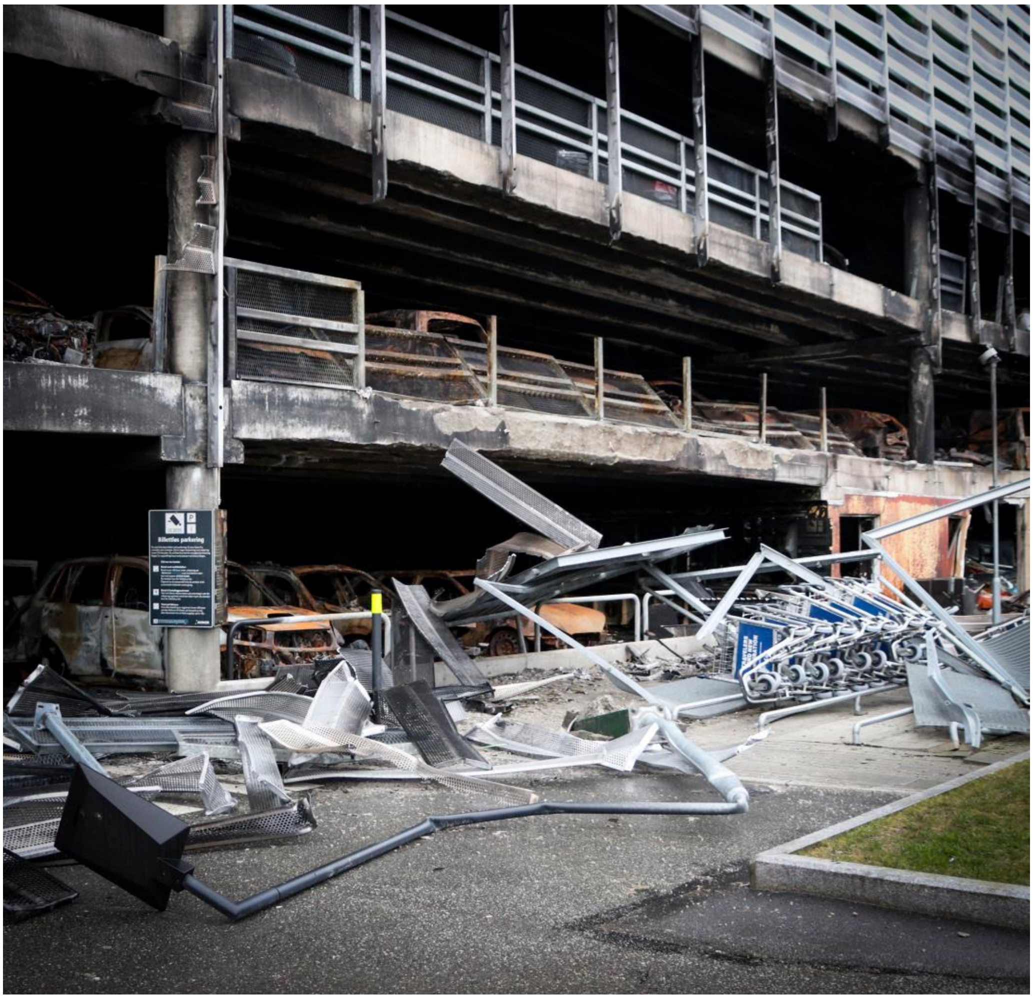
SAFETY & TRANSPORT
RISE FIRE RESEARCH



Evaluation of fire in Stavanger airport car park 7 January 2020

Karolina Storesund, Christian Sesseng, Ragni F. Mikalsen, Ole Anders Holmvaag (Norwegian Fire Academy), Anne Steen-Hansen

RISE-report 2020:91

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Abstract

This report is commissioned by the Norwegian Directorate for Civil Protection (DSB) and the Norwegian Building Authority (DiBK). RISE Fire Research has been commissioned to evaluate the fire in the multi-storey car park at Stavanger airport Sola on the 7th January 2020. The aim is to promote learning points for public benefit with regard to the extent of the fire, regulations, extinguishing efforts, structural design, effects on the environment and the role of electric vehicles in the fire development. Information has been collected via interviews, on-site inspection, contact with stakeholders, review of relevant regulations, documents and literature.

Design of the building: Active, passive and organizational fire protection measures have been evaluated. In our opinion, the multi-storey car park should have been placed in Fire class 4 ("brannklasse 4"), since it was adjacent to important infrastructure for society. The fire design documentation for building stages B and C has shortcomings in terms of assessment of sectioning, installation of fire alarm or extinguishing systems, as well as assessment of the fire resistance of the loadbearing structure. There are a number of inconsistencies that indicate that the fire risk has not been fully mapped and assessed in connection with the preparation of the fire designs.

Regulations: No deficiencies were found in the regulations relevant to this incident. Small adjustments in wording between different editions of regulations (e.g. guidance for technical regulations) can have a major impact on how the regulations should be interpreted. It is important that the authorities highlight such changes and that the fire consultant who develop a fire engineering concept avoid uncritical reuse of content from older fire concepts.

Handling of the incident: How the fire service and other parties handled the incident during the emergency phase has been evaluated, and learning points have been identified for the following areas (details in section 7.3): The basis for creating national learning after major events, action plans, exercise and training, collaboration and common situational understanding, management tools, call-out, information sharing and initial situation report, immediate measures, the goal of the effort and tactical plan, organization of the site, communication and collaboration, logistics and depots, as well as handling uncertainties and follow-up.

Electric vehicles: Water analyses of selected metals relevant for batteries in electric vehicles did not show any lithium, and only low concentrations of cobalt. This indicates that batteries in electric vehicles did not contribute to pollution of nearby water resources. Observations during the fire indicate that electric vehicles did not contribute to the fire development beyond what is expected from conventional vehicles. Further technical studies of the batteries from the burned electric and hybrid vehicles are necessary to evaluate whether batteries from electric vehicles were involved in the fire.

Environmental impact, extinguishing foam: During the incident, a lot of extinguishing foam was used, but this led to a limited environmental impact. The extinguishing foam was found not to add substantial amounts of PFAS during the extinguishing efforts. Analyses conducted by COWI still show PFAS content in all water samples, which is linked to previous emissions. Oxygen depletion as a result of release of extinguishing foam is considered to have led to local toxic effects on the aquatic environment, but not a general negative effect on the sea life in

Solavika. There is a need for stronger awareness of, and focus on the use of, extinguishing foams and logging of the amount of foam used. Here one may learn from Sweden.

Environmental impact, smoke: Smoke from the fire was mainly not driven in the direction of the terminal buildings, and during the first period only in the direction of areas with low population density. The fire smoke affected the evacuation of a nearby hotel. Eventually, the wind turned in the direction of areas with higher population density, and a population warning was sent out. Based on few health consultations (11 at the emergency room and 2 in hospital), as well as the municipality's assessment of the incident, it is assumed that the fire smoke had limited health consequences for neighbours. The smoke content has not been analyzed.

Finally; learning points from evaluation of the fire are relevant for many stakeholders, such as the fire service, authorities, construction design, for the owner and for research in the field.

Key words: Investigation, car fire, vehicles, electric vehicles, parking facility, parking garages, fire service, extinguishment, regulations, environment.

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Foreword

The car park fire at Sola airport 7 January 2020 is of considerable interest to many stakeholders. This evaluation was commissioned by the Norwegian Directorate for Civil Protection and the Norwegian Building Authority and had a limited mandate. Project objectives and framework are described in chapter 1 in the report, and the evaluation is based on information and sources to which we had access.

The project group at RISE Fire Research wishes to thank all contributors to the evaluation work, both those who took part in the inspection at the site of fire, in the collection of information, in interviews, and in professional discussions and assessments. A special thank goes to Ole Anders Holmvaag at the Norwegian Fire Academy, who is co-author to this report.

Karolina Storesund
Project Manager
June 2020

1 Introduction

In connection with fire at a car park owned by Avinor at Stavanger airport Sola 7 January 2020, the Norwegian Directorate for Civil Protection (DSB) and the Norwegian Building Authority (DiBK), wished to have an independent evaluation of the incident. The purpose was to create national learning and assess regulations relevant to the incident.

The DiBK and DSB respectively manage the Planning and Building Act (Norw. *Plan- og Bygningsloven*) with regulations, and the Fire and Explosion Prevention Act (Norw. *brann-og eksplosjonsvernloven*) with regulations.

