ 160 \\ 82 \\ 82 \\ 404 \\ 243 \\ 180 \end{bmatrix} \qquad \sum_{i=1}^{20} y_{Satisfying\ Level\ of\ Fire\ Safety} = 5{,}524$$

Each weight in the 20 × 1 weight matrix is divided by the sum, and multiplied by a factor 1,000:

$$\begin{bmatrix} 565 \\ 484 \\ 394 \\ 471 \\ 160 \\ 359 \\ 122 \\ 282 \\ 200 \\ 163 \\ 160 \\ 610 \\ 203 \\ 200 \\ 160 \\ 82 \\ 82 \\ 404 \\ 243 \\ 180 \end{bmatrix} \times \frac{1{,}000}{5{,}524} \approx \begin{bmatrix} 102 \\ 88 \\ 71 \\ 85 \\ 29 \\ 65 \\ 22 \\ 51 \\ 36 \\ 30 \\ 29 \\ 110 \\ 37 \\ 36 \\ 29 \\ 15 \\ 15 \\ 73 \\ 44 \\ 33 \end{bmatrix}$$

B.2 Components Weights – Retail with High Rack Storage

Table B-4. Component weights in relation to each strategy.

	Strategies			
Components	**Prevent ignition**	**Limit fire and smoke spread**	**Provide safe egress**	**Extinction of fire**
Sprinkler system	0	5	4	5
Fire detection system	0	2	5	1
Customers	2	1	4	1
Personnel	2	2	3	1
Guiding signage	0	0	4	0
Fire load	1	4	2	4
Compartmentation	0	2	1	0
Fire service	0	1	1	2
Evacuation alarm	0	0	5	0
Internal linings	0	2	0	1
Emergency lighting	0	0	4	0
Inspection, testing & maintenance	3.5	4	4	4
Smoke evacuation	0	2	0	2
Escape routes	0	0	5	0
Structure – load bearing	0	0	1	2
Structure – separating	0	2	0	0
Ventilation system	0	1	0	0
Building geometry	0	2	3	3
Fire extinguishing equipment	0	2	0	2
Electrical installations	5	0	0	0

Table B-5. Component weights in relation to each objective.

	Objectives		
Strategies	**Provide life Safety**	**Provide property protection**	**Provide business continuance**
Prevent ignition	3	3	3
Limit fire and smoke spread	5	3	3
Provide safe egress	5	1	3
Extinction of fire	1	5	5

Table B-6. Component weights in relation to the policy.

	Policy
Objectives	**Satisfying level of fire safety**
Provide life safety	5
Provide property protection	3
Provide business continuance	4

B.2.1 Components Weights in Relation to Each Strategy

$$\begin{bmatrix} 0 & 5 & 4 & 5 \\ 0 & 2 & 5 & 1 \\ 2 & 1 & 4 & 1 \\ 2 & 2 & 3 & 1 \\ 0 & 0 & 4 & 0 \\ 1 & 4 & 2 & 4 \\ 0 & 2 & 1 & 0 \\ 0 & 1 & 1 & 2 \\ 0 & 0 & 5 & 0 \\ 0 & 2 & 0 & 1 \\ 0 & 0 & 4 & 0 \\ 3.5 & 4 & 4 & 4 \\ 0 & 2 & 0 & 2 \\ 0 & 0 & 5 & 0 \\ 0 & 0 & 1 & 2 \\ 0 & 2 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 2 & 3 & 3 \\ 0 & 2 & 0 & 2 \\ 5 & 0 & 0 & 0 \end{bmatrix}$$

$$\sum_{i=1}^{20} y_{Prevent\ Ignition\ (column\ 1)} = 13.5$$

$$\sum_{i=1}^{20} y_{Limit\ Fire\ and\ Smoke\ Spread\ (column\ 2)} = 32$$

$$\sum_{i=1}^{20} y_{Provide\ Safe\ Egress\ (column\ 3)} = 46$$

$$\sum_{i=1}^{20} y_{Extinction\ of\ Fire\ (column\ 4)} = 28$$

Each weight in the 20 × 4 matrix is divided by the sum of the respective column, and multiplied by a factor 1,000:

$$\begin{bmatrix} 0 \\ 0 \\ 2 \\ 2 \\ 0 \\ 1 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 3.5 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 5 \end{bmatrix} \times \frac{1{,}000}{13.5} \approx \begin{bmatrix} 0 \\ 0 \\ 148 \\ 148 \\ 0 \\ 74 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 259 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 370 \end{bmatrix}, \begin{bmatrix} 5 \\ 2 \\ 1 \\ 2 \\ 0 \\ 4 \\ 2 \\ 1 \\ 0 \\ 2 \\ 0 \\ 4 \\ 2 \\ 0 \\ 0 \\ 2 \\ 1 \\ 2 \\ 2 \\ 0 \end{bmatrix} \times \frac{1{,}000}{32} \approx \begin{bmatrix} 156 \\ 63 \\ 31 \\ 63 \\ 0 \\ 125 \\ 63 \\ 31 \\ 0 \\ 63 \\ 0 \\ 125 \\ 63 \\ 0 \\ 0 \\ 63 \\ 31 \\ 63 \\ 63 \\ 0 \end{bmatrix}, \begin{bmatrix} 4 \\ 5 \\ 4 \\ 3 \\ 4 \\ 2 \\ 1 \\ 1 \\ 5 \\ 0 \\ 4 \\ 4 \\ 0 \\ 5 \\ 1 \\ 0 \\ 0 \\ 3 \\ 0 \\ 0 \end{bmatrix} \times \frac{1{,}000}{46} = \begin{bmatrix} 87 \\ 109 \\ 87 \\ 65 \\ 87 \\ 43 \\ 22 \\ 22 \\ 109 \\ 0 \\ 87 \\ 87 \\ 0 \\ 109 \\ 22 \\ 0 \\ 0 \\ 65 \\ 0 \\ 0 \end{bmatrix}, \begin{bmatrix} 5 \\ 1 \\ 1 \\ 1 \\ 0 \\ 4 \\ 0 \\ 2 \\ 0 \\ 1 \\ 0 \\ 4 \\ 2 \\ 0 \\ 2 \\ 0 \\ 0 \\ 3 \\ 2 \\ 0 \end{bmatrix} \times \frac{1{,}000}{28} \approx \begin{bmatrix} 179 \\ 36 \\ 36 \\ 36 \\ 0 \\ 143 \\ 0 \\ 71 \\ 0 \\ 36 \\ 0 \\ 143 \\ 71 \\ 0 \\ 71 \\ 0 \\ 0 \\ 107 \\ 71 \\ 0 \end{bmatrix}$$

The normalised matrix can now be written as:

$$\begin{bmatrix} 0 & 156 & 87 & 179 \\ 0 & 63 & 109 & 36 \\ 148 & 31 & 87 & 36 \\ 148 & 63 & 65 & 36 \\ 0 & 0 & 87 & 0 \\ 74 & 125 & 43 & 143 \\ 0 & 63 & 22 & 0 \\ 0 & 31 & 22 & 71 \\ 0 & 0 & 109 & 0 \\ 0 & 63 & 0 & 36 \\ 0 & 0 & 87 & 0 \\ 259 & 125 & 87 & 143 \\ 0 & 63 & 0 & 71 \\ 0 & 0 & 109 & 0 \\ 0 & 0 & 22 & 71 \\ 0 & 63 & 0 & 0 \\ 0 & 31 & 0 & 0 \\ 0 & 63 & 65 & 107 \\ 0 & 63 & 0 & 71 \\ 370 & 0 & 0 & 0 \end{bmatrix}$$