1.1 Background

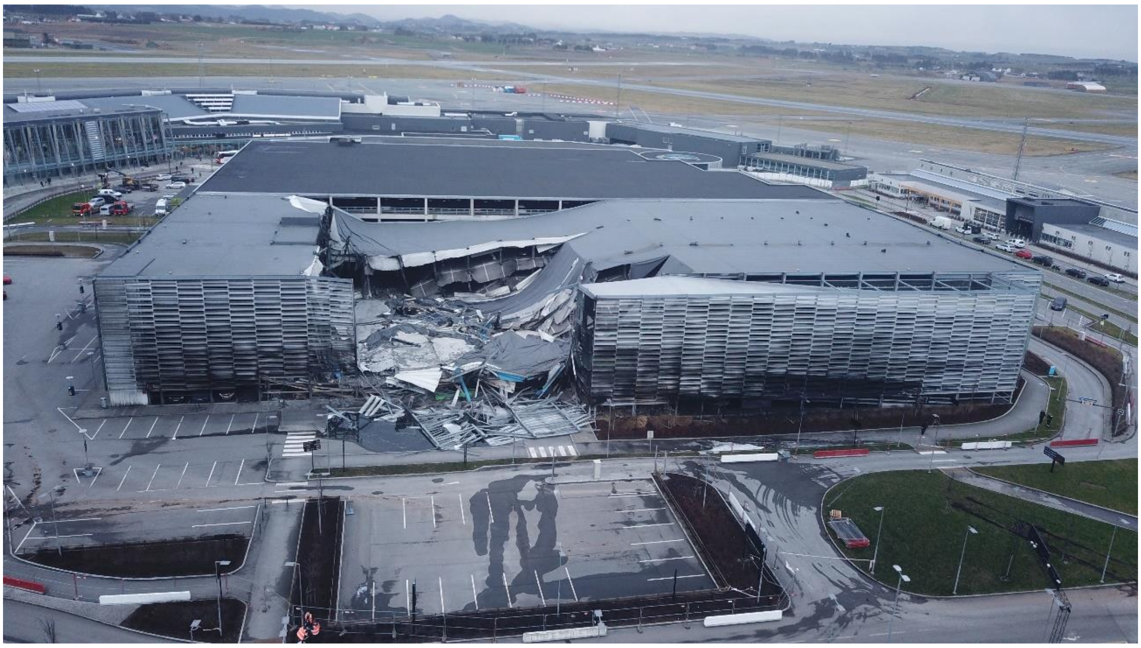

Figure 1-1 The car park at Stavanger airport Sola after the fire 7 January 2020. Photo: Nordic Unmanned.

On 7 January 2020 at approx. 15:25 hours a fire broke out in an Opel Zafira, parked on the ground floor in the car park at Stavanger airport Sola. The incident had huge financial consequences. The car park partly collapsed (Figure 1-1), several hundred vehicles were damaged, and the airport was shut down. Additionally, there were other safety related and financial consequences as a result of disruption of air traffic and spread of smoke to the airport area and surrounding areas.

1.2 Objective

The purpose of the evaluation was to promote points of learning for public benefit by identifying whether the relevant fire object and organization of fire protection complied with regulatory requirements, whether regulations are working as intended, and, if possible, to recommend measures aimed at preventing similar incidents in the future.

The objective was to evaluate why the fire became as extensive as it did, compared against regulatory requirements.

Issues of concern that are discussed:

- Was the construction designed and built in compliance with current building regulations? This applies both in terms of building characteristics, and arrangements and accessibility for firefighters.
  - If yes: Why did the fire become so extensive, and does it give a basis for considering rule amendments?
  - If no: Which elements were not in compliance with regulations, and how were any deviations documented? Which impact did any deviations and derogations have on the outcome and extent of the fire?

This was further evaluated against:

- Active fire protection measures
  - Which active fire protection measures were in place, and how did they work?

- Passive fire protection measures
  - Which passive fire protection measures were in place, and how did they work?

- Organizational measures
  - Which organizational fire protection measures were in place, and how did they work?

One aim was to evaluate extinguishing efforts, in order to ensure learning and identify any points with potential for improvement in emergency preparedness work that may impact on future incidents.

The extent to which the electric vehicles in the car park impacted on the magnitude of the fire was also evaluated.

1.3 Methods

A summary of regulations under the Planning and Building Act and Fire and the Explosion Prevention Act for the affected parts of the car park is found in 0. Two of the three parts of the building were damaged in the fire; which are designed with basis in the technical regulation from 1997 (TEK97), and technical regulation from 2010 (TEK10) respectively.

An on-site inspection and meeting with stakeholders were conducted 23 January 2020. Karolina Storesund and Christian Sesseng represented RISE Fire Research. Four persons from Avinor were present: our contact in connection with the case, two persons from the emergency organization (airport fire service), and one person from the Exterior environment department. From Rogaland fire and rescue IKS (hereafter referred to as «RBR»), the responsible leader in dept. of fire and explosion investigations took part.

A number of documents (e.g. fire strategy and supervision documents) have been reviewed. These documents were made available to the project by Avinor, the RBR, Sola Municipality, and the

County Authority of Rogaland. Additionally, some documents openly available online were reviewed. Reference to each document is stated continuously in the report.

Avinor is used as a source of information in multiple places in the report. This applies to information provided verbally during the inspection 23 January 2020, plus correspondence with contacts on e-mail and on the phone in February and March 2020. This information is in the report referred to as «according to Avinor».

The RBR's own evaluation report [1] following the incident was made available in April 2020, and was used as basis for assessing the extinguishing efforts. In addition to that, interviews of personnel attached to the RBR, the airport fire service, and police involved in the incident were carried out. Interviews were conducted online, and all interviews were taped and partly transcribed afterwards. Information from these interviews is rendered in the report. The interview program is enclosed as 0. Themes of the interview program were peer-reviewed by the educational section of the Norwegian Fire Academy. Findings in interviews were as far as possible compared with the available documents (as mentioned above), in order to provide a fair picture of the incident.

The data collection included interviews with six persons with six different functions (given in 0) in the incident. In some places quotes from respondents are used, put in italics and quotation marks.

1.4 Limitations

The first building stage of the car park (building A in the report) is only to a small extent dealt with in this study, since this part of the car park was not damaged in the fire, and was fully operative again the day after.

2 Description of the fire scene and incident

2.1 Stavanger airport, Sola

Stavanger airport Sola is Norway's oldest civil airport (opened in 1937), situated in Sola municipality approx. 14 km southeast of Stavanger. The airport operates both national and international flights, and has a helicopter terminal operating traffic to and from North Sea oil rigs. Figure 2-1 shows the airport and the surrounding areas, marked with points of interest. The car park is the building inside the horseshoe, which makes up the terminal buildings.

Figure 2-1 Overview of the airport areas, scale 100 m is indicated at the bottom of image. Map section from www.norgeskart.no (© Kartverket, CC BY 4.0), points of interest are given: The three different buildings of the car park, (A, B, C), terminal buildings (D), Scandic hotel (E), Clarion hotel (F), airport fire station (G). The orange asterix indicates where the fire originated. The image is oriented to the north.

2.2 Brief description of the incident

On 7 January 2020, at approx. 15:25 hours, a fire broke out in an Opel Zafira, parked on the ground floor at the car park of Stavanger airport Sola, marked with a cross in Figure 2-2. The car ignited a short time after it was started. Eight minutes later the *110-sentralen* (Emergency Operations Centre) received the first report of a car fire. Almost at the same time the Emergency medical response received an identical report. Both the municipal fire service and the airport fire service responded.

In the minutes that followed the fire service received a number of alerts about the incident. It was reported that the car park was full, and that there was a risk of the fire spreading to 3-4 vehicles. Not long after reports stated that around 10 vehicles were on fire.

Around 20 minutes after start of fire RBR reached the fire scene, starting to prepare for extinguishing efforts. After a further 30 minutes the airport closed to traffic, to allow the airport fire service to contribute to the response. Five minutes after that it was reported that the fire had spread to the first floor. Around 2 hours after start of fire parts of the car park collapsed.

Four hours after the start of fire the effects of extinguishing efforts became apparent, but the RBR were not able to finish their efforts until 6 pm the following day.

Some of the first phone messages received reported that an electric vehicle was on fire, and the police informed the media correspondingly at an early stage during the incident[1]. As a result of this electric vehicles were at the focus of media reports covering the incident, in particular during the first 24 hours.