B.2.2 Components Weights in Relation to each Objective

$$\begin{bmatrix} 0 & 5 & 4 & 5 \\ 0 & 2 & 5 & 1 \\ 2 & 1 & 4 & 1 \\ 2 & 2 & 3 & 1 \\ 0 & 0 & 4 & 0 \\ 1 & 4 & 2 & 4 \\ 0 & 2 & 1 & 0 \\ 0 & 1 & 1 & 2 \\ 0 & 0 & 5 & 0 \\ 0 & 2 & 0 & 1 \\ 0 & 0 & 4 & 0 \\ 3.5 & 4 & 4 & 4 \\ 0 & 2 & 0 & 2 \\ 0 & 0 & 5 & 0 \\ 0 & 0 & 1 & 2 \\ 0 & 2 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 2 & 3 & 3 \\ 0 & 2 & 0 & 2 \\ 5 & 0 & 0 & 0 \end{bmatrix} \times \begin{bmatrix} 3 & 3 & 3 \\ 5 & 3 & 3 \\ 5 & 1 & 3 \\ 1 & 5 & 5 \end{bmatrix} = \begin{bmatrix} 50 & 44 & 52 \\ 36 & 16 & 26 \\ 32 & 18 & 26 \\ 32 & 20 & 26 \\ 20 & 4 & 12 \\ 37 & 37 & 41 \\ 15 & 7 & 9 \\ 12 & 14 & 16 \\ 25 & 5 & 15 \\ 11 & 11 & 11 \\ 20 & 4 & 12 \\ 54.5 & 46.5 & 54.5 \\ 12 & 16 & 16 \\ 25 & 5 & 15 \\ 7 & 11 & 13 \\ 10 & 6 & 6 \\ 5 & 3 & 3 \\ 28 & 24 & 30 \\ 12 & 16 & 16 \\ 15 & 15 & 15 \end{bmatrix}$$

$$\sum_{i=1}^{20} y_{Provide\ Life\ Safety\ (column\ 1)} = 458.5$$

$$\sum_{i=1}^{20} y_{Provide\ Property\ Protection\ (column\ 2)} = 322.5$$

$$\sum_{i=1}^{20} y_{Provide\ Business\ Continuance\ (column\ 3)} = 414.5$$

Each weight in the 20 × 3 matrix is divided by the sum of the respective column, and multiplied by a factor 1,000:

$$\begin{bmatrix} 50 \\ 36 \\ 32 \\ 32 \\ 20 \\ 37 \\ 15 \\ 12 \\ 25 \\ 11 \\ 20 \\ 54.5 \\ 12 \\ 25 \\ 7 \\ 10 \\ 5 \\ 28 \\ 12 \\ 15 \end{bmatrix} \times \frac{1{,}000}{458.5} \approx \begin{bmatrix} 109 \\ 79 \\ 70 \\ 70 \\ 44 \\ 81 \\ 33 \\ 26 \\ 55 \\ 24 \\ 44 \\ 119 \\ 26 \\ 55 \\ 15 \\ 22 \\ 11 \\ 61 \\ 26 \\ 33 \end{bmatrix}, \begin{bmatrix} 44 \\ 16 \\ 18 \\ 20 \\ 4 \\ 37 \\ 7 \\ 14 \\ 5 \\ 11 \\ 4 \\ 46.5 \\ 16 \\ 5 \\ 11 \\ 6 \\ 3 \\ 24 \\ 16 \\ 15 \end{bmatrix} \times \frac{1{,}000}{322.5} \approx \begin{bmatrix} 136 \\ 50 \\ 56 \\ 62 \\ 12 \\ 115 \\ 22 \\ 43 \\ 16 \\ 34 \\ 12 \\ 144 \\ 50 \\ 16 \\ 34 \\ 19 \\ 9 \\ 74 \\ 50 \\ 47 \end{bmatrix}, \begin{bmatrix} 52 \\ 26 \\ 26 \\ 26 \\ 12 \\ 41 \\ 9 \\ 16 \\ 15 \\ 11 \\ 12 \\ 54.5 \\ 16 \\ 15 \\ 13 \\ 6 \\ 3 \\ 30 \\ 16 \\ 15 \end{bmatrix} \times \frac{1{,}000}{414.5} \approx \begin{bmatrix} 125 \\ 63 \\ 63 \\ 63 \\ 29 \\ 99 \\ 22 \\ 39 \\ 36 \\ 27 \\ 29 \\ 131 \\ 39 \\ 36 \\ 31 \\ 14 \\ 7 \\ 72 \\ 39 \\ 36 \end{bmatrix}$$