No lives were lost, and no one was injured in the incident. However, the fire led to huge material damage to the car park and the several hundred vehicles parked at the car park at the time of fire. Figure 2-2 shows the areas (pink marking) of the ground floor that had structural damage, and the parts that collapsed (pink cross). Further, the fire had ripple effects on air traffic as the airport had to shut down.

[1] Ref: The police presentation at meeting with the County Authority of Rogaland 3 March 2020

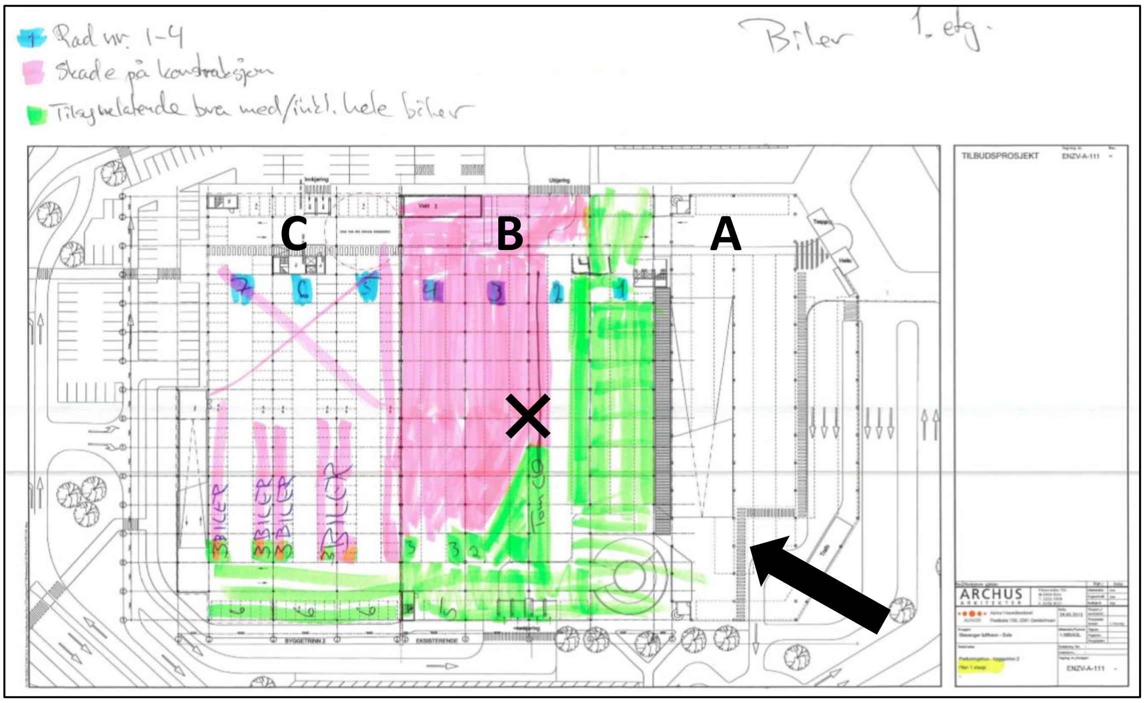

Figure 2-2 Sketch indicating areas on the car park ground floor with structural damage. Green indicates an apparently undamaged structure, while pink indicates a damaged structure. The pink cross indicates the collapsed area. The black cross shows location of the vehicle of origin. The arrow indicates the wind direction at start of fire (toward the north). The sketch was prepared by Nordic Unmanned on assignment from Avinor.

2.3 Climate and weather data

Typical wind directions and wind force at Sola airport through one year are shown in Figure 2-3. The climate data shows that the prevailing wind direction is from the north-west and south-east. The car park is located to the west and north-west of the terminal buildings.

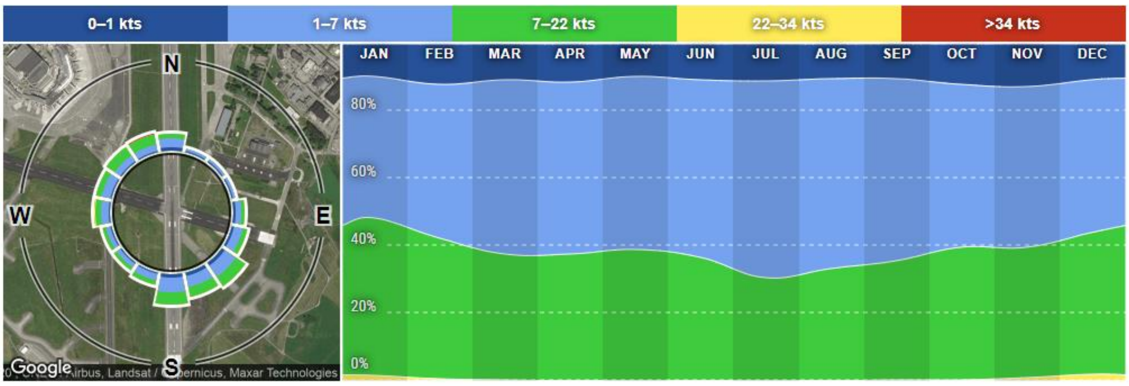

Figure 2-3 Climate data, wind direction and wind force stated in knots (*knots* – kts, 1 knot is 0.51 m/s) for months of the year, based on daily observations during the January 2002 – March 2020 period. Taken from: https://www.windfinder.com/windstatistics/stavanger_sola

Observed weather conditions at Stavanger airport on 7 and 8 January 2020 are graphically presented in Figure 2-4 and Figure 2-5. The fire started approx. at 15:25 hours. Weather information is taken from www.yr.no. At start of fire the temperature was approx. 7 °C and temperatures rose to 10 °C towards the evening. At night the temperature sank and was approx. 6 °C at 9 hours the next day. At start of fire the wind direction was from the south-southeast. Towards evening winds turned and came from the south-west. Wind force at start of fire was approx. 11-12 m/s (strongest gust of wind approx. 16-17 m/s), which corresponds to a strong breeze. The wind increased to a peak of 12.8 m/s (strongest gust of wind 19.3 m/s) at 18 hours, and then abated somewhat in the evening. At night the wind force was approx. 9-12 m/s. At start of fire there was some precipitation in the form of rain (0.5- 1.5 mm), which increased to 2.8 mm at 18 hours, then abating and increasing again, to 2 mm at 21 hours. After this and until the next morning there was little measured precipitation, maximum 0.3 mm at 4 in the morning.

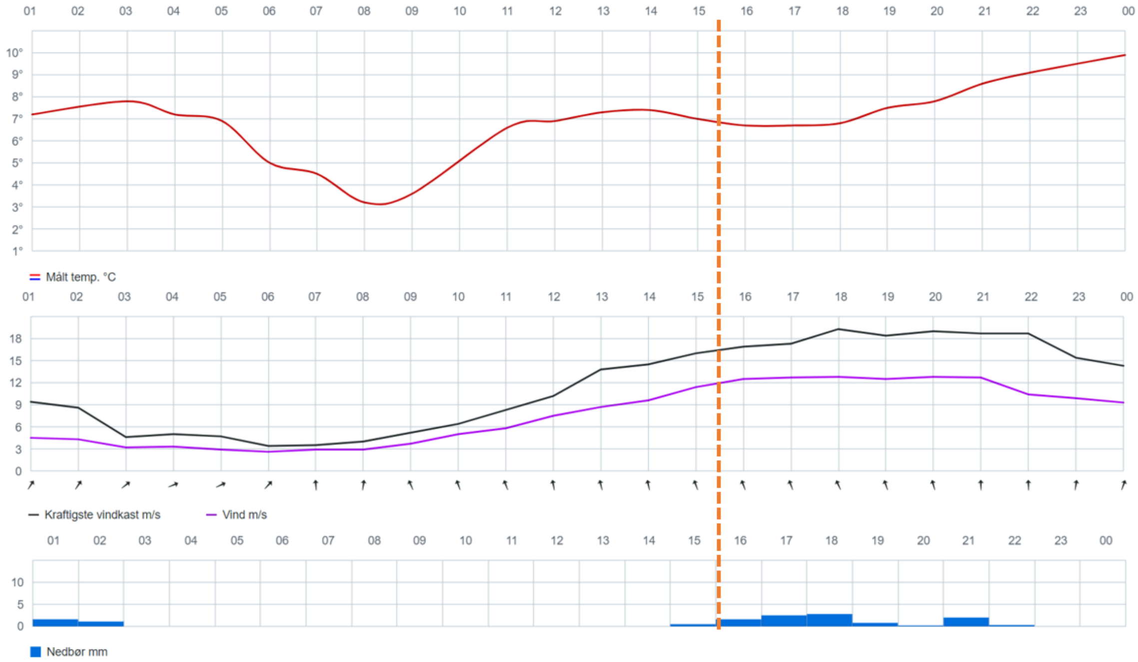

Figure 2-4 Weather data for 7 January 2020 from Stavanger airport weather station. Temperature (°C), Wind and strongest gust of wind (m/s) and Precipitation (mm). Fire start approx. 15:25 hrs. is marked by an orange dotted line. Source: [www.yr.no/nb/historikk.](www.yr.no/nb/historikk)

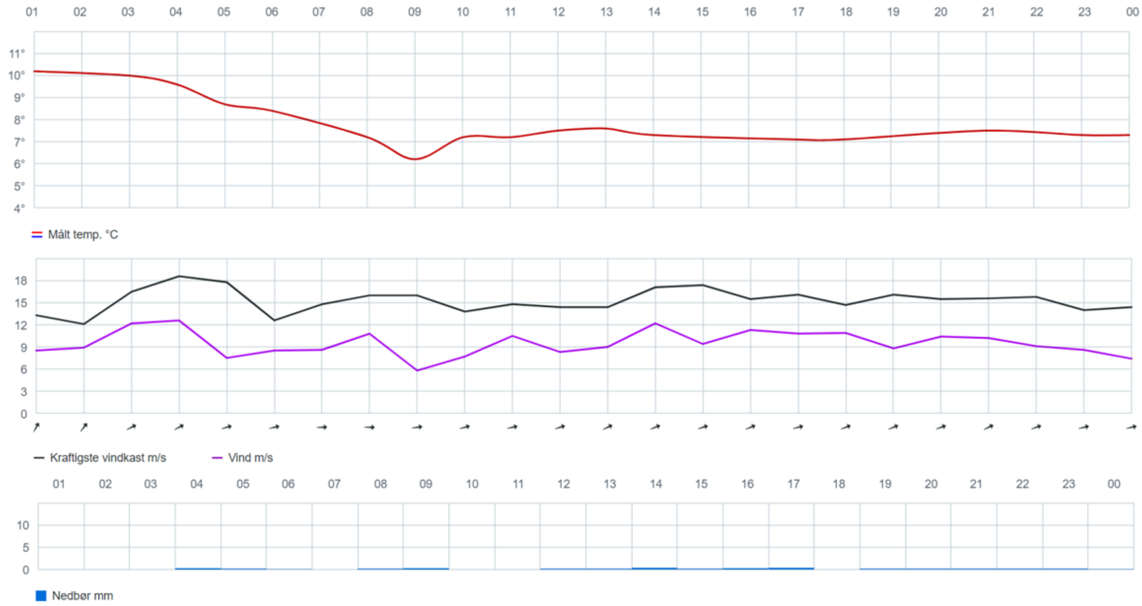

Figure 2-5 Weather data for 8 January 2020 from Stavanger airport weather station. Temperature (°C), Wind and strongest gust of wind (m/s) and Precipitation (mm). Source: www.yr.no/nb/historikk

3 Building and fire protection measures

3.1 Description of car park

The fire scene is a five-storey car park built in three building stages, marked A, B and C in Figure 3-1. The car park is the building inside the horseshoe, which makes up the terminal buildings at Stavanger airport Sola.

Figure 3-1 employs names A, B and C to refer to the different buildings. Other documents employ different numbering to refer to the various buildings. For example, buildings B and C are in some documents referred to as building stage 1 and 2 respectively, while being called building stage 2 and 3 in other documents. In this report we therefore opted to use letters to avoid confusion as to which building that is being mentioned.

Figure 3-1 Air photo of car park at Stavanger airport Sola. Taken from Gulesider.no. The image is oriented toward the north.

The building from building stage A (hereby referred to as building A) was first put to use in 1991 [1], and had a base of approx. 4 700 m^2 (estimated with basis in information provided in fire strategies for buildings B and C). The building from building stage A was not damaged in the fire, and will not be mentioned further in this report.

The building from building stage B (hereby referred to as building B) had a base of 7 800 m^2, and was taken into use in 2011. The fire started in this building. The building has five floors, executed in concrete elements with steel stabilizing framework. Originally, the designed fire resistance rating was R 15 for columns and R 10 for beams and girders (see section 3.1.1), however, solutions with a fire resistance rating of R 60were selected. [1]

The building from building stage C (hereby referred to as building C) had a base of 6 000 m^2, and was taken into use in 2014. This building also has five floors. The building is executed in steel main structure and deck elements consisting of steel plates and concrete. [1]

Fire strategies and further descriptions of buildings B and C are provided in sections 3.1.1 and 3.1.2 respectively. Figure 3-2 shows the facade of parts B and C of the car park after the fire.

Figure 3-2 North-eastern part of car park after the fire. The left section shows building B and the right section building C.

3.1.1 Building B fire strategy

Fire strategy for building B of the car park was prepared according to TEK97 with appurtenant guideline (4th version 2007, hereby referred to as VTEK97 for the sake of simplicity). Relevant regulatory provisions are rendered in 0, section A.2.2. The strategy employs a mix of pre-accepted performance level and analyses in those cases where VTEK97 is departed from. Table 3-1 summarizes the design prerequisites of the fire strategy. The fire strategy is summarized in this paragraph.

Table 3-1 Design prerequisites provided in the fire strategy for building B. Formulations are rendered in their entirety.

Prerequisite	**Criteria**
Building regulations	Technical regulation 1997 (TEK97)
Number of floors	5
Base	Approx. 7 800 m^2 for current stage.
Hazard category	RKL 2
Fire class	BKL 3
Enterprise classification	Not stated.
Occupant load	Design occupant load will be moderate, and will not be dimensioning for the detail design of escape routes.
Fire load	50-400 MJ/m^2, cf. recognized statistical values (NS 3478 and VTEK97).
Special risk, ref. table *Hazard category* in VTEK97	Not stated.
Location of adjacent buildings/boundary of adjoining property	To be established in conjunction with an existing open car park. Distance between them will be 4.8 m.

Local framework conditions (minutes of pre-conference)	No information has emerged suggesting that:
	• a safety level beyond regulatory requirements is desired
	• special measures beyond normal fire protection will be required or needed as a consequence of:
	  ○ abnormal use
	  ○ risk of explosion
	  ○ particularly high fire load or storage/use of flammable products
	• the municipality has set special fire prevention requirements in connection with the specific building application.

Special fire object	Not stated.
Response time of fire service	Under 10 minutes.

Load-bearing capacity and stability

Under the fire strategy the building must have a load-bearing capacity and stability as shown in Table 3-1. However, a solution giving a higher fire resistance rating of execution was selected.

Table 3-1 Specification of load-bearing capacity and stability of various building components in the car park for building B.

Building component	**Solution**
Columns	R 15
Beams	R 10
Flight of steps	R 30
Roof	R 0
Fire dividing structures towards staircases	R 60

Fire sections and fire compartments

Under the fire strategy there is no need or requirement for fire compartmentation of this type of open car park, as open wall surfaces will constitute at least 50 % of total wall surfaces. The facility is thus considered as being ”in the outdoors”, and a potential extension of the facility towards the north will not trigger new requirements for compartmentation, provided that the facility is designed in the same way as concerns openness of facades.

The strategy further describes that one staircase will be established, and that staircases and any technical rooms will constitute separate fire compartments. Fire resistance rating of fire compartments and appurtenant building components are rendered in Table 3-2.

Table 3-2 Specification of fire resistance rating in building B for various parts of the car park.

Building component	**Solution**
Fire resistance rating of fire compartments	EI 60, executed in non-combustible materials
Doors/hatches towards any technical rooms	EI 60S
Fire resistant doors towards staircases	EI 30CS

Materials and product properties in a fire

Under the fire strategy all cladding and surfaces in general must be executed in non-combustible materials.

It is stated that all insulation must be non-combustible.

The strategy further describes that pipe and duct insulation in general must be PII or better, and minimum PI in staircases[2].

Cable routing in staircases must not come to fire load more than 50 MJ per consecutive metres.