The normalised matrix can now be written as:

$$\begin{bmatrix} 109 & 136 & 125 \\ 79 & 50 & 63 \\ 70 & 56 & 63 \\ 70 & 62 & 63 \\ 44 & 12 & 29 \\ 81 & 115 & 99 \\ 33 & 22 & 22 \\ 26 & 43 & 39 \\ 55 & 16 & 36 \\ 24 & 34 & 27 \\ 44 & 12 & 29 \\ 119 & 144 & 131 \\ 26 & 50 & 39 \\ 55 & 16 & 36 \\ 15 & 34 & 31 \\ 22 & 19 & 14 \\ 11 & 9 & 7 \\ 61 & 74 & 72 \\ 26 & 50 & 39 \\ 33 & 47 & 36 \end{bmatrix}$$

B.2.3 Components Weights in Relation to the Policy

$$\begin{bmatrix} 0 & 5 & 4 & 5 \\ 0 & 2 & 5 & 1 \\ 2 & 1 & 4 & 1 \\ 2 & 2 & 3 & 1 \\ 0 & 0 & 4 & 0 \\ 1 & 4 & 2 & 4 \\ 0 & 2 & 1 & 0 \\ 0 & 1 & 1 & 2 \\ 0 & 0 & 5 & 0 \\ 0 & 2 & 0 & 1 \\ 0 & 0 & 4 & 0 \\ 3.5 & 4 & 4 & 4 \\ 0 & 2 & 0 & 2 \\ 0 & 0 & 5 & 0 \\ 0 & 0 & 1 & 2 \\ 0 & 2 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 2 & 3 & 3 \\ 0 & 2 & 0 & 2 \\ 5 & 0 & 0 & 0 \end{bmatrix} \times \begin{bmatrix} 3 & 3 & 3 \\ 5 & 3 & 3 \\ 5 & 1 & 3 \\ 1 & 5 & 5 \end{bmatrix} \times \begin{bmatrix} 5 \\ 3 \\ 4 \end{bmatrix} \approx \begin{bmatrix} 590 \\ 332 \\ 318 \\ 324 \\ 160 \\ 460 \\ 132 \\ 166 \\ 200 \\ 132 \\ 160 \\ 630 \\ 172 \\ 200 \\ 120 \\ 92 \\ 46 \\ 332 \\ 172 \\ 180 \end{bmatrix}$$

$$\sum_{i=1}^{20} y_{Satisfying\ Level\ of\ Fire\ Safety} = 4{,}918$$

Each weight in the 20 × 1 weight matrix is divided by the sum, and multiplied by a factor 1,000:

$$\begin{bmatrix} 590 \\ 332 \\ 318 \\ 324 \\ 160 \\ 460 \\ 132 \\ 166 \\ 200 \\ 132 \\ 160 \\ 630 \\ 172 \\ 200 \\ 120 \\ 92 \\ 46 \\ 332 \\ 172 \\ 180 \end{bmatrix} \times \frac{1{,}000}{4{,}918} \approx \begin{bmatrix} 120 \\ 68 \\ 65 \\ 66 \\ 33 \\ 94 \\ 27 \\ 34 \\ 41 \\ 27 \\ 33 \\ 128 \\ 35 \\ 41 \\ 24 \\ 19 \\ 9 \\ 68 \\ 35 \\ 37 \end{bmatrix}$$

Appendix C – Fictitious Input Data to Indicator Examples (Chapter 8)

C.1 Sprinkler Indicators

C.1.1 Accumulated Number of Sprinkler Activations per 10^6 m^2 – one Year

Benchmark: 10 activations/10^6 m^2 for 2019.