Measures to prevent spread of fire between buildings

As concern measures to prevent the spread of fire between buildings, the fire strategy states that the building is part of the existing parking garage, and that the distance to the existing parking garage (building A) will be 4.8 m. Further, it is accounted that there is no need or requirement for special measures to protect the building against spread of fire to or from neighbouring buildings. Moreover, the building will be located more than 8 m and 4 m from the boundary of adjoining properties and neighbouring buildings respectively, and that potential extension of the facility towards the north will not trigger new requirements for fire walls, provided that the facility is designed in the same way as concerns openness of facades.

Measures affecting time of escape and rescue

As concern measures affecting the time of escape and rescue, the fire strategy underlines that it is not a relevant option to sprinkle the building, and that there is no requirement for fire alarm installations.

Doors and exits from parking areas will be marked with illuminated exit signs. Staircases must be executed with Safety Wayguidance System.

As concerns arrangement for manual extinguishing, the fire strategy describes that portable hand extinguishers are sufficient, that *the equipment must cover* all areas, and that extinguishing equipment must be easily visible and marked according to applicable norms. The strategy does not indicate the number of extinguishers, and at which distance they are to be installed in order to *cover all areas*.

Arrangements for rescue crews and firefighters

The fire strategy also deals with arrangements for rescue crews and firefighters. The strategy states that «there will be a serviceable access for fire service’s material up to the building. The fire service will have satisfactory conditions for response through access to staircases, via car ramps, as well as access to each level by means of the vehicle’s aerial apparatus. Further it is commented: «The matter has been clarified with the local fire service».

Under the description 2 pcs. of 65 mm rising mains for the fire service must be installed at each of the two car ramps, with water outlet on each floor.

[2] PI and PII are old fire classes for pipe and duct insulation, which now have been replaced by classes provided by NS-EN 13501-1.

Deviations from pre-accepted performance level

The fire strategy states that a R 10 fire resistance rating for load-bearing beams is a deviation from VTEK97, which prescribes R 15 as a pre-accepted performance level. However, the strategy documents that the deviation is acceptable with basis in the grounds rendered below (the fire strategy's references are supplemented with reference to the reference list of this report):

1. A minimum of 50 % open facades in the car park is assumed, and no internal division by walls. This will prevent critical pressure and temperature build-up which may impact on the steel to an extent which may entail collapse before escape and rescue have been achieved. Flue gases with high temperatures will be ventilated and cooled through incorporation of fresh air. Long-term fire exposure of the load-bearing structure of a magnitude that causes the steel to lose its load-bearing capacity is therefore not very likely, even if it were to be directly exposed to fire. Reference is made to study ”Open-deck car park fire tests” /1/ (our ref. [2]) where the results of full scale trials document that the steel will not reach a critical temperatures. The trials do not take manual extinguishing efforts by the fire service into consideration, which further reduces the probability of a critical damage to the steel through fire exposure.
2. A potential collapse of beams locally across the fire scene will not entail collapse of the building at large. The most likely fire scenario is a car fire on one of the parking decks. Such a fire has a scant likelihood of spreading to other cars /1/ (our ref. [2]). Besides, there will not be other combustible material on the parking decks. This means in all probability that only a small local part of the load-bearing structure in the immediate vicinity of the burning vehicle will be affected.
3. The general public will be alert and in movement to/from exits. They will be quickly moving away from a potential car fire (which is the likely scenario in this case), before any beams are critically damaged by the fire.
4. The safety of firefighters is ensured through the given prerequisites. Whether the load-bearing structure holds out for 10 or 15 minutes does not change the response strategy of the fire service. They need to take the same precautions in both cases.
5. At a temperature of 500 °C the steel will have lost around 50 % of its (yield) strength. This is considered as the critical temperature range for most exposed steel structures /2/ (our ref. [3]). The steel's ability to absorb heat is of paramount importance when it comes to whether the steel will be able to reach a critical temperature of around 500 °C. The thermal conduction of steel structures is indicated by the emissivity ε_r /2/ (our ref. [3]). For an exterior column it is stated to be 0.3 /2/ (our ref. [3]),which means that the steel in exterior columns has a low ability to absorb heat. As concern interior beams with sheets on top, it is 0.5 /1/ (our ref. [2]). The emissivity for exterior beams is not stated, but we assume it will be as low as for interior beams, as a minimum. This supports the conclusions of the study mentioned in the first item. We have to assume that the background to the ”pre-accepted” reduction, e.g. an open car park, are the same favourable conditions described above.
6. Finally, we would mention the experiences derived from a fire under an open car park at the centre of Bergen in 2000. The fire started in a towed vehicle under the Bygaragen, which in its entirety is built in unprotected steel structures. After the fire, a state analysis of the load-bearing structures in the ground floor of Bygaragen, /3/ (non-defined reference) was conducted. These structures were directly affected by the fire. The fire service extinguished the fire after 30-45 minutes. The state analysis concludes that even though the fire developed considerable heat no damage was recorded to the main load-bearing structure. The secondary load-bearing structure was affected by the fire in that one of the secondary beams right above the fire scene had started to sag as a result of a weakening of steel strength. The load-bearing structure was exposed to a severe fire, much more extensive than a fire in a private vehicle. The steel was exposed to the fire for more than 30 minutes, without collapsing. This substantiates that, given

the conditions prevailing at the Sola car park; beams in untreated steel do not contribute to increasing the risk in fires beyond the functional requirement in TEK.

7. With basis in the fire strategy prerequisites of and the review above, we conclude that alternative solutions using beams in untreated steel with fire resistance rating ~10, are documented as meeting the relevant regulatory requirement provided in TEK § 7-23; " Load-bearing main systems in fire classes 3 and 4 must be constructed in a way that enables the building to maintain its stability and load-bearing capacity through the entire course of fire. Secondary structures and structures that are load-bearing only for one floor, or for the roof, must maintain their stability and load-bearing capacity during the period required to escape and rescue persons in and out of the building."

3.1.2 Building C fire strategy

The fire strategy for the last building stage of the car park was prepared in accordance with TEK10 with appurtenant guideline (hereby referred to as VTEK10 for the sake of simplicity). Relevant regulatory provisions are rendered in Appendix A. The strategy employs a mix of pre-accepted performance level and analyses in those cases where VTEK10 is departed from. Table 3-3 summarizes the design prerequisites of the fire strategy. The fire strategy is summarized in this paragraph.

Table 3-3 Design prerequisites provided by the fire strategy for building C. Formulations are rendered in their entirety.

Prerequisite	**Criteria**
Building regulations	Technical regulation 2010 (TEK10)
Number of floors	5
Base	Approx. 6 000 m^2 for the current stage, which gives an overall base of approx. 18 500 m^2.
Hazard category	RKL 2
Fire class	BKL 3
Enterprise classification	3
Occupant load	Occupant load will normally be moderate, as there are no areas where people will linger, and it will not be dimensioning for the detail design of escape routes
The fire load	50-400 MJ/m^2 total surface areas cf. Byggforskseriens blad 520.333.
Special risk, ref. table *Hazard category* in VTEK10	No
Location of adjacent buildings/boundary of adjoining property	Part of an existing, open car park. Distance to neighbouring buildings/boundary will be over 8/4 m.
Local framework conditions (minutes of pre-conference)	No information has emerged suggesting that: • Special measures beyond normal fire protection will be required as a consequence of: o Planned use o Risk of explosion • The municipality has set special fire prevention requirements in connection with the specific building application.
Special fire object	No
Fire service response time	Approx. 10 minutes.

Load-bearing capacity and stability

Load-bearing capacity and stability as specified in the fire strategy are rendered in Table 3-4.

Table 3-4 Specification of load-bearing capacity and stability of the various building components in the car park for building C.

Building component	Solution
Columns	R 15 [A2-s1, d0]
Beams	R 10 [A2-s1, d0]
Flights of steps	R 30 [A2-s1, d0]
Roof	R 0 [A2-s1, d0]
Fire diving structures towards staircases	R 60 [A2-s1, d0]

Fire sections and fire compartments

Under the fire strategy there is no need for requirement for compartmentation of this type of open parking garage, provided that there are at least 50 % open wall surfaces.

The fire strategy describes that the staircases defined as escape routes, and any technical rooms must constitute separate fire compartments. Fire resistance rating of fire compartments and appurtenant components are rendered in Table 3-5.

Table 3-5 Specification of fire resistance rating in building C for the various parts of the car park.

Building component	Solution
Fire compartments fire resistance rating	EI 60 [A2-s1, d0]
Doors/hatches towards any technical rooms	EI_2 60-S_a [A60]
Fire resistance rating of doors towards staircases	EI_2 30-CS_a [B30S]

Further it is emphasised that all doors with fire resistance must be executed with a threshold in order to obtain a satisfactory smoke tightness.

Materials and product properties in a fire

Under the fire strategy all cladding and surfaces in general must be executed in non-combustible materials. Further it is stated that floor surfaces in defined escape routes (staircases) must be class D_{fl}-s1 [G], and that roofing must be class B_{ROOF}(t2) [Ta].

It is stated that all insulation, including insulation in roof constructions, must meet class A2-s1,d0, which entails that the material must be non-combustible or combustible to a limited degree.

Combustible insulation is however accepted in classified sandwich structure or on concrete floors with integral cast. On this point the fire strategy refers to Byggdetaljblad 520.339.

Further it is described that «pipe and duct insulation must be non-combustible and meet class $A2_L$-s1,d0», but there is an exception for condensation insulation for cold water pipes and ducts where there is a risk of condensation, which have to meet class C_L-s3,d0 and B_L-s1,d0 in escape routes.

Measures to prevent spread of fire between buildings

As concern measures to prevent spread of fire between buildings, the fire strategy states that the building is part of an existing parking garage, and that the distance to neighbouring buildings is more than 8 m.

Measures affecting time of escape and rescue

As concern measures affecting the time of escape and rescue, the fire strategy underlines that there is no requirement for sprinkling the building or installing fire alarms, but it is recommended that the builder consider installing fire alarms due to the size and content of the facility.

Doors and exits from parking areas will be marked with illuminated exit signs. Staircases must be executed with Safety Wayguidance System. Fire safety installations in common areas must be clearly marked.

As concerns arrangements for manual extinguishing, the fire strategy recommends that the facility be equipped with a suitable number of hand-held extinguishers. How many a «suitable number» will be, is however not specified.

Arrangements for rescue crews and firefighters

The fire strategy also deals with arrangements for rescue crews and firefighters. The strategy states that «there will be a serviceable access for fire service's material up to the building. The fire service will have satisfactory conditions for response through access to staircases, via car ramps, as well as access to each level by means of its aerial apparatus. Further it is commented: «The matter has been clarified with the local fire service». [...]» This was presumably clarified through e-mail. It is further commented that «The email related to stage 1 (read: building B) and we consider the matter to be identical to stage 2 (read: building C)».

Further, it is provided that 2 × 65 mm rising mains for the fire service must be installed at each of the two staircases.

Deviations from pre-accepted performance level

The fire strategy states that a R 10 fire resistance rating for load-bearing beams and girders is a deviation from VTEK10, which prescribes R 15 as a pre-accepted performance level. However, the strategy documents that the deviation is acceptable with basis in the grounds rendered below (the fire strategy's references are supplemented with reference to the reference list of this report):

1. A minimum of 50 % open facades in the car park is assumed, and no internal division by walls. This will prevent critical pressure and temperature build-up which may impact

on the steel to an extent which may entail collapse before escape and rescue have been carried out. Flue gases with high temperatures will be ventilated and cooled through incorporation of fresh air. Long-term fire exposure of the load-bearing structure of a magnitude that causes the steel to lose its load-bearing capacity is therefore not very likely, even if it were to be directly exposed to fire. Reference is made to study ”Open-deck car park fire tests” /1/ (our ref. [2]) where the results of full scale trials document that the steel will not reach a critical temperatures. The trials do not take manual extinguishing efforts by the fire service into consideration, which further reduces the probability of a critical damage to the steel through fire exposure.

2. A potential collapse of beams locally across the fire scene will not entail collapse of the building at large. The most likely fire scenario is a car fire on one of the parking decks. Such a fire has a scant likelihood of spreading to other cars /1/ (our ref. [2]). Besides, there will be no other combustible material on the parking decks. This means in all probability that only a small local part of the load-bearing structure in the immediate vicinity of the burning vehicle will be affected.
3. The general public will be alert and in movement to/from exits. They will be quickly moving away from a potential car fire (which is the likely scenario in this case), before any beams are critically damaged by fire.
4. The safety of firefighters is ensured through the given prerequisites. Whether the load-bearing structure holds out for 10 or 15 minutes does not change the response strategy of the fire service. They need to take the same precautions in both cases.
5. At a temperature of 500 °C the steel will have lost around 50 % of its (yield) strength. This is considered as the critical temperature range for most exposed steel structures /2/ (our ref. [3]). The steel’s ability to absorb heat is of paramount importance when it comes to whether the steel will be able to reach a critical temperature of around 500 °C. The thermal conduction of steel structures is indicated by the emissivity ε_r /2/ (our ref. [3]). For an exterior column it is stated to be 0.3 /2/ (our ref. [3]),which means that the steel in exterior columns has a low ability to absorb heat. As concern interior beams with sheets on top, it is 0.5 /1/ (our ref. [2]). The emissivity for exterior beams is not stated, but we assume it will be as low as for interior beams, as a minimum. This supports the conclusions given in the study mentioned in the first item. We have to assume that the background to the ”pre-accepted” reduction, e.g. an open car park, are the same favourable conditions described above.
6. Finally, we would mention the experiences derived from a fire under an open car park at the centre of Bergen in 2000. The fire started in a towed vehicle under the Bygaragen, which in its entirety is built in unprotected steel structures. After the fire, a state analysis of the load-bearing structures in the ground floor of Bygaragen, /3/ (non-defined reference) was conducted. These structures were directly affected by the fire. The fire service extinguished the fire after 30-45 minutes. The state analysis concludes that even though the fire developed considerable heat no damage was recorded to the main load-bearing structure. The secondary load-bearing structure was affected by the fire in that one of the secondary beams right above the fire scene had started to sag as a result of a weakening of steel strength. The load-bearing structure was exposed to a severe fire, much more extensive than a fire in a private vehicle. The steel was exposed to the fire for more than 30 minutes, without collapsing. This substantiates that, given the conditions prevailing at the Sola car park, beams in untreated steel do not contribute to increasing the risk in fires beyond the functional requirement in TEK.
7. With basis in the prerequisites of the fire strategy and the review above, we conclude that alternative solutions using beams in untreated steel with fire resistance rating ~10, are documented as meeting the relevant regulatory requirement provided in TEK § 7-23; ” Load-bearing main systems in fire classes 3 and 4 must be constructed in a way that enables the building to maintain its stability and load-bearing capacity through the entire course of fire. Secondary structures and structures that are load-bearing only for one floor, or for the roof, must maintain their stability and load-bearing capacity during the period required to escape and rescue persons in and on the building.”

3.1.3 Control of fire safety strategies

The fire safety strategies for building stages B and C are both signed by a person with acceptance function, and has thus probably been subject to independent control as described in the guideline to regulation on form of procedure and control in building cases (SAK) from 2003 (see Appendix A). We have not had access to documentation showing whether an independent control of strategies has been carried out.

3.2 Fire inspection

Rogaland fire and rescue IKS (RBR) has on a regular basis conducted fire inspections at Sola airport, amongst other in 2015 and 2016. This in spite of the fact that the RBR in isolation did not consider the car park as a particular fire object, neither according to the Fire and Explosion Prevention Act §13, or local bylaws. Nevertheless, the RBR considered all buildings connected to the airport as one unit, and as one particular fire object, of which the car park was a part. Therefore, inspections of the car park were carried out.[3]

The purpose of such fire inspection is for one described in the supervision report dated 28 October 2015: *the purpose of the control was to evaluate whether the owner and user at the object are working systematically as concerns fire safety. The control comprised amongst other an examination of:*

- *whether the fire object is built, equipped and maintained in compliance with current laws and regulations relating to prevention of fire*
- *whether the fire object is available and facilitated for rescue and extinguishing efforts*
- *whether the internal control of the activity is expedient in terms of meeting goals in the area of safety*

Both inspections these years report of deviations in the form of «lack of agreement/ collaboration scheme between owner, lessee, and enterprises/users», and further that «the agreement/collaboration scheme is to define responsibilities and duties for organizational and practical fire prevention and safety measures». This is further addressed in section 3.2.2. The 2015 control also reported deviations relating to lack of risk mapping in connection with use of the car park, which is further addressed in section 3.2.1.

[3] Information given in talk with fire service representative.