Table C-1. Building group 1 input data for Figure 8-2.

Date	Number of sprinkler activations	Accumulated Number of sprinkler activations	Building area (10^6 m^2)	Number of sprinkler activations per 10^6 m^2
2019/01/07	1	1	0.63459	1.57
2019/02/19	1	2		3.15
2019/03/30	1	3		4.73
2019/06/04	1	4		6.30
2019/06/18	1	5		7.88
2019/08/01	1	6		9.45
2019/09/14	1	7		11.03
2019/11/20	1	8		12.60
2019/12/22	1	9		14.18

Table C-2. Building group 2 input data for Figure 8-2.

Date	Number of sprinkler activations	Accumulated Number of sprinkler activations	Building area (10^6 m^2)	Number of sprinkler activations per 10^6 m^2
2019/04/12	1	1	0.21153	4.73
2019/08/10	1	2		9.45
2019/12/18	1	3		14.18

C.1.2 Number of Sprinkler Activations per 10^6 m^2 per Year

Benchmark: 50 activations/10^6 m^2 yearly.

Table C-3. Building group 1 input data for Figure 8-1.

Year	Number of sprinkler activations	Total area (10^6 m^2)	Number of sprinkler activations per 10^6 m^2
2009	9	0.2	45
2010	7		35
2011	12		60
2012	10		50
2013	9		45
2014	7		35
2015	6		30
2016	8		40
2017	6		30
2018	5		25
2019	9		45

Table C-4. Building group 2 input data for Figure 8-1.

Year	Number of sprinkler activations	Total area (10^6 m^2)	Number of sprinkler activations per 10^6 m^2
2009	8	0.125	64
2010	6		48
2011	5		40
2012	9		72
2013	5		40
2014	6		48
2015	7		56
2016	8		64

2017	5		40
2018	9		72
2019	7		45

C.2 Personnel Indicators

Personnel per area unit daily are not included due to amount of data.

C.2.1 Number of Personnel per 1,000 m^2

Benchmark: 35 personnel/10^3 m^2 weekly.

Table C-5. Building 1 input data for Figure 8-5.

Week	Number of personnel	Total area (10^3 m^2)	Number of personnel per 10^3 m^2
1	499	12	42
2	489		41
3	492		41
4	507		42
5	483		40
6	487		41
7	480		40
8	479		40
9	457		38
10	469		39
11	460		38
12	468		39
13	464		39
14	462		39
15	459		38
16	443		37
17	438		37
18	463		39
19	465		39
20	449		37
21	457		38
22	445		37
23	455		38
24	440		37
25	446		37
26	434		36
27	445		37
28	436		36
29	452		38
30	455		38
31	444		37
32	441		37
33	443		37
34	437		36
35	431		36
36	445		37
37	434		36
38	423		35
39	432		36
40	436		36
41	432		36
42	430		36
43	426		36

44	424		35
45	417		35
46	433		36
47	441		37
48	429		36
49	402		34
50	437		36
51	494		41
52	460		38

Table C-6. Building 2 input data for Figure 8-5.

Week	**Number of personnel**	**Total area (10^3 m^2)**	**Number of personnel per 10^3 m^2**
1	647	18	36
2	665		37
3	645		36
4	665		37
5	649		36
6	645		36
7	665		37
8	644		36
9	654		36
10	661		37
11	672		37
12	673		37
13	686		38
14	673		37
15	664		37
16	686		38
17	673		37
18	675		38
19	693		39
20	668		37
21	686		38
22	689		38
23	671		37
24	697		39
25	673		37
26	703		39
27	688		38
28	692		38
29	680		38
30	693		39
31	669		37
32	713		40
33	716		40
34	684		38
35	721		40
36	702		39
37	666		37
38	700		39
39	713		40
40	721		40
41	743		41
42	735		41
43	716		40
44	723		40

45	709		39
46	744		41
47	749		42
48	729		41
49	738		41
50	761		42
51	728		40
52	740		41

C.2.2 Personnel per 100 customers

Benchmark: 1.1 personnel per 100 customers.