3.2.1 Risk mapping

A deviation reported in the 2015 report was related to lack of risk mapping connected to the parking facility. The report bases the deviation on the following:

> *The inspection focused on mapping of risk elements in the use of the car park. The consequences of a car fire with subsequent spreading were discussed in this context. The car park is equipped with risers. These are inadequately marked, which means it may be difficult to grasp where they are located in a potential response /fire.*
>
> *Other aspects may be; Electric vehicles and gas operated cars (routines for charging, location and similar), plus traffic challenges relating to meetings between cyclists and pedestrians, and vehicles. The operation should identify risk elements relating to use of the parking facility, and if needed, implement measures (i.e. exercises and training).*

The year after, on 14 September 2016, a new inspection was carried out. The inspection report points out that work to correct the deviations of the previous inspection (see above) had been initiated, but that the deviations had still not been closed:

> *This issue has been pointed out in previous inspection reports. This year's inspection accounted for mapping and further progress, and it was stated that the cost level had delayed the process. The deviation will according to the owner be closed in a short matter of time. The owner has started the process of closing the deviation and needs three months to do this.*

In its reply to the RBR's inspection report Avinor on 28 December 2016 writes that it has prepared a r*isk mapping* of the car park, in which also the user of the building (Europark, who leases and operates the parking facility) has been involved. Enclosed with the reply is *Risikoanalyse Parkeringshus* (car park risk analysis), prepared by Multiconsult 23 December 2016 [4].

The risk analysis, which is based on NS 3901:2012 [5], categorizes a set of possible incidents with basis in the probability of their occurring and the consequences they may lead to. Probability is categorized as shown in Table 3-6.

Table 3-6 Definition of five probability classes used in Multiconsult's risk analysis [4].

Class	**Probability**	**Frequency**
1	Very unlikely	Less than once per 1 000 years
2	Not very likely	once per 100-1 000 years
3	Likely	once per 10-100 years
4	Quite likely	once per 1-10 years
5	Very likely	More than once per year

Consequences are categorized either with basis in personal injury, damage to material or reputation, as shown in Table 3-7, Table 3-8 and Table 3-9 below.

Table 3-7 Definition of five classes impacting on humans used in Multiconsult's risk analysis [4].

Class	**Consequence**	**For humans**
1	Limited	Limited personal injury
2	Moderate	Minor personal injuries involving medical treatment, medical certificate up to 16 days
3	Median	Personal injury involving medical treatment, medical certificate exceeding 16 days
4	Severe	Severe injury on one or more persons
5	Very severe	Deaths

Table 3-8 Definition of five classes impacting on facility operation used in Multiconsult's risk analysis [4].

Class	**Consequence**	**For operations**
1	Limited	No impact on operations
2	Moderate	Minor impact on operations
3	Median	Downtime in limited areas. Otherwise operation as normal.
4	Severe	Downtime in parts of car park
5	Very severe	Downtime in all or large parts of car park

Table 3-9 Definition of five classes impacting on reputation used in Multiconsult's risk analysis [4].

Class	**Consequence**	**For reputation**
1	Limited	Little/no risk of loss of reputation
2	Moderate	Little/no risk of loss of reputation
3	Median	Little/no risk of loss of reputation
4	Severe	Possibility of loss of reputation
5	Very severe	Risk of loss of reputation

The incidents are placed in risk matrixes with basis in which class one ends up with for probability and consequence respectively. An example of such matrix is shown in Table 3-10. If the incident is placed in the red zone, measures should be implemented to reduce the probability or consequences for the incident, so that the incident ends in the green zone.

Table 3-10 Risk matrix used in Multiconsult's risk analysis [4].

Frequency/Consequence	1	2	3	4	5
5					
4					
3					
2					
1					

The risk analysis lists seven different scenarios related to fire in the parking facility:

1. Car fire in connection with collision
2. Car fire in parked vehicle
3. Fault on electrical installations
4. Fire in technical rooms
5. Fire in transformer
6. Fire in parking office
7. Fire in hire car offices

In this connection scenario 2 is the interesting one. This scenario is further divided into electric vehicles, cars operated by gas and fossil fuel, and further into causes of fires such as technical fault, arson, and charging points (only applies to electric vehicles). All incidents were classified as probability class 3, except from *arson*, which is considered less likely, and was classified as probability class 2. This signifies that a fire in a parked vehicle is assumed to arise once per 10-100 years. As concerns the consequence class, all scenarios listed above were classified as consequence class 3: downtime in *limited areas, otherwise operation as normal*. The basis for the probability assessment relating to the scenario involving fire in cars operating on fossil fuel, is not provided. As concerns the assessment of consequence, reference is made to the fact that 80 % of all car fires in open parking facilities (the selection comprises incidents in Paris in the 90s) did not spread to the adjacent car [6]. The local wind conditions, and how they may affect a potential fire development, were not evaluated in this risk mapping.

3.2.2 Organizational fire protection measures

Organizational fire protection measures are operational, maintenance and emergency preparedness related measures implemented to handle fire safety. They are internal or external fire protection measures that are implemented by persons or organizations, and are planned activities, interaction and responsibilities between individuals in the organization in order to attain organizational goals. [7]

As mentioned above the supervision reports of 2015 and 2016 report on deviations in the form of «lack of agreement/collaboration scheme between owner, lessee and enterprises/users», and further that «the agreement/collaboration scheme is to define responsibilities and duties for organizational and practical fire prevention and safety measures».

The supervision in 2016 also had remarks relating to inadequate routines for monitoring and reviewing systematic safety work.

A respite until December 2016 was given to correct deficiencies and deviations, to which Multiconsult's risk analysis of the car park [4] (section 3.2.1) was a response. The analysis states that the building normally is manned around the clock (changed later, after the registration of vehicles became automatic). It is also stated that there was video surveillance in entrances and exits.[8]

Further it is stated that marked manual extinguishing equipment had been deployed in the car park in the form of 6 kg powder extinguishers. It is not stated how many and where they were located. «The rough analysis» of the risk assessment also mentions relating to defined risks that existing measures include powder extinguishers, but that no assessment is made of whether they may be used to extinguish car fires, or the likelihood of their being used for this purpose. [8]

It is stated that the fire service has access around the entire car park, and that the building is designed with the aim of all facades being reached with maximum deployment of hose line from the fire truck. [8]

Avinor's reply to RBR's inspection report of 21 January 2020 [9] states that the building does not have 24 hour manning owing to the fact that automatic sign recognition has been adopted. Avinor had taken over operation of the entire building when the partnership with Europark was discontinued in 2018. Avinor's airport service performs cleaning, marking, clearance and day-to-day inspection. Fire safety is handled by technical operations. Fire safety equipment was recorded in a system for follow-up of operations and controlled periodically. Video surveillance only covered the taxi stand and taxi line-up. Crisis management exercises relating to handling of the airport were conducted for tactical and operative staff. This was related to handling of air traffic and the public in an evacuation situation.

According to Attachment 1, fixed asset register [9] of Avinor's reply mentioned above, there were a number of powder extinguishers located in all floors as shown in Table 3-11.

Table 3-11 Number of powder extinguishers per floor in the different buildings [9].

	Car park 1 (A)	**Car park 2 (B)**	**Car park 3 (C)**
Floor	Number	Number	Number
1	4	6	5
2	4	7	5
3	4	7	5
4	-	7	5
5		7	5

An internal control of the Photo Luminescent Safety Wayguidance System was planned for every 6 months, a monthly check of the electric Safety Wayguidance System, and an annual check of electric emergency lighting equipment. Annual checks of fire alarm control panels by Autronica were also planned.

In its evaluation report conducted after the fire the RBR writes that the inspection of the airport area has been completed and reported, and that the issues have been closed in a satisfactory manner. There is a perception that Avinor has experienced the follow-up in a positive way, and that they have an adequate fire prevention and safety organization, with good management tools. The RBR is of the opinion that Avinor has handled and followed up deviations identified in the inspection in a satisfactory manner [1]

4 Fire in vehicles and parking facilities

4.1 Knowledge base on fire in vehicles and parking facilities

RISE Fire Research has published a number of publications [10–14] studying fires in vehicles and parking facilities. The publications primarily focus on enclosed rooms in parking facilities, mainly subterranean parking basements. Based on the overall information of these sources this section will present background information on fires in vehicles and parking facilities. See the publications for more detailed information.