Table C-7. Building 1 input data for Figure 8-7.

Week	**Number of personnel**	**Number of customers (10^2)**	**Number of personnel per 10^2 customers**
1	499	360	1.38
2	489	360	1.36
3	492	367	1.34
4	507	365	1.39
5	483	357	1.35
6	487	359	1.36
7	480	364	1.32
8	479	356	1.34
9	457	360	1.27
10	469	360	1.30
11	460	372	1.24
12	468	362	1.29
13	464	369	1.26
14	462	366	1.26
15	459	357	1.28
16	443	363	1.22
17	438	362	1.21
18	463	370	1.25
19	465	354	1.31
20	449	361	1.24
21	457	355	1.29
22	445	367	1.21
23	455	364	1.25
24	440	361	1.22
25	446	350	1.27
26	434	341	1.27
27	445	368	1.21
28	436	358	1.22
29	452	370	1.22
30	455	357	1.28
31	444	362	1.23
32	441	367	1.20
33	443	358	1.24
34	437	361	1.21
35	431	359	1.20
36	445	360	1.24
37	434	365	1.19
38	423	362	1.17
39	432	358	1.21
40	436	385	1.13
41	432	359	1.20
42	430	366	1.18
43	426	374	1.14

44	424	364	1.16
45	417	354	1.18
46	433	362	1.20
47	441	367	1.20
48	429	356	1.20
49	402	367	1.10
50	437	372	1.18
51	494	359	1.38
52	457	365	1.25

Table C-8. Building 2 input data for Figure 8-7.

Week	**Number of personnel**	**Number of customers (10^2)**	**Number of personnel per 10^2 customers**
1	239	206	1.16
2	229	213	1.08
3	231	211	1.10
4	239	213	1.12
5	231	213	1.09
6	231	214	1.08
7	227	213	1.07
8	238	209	1.14
9	228	211	1.08
10	236	212	1.11
11	223	211	1.06
12	237	208	1.14
13	219	210	1.04
14	227	206	1.10
15	224	211	1.06
16	233	209	1.11
17	227	205	1.11
18	227	211	1.08
19	233	209	1.11
20	227	208	1.09
21	225	209	1.08
22	238	209	1.14
23	235	210	1.12
24	229	209	1.09
25	225	215	1.05
26	229	214	1.07
27	218	207	1.06
28	225	214	1.05
29	225	206	1.09
30	232	208	1.12
31	223	210	1.06
32	238	209	1.14
33	222	207	1.07
34	225	210	1.07
35	225	209	1.08
36	238	205	1.16
37	219	210	1.04
38	219	212	1.03
39	225	204	1.10
40	229	213	1.08
41	225	209	1.08
42	225	209	1.08
43	223	206	1.08
44	231	209	1.10
45	229	215	1.06
46	227	208	1.09
47	215	206	1.04

48	219	216	1.01
49	223	209	1.07
50	219	207	1.06
51	225	207	1.09
52	226	210	1.07

C.2.3 Number of Weighted Fire Safety Training Sessions per Year

Benchmark: 3.0 fire safety training sessions per year.

Table C-9. Input data for Figure 8-9.

Year	Number of weighted training sessions for building 1	Number of weighted training sessions for building 2
2009	4.05	3.11
2010	3.70	2.98
2011	3.90	2.68
2012	3.74	3.08
2013	3.98	3.24
2014	3.68	3.38
2015	3.58	3.84
2016	3.82	4.01
2017	3.29	4.00
2018	3.11	3.87
2019	3.24	4.20