Parameters affecting the spread of fire may be:

1. Heat radiation to adjacent vehicle, which depends on:
    - Size of fire and temperature, which again depends on the amount of combustible material
    - Distance between vehicles, which against depends on the width of parking spaces, width of vehicles, the number of vehicles present
    - The degree of enclosure (which again will impact on the size of fire and temperature)
2. The materials' critical heat flux for ignition
    - Material specific property (see examples of critical heat flux for different materials, table A.35 in SFPE Handbook of Fire Protection Engineering [15])
3. Time before firefighting measures are deployed, which depends on:
    - Time until detection and alert
    - Time from the response team is alerted until it is at work on scene of damage (including turnout time, response time and time for preparations)
    - Fire accessibility, including crew safety

In addition, there are external conditions, such as wind and ventilation. Ignited liquid fuel might also contribute to the spread of fire, and in this case technical building details, such as gutters to collect rainwater and wash water, might impact on the spread of fire.

The car park has changed, with modern cars containing more combustible materials than older cars. This may lead to more intense and long-lasting fires. Further, cars have on average become wider (e.g. a width of a Golf from 1983 is 1.7m, and from 2012 approx. 1.8m [4], while parking spaces generally have not become wider, which leads to cars being parked closer than in the past. Combined, these factors explain why it takes a shorter time today for the fire to spread from one vehicle than was the case before. This is supported by a study made by BRE in 2010, which compares modern cars with older ones. BRE's study suggests that modern cars contribute to a more intense course of fire than older cars, which gives a greater risk of the fire spreading to more vehicles [16].

[4] Source: https://www.auto-data.net/no/

Because of this change the historical assumptions on fire safety in open parking facilities are not necessarily valid today according to Collier, who in a report from 2011 [17] presents some examples of historical assumptions:

1. *It's unlikely that a fire in a vehicle will cause an uncontrolled fire in a parking facility. Anticipated damage to a parking facility will not be critical provided the facility is built in non-combustible materials»*

2. *The risk of fire in an open parking facility is very small. Exposed steel provides sufficient safety against building collapse in a fire*

The time it takes before the fire service can start extinguishing efforts may be linked to a number of different challenges connected with fires in parking facilities. Some of the challenges are:

- Great variation in geometry, safety level, size and so on
- Poor access –fire engine is unable to drive in
- Long distances – long hose line deployments
- Poor visibility – relocation takes time, it is easy to lose the sense of direction
- Potentially high heat
- Limited working periods per smoke diver (~20-25 min)

All this contributes to prolonging the time from start of fire until the fire service can start their extinguishing efforts. In general, it is difficult to indicate an accurate number as concerns the time expected from ignition until a fire spreads to an adjacent vehicle, or as concerns the expected extensiveness of the fire. E.g., a study by Watanabe et.al. [18] shows that in an external start of fire along the bumper, fire spread was observed along the outside of a Nissan Leaf approx. 9 minutes after start of fire (the study comprises only two full scale experiments with electric vehicles, in addition to diesel automobiles and fire tests of batteries). Lecocoq et.al.[19] found that the fire development in terms of heat transfer velocity and effective heat of combustion in two electric vehicles and two vehicles with combustion engine resembled each other, based on four full scale experiments. These experiments measured an increase in heat transfer a few minutes after ignition. Maximum heat transfer was reached approx. 15-35 minutes after ignition. More information on experimental studies of vehicles is collocated in reports [10,12].

The structure's fire resistance

As accounted for in sections 3.1.1 and 3.1.2 an assumed pre-accepted fire resistance rating of R 15 for load-bearing beams and girders is deviated from. The fire resistance rating is reduced to R 10, which is defended amongst others by referring to a study from 1985 [2], which shows that a car fire in a car park will not lead to the steel reaching a critical temperatures.

The motivation for conducting the 1985 study was that previous studies (conducted in 1968, 1970 and 1972) were considered as not being relevant. This was based on the increased use of plastic materials in cars (in 1985), and the fact that cars had become bigger, and consequently that the distance between parked cars had shrunk. The study conducted two tests in a two-story half-open garage construction (built for the tests). In the tests five cars were placed on each level with a reciprocal distance of 0.4 m. The fuel tanks of cars were 50 % full in the two tests, with the exception of the car where the fire originated, which in the second test had a fuel tank that was 80 % full. The results of the first test showed that the fire did not spread from the car where the fire started, and that the highest steel temperature recorded in the structure was 285 °C. In the second test the fire spread to two of the cars parked closest to the car where the fire started after 14 and 35 minutes, respectively. The highest temperature recorded in the steel structure was 340 °C. The study concluded that these temperatures provided a sufficient safety margin in a car park built in unprotected steel, meaning there is no need to implement safety measures. [20]

Since 1985 a number of studies have been conducted, where experiments with car fires in open and half-open parking garages are carried out. In 1999 Schleich et al. [20,21] carried out two experiments in an half-open structure of 85 m × 55 m × 3 m (length × width × height). In the test three cars were placed with a reciprocal distance of 0.5 m and 0.7 m, respectively. The experiments showed that the fire spread from the car of origin located in the middle to the two other cars, and the conclusion was that the distance between cars may impact on the time before the fire starts to spread.

Anon conducted in 2000 [22] an experiment in an open parking garage with measurements 32 m × 15 m × 3 m (length × width × height), according to information rendered by Li [20] (the original study is not available in English). Three cars were placed in the garage, where the car in the middle was set on fire. After 4 minutes the petrol tank began burning, and there was a petrol leakage, which again led to the fire spreading to the two other cars. After 15 minutes heat transfer peaked and after 35 minutes the fire died out. In the steel construction the highest recorded temperature was 650 °C above the point of origin. After the test, a 40 mm deflection in the steel was observed, and three destroyed bolts were found in connection with fastening a beam to the column. It was further assumed that wind had contributed to the fast fire development, however measurements of wind force and direction are not stated. The study concluded that structural stability was intact, and that there was no requirement for further measures.

Kitano et al. [23] conducted in 2000 an experiment in a four-floor parking facility measuring 30 m × 20 m × 10 m (length × width × height). Twelve cars were placed on each floor in lines of 2 × 6 cars. The fire was started in a car located on the ground floor. The fire spread, in the end involving seven other cars. After the test, steel construction deflections between 1/4 and 1/3 of what was considered critical value were observed. The study concludes there is no risk of structural collapse.

Zaho and Kruppa [24] conducted in 2004 similar tests, with the same test equipment as Anon, arriving at similar results. They concluded that unprotected steel constructions may be used in car parks without any risk of collapse in the event of fire.

In 2010 British BRE conducted a study of fire spread in parking garages [16], analysing fire statistics from Great Britain for the 1994 – 2005 period. One conclusion was that the majority of car fires in parking garages do not spread from the car of origin to more cars, and that the majority of fires do not spread to more floors. Further it is emphasised that once the fire starts spreading, becoming big enough, it might also spread between cars separated by free parking spaces. In such situations, where many cars are burning simultaneously, the fire will be aggravated owing to heat back radiation, and heat transfer rates over 16 MW might be reached from 2-3 burnings cars.

Automatic fire extinguishing systems in car parks

Studies examining the effect of automatic fire extinguishing systems on car fires in car parks show that such systems may have a good effect when it comes to delaying the development of fire and limiting the consequences. BRE in 2007/2008 completed a number of fire tests [16] where they amongst other examined the effect of sprinkler systems, showing that sprinkler systems may prevent fires spreading to other vehicles. They concluded that sprinkler systems definitely contribute to reducing structural damage. A different study [25] explored whether sprinkler systems and water mist systems might limit the fire spread between vehicles, and also concluded that both systems were capable of controlling the fire without temperatures reaching levels potentially damaging to the construction.

In both these studies the experiments were conducted in enclosed rooms without any wind impact. In a partially open car park where there may be some wind impact, it is conceivable that it is the downstream sprinkler nozzles that are released rather than a nozzle that for example is located right above the burning car. In this case it may be that water cannot be applied directly on the origin of fire, and that it will burn unaffectedly. Nevertheless, it is likely that downstream sprinkler nozzles will cool the smoke and moisten other cars, delaying the spread of fire.

Investigations

Next to experimental studies, an evaluation of other similar incidents might generate information on fire safety in open parking facilities. The last decades have seen a number of large fires in parking facilities, e.g. in Switzerland in 2006, where seven firefighters lost their lives in efforts to put out the fire in a parking basement, because the roof collapsed [17]. In Great Britain in 2006, 22 cars were destroyed and the fire spread to an adjacent nursing home, while the sprinkler system in the nursing home stopped further spreading [17]. In 2010 there was a fire in the car park at London Stansted airport, where 25 firefighters spent more than 2 hours to get control, while 24 cars were destroyed [17]. In France in 2014, 50 cars were burnt out in a parking facility, 80 firefighters spent several hours in extinguishing the fire, and it led to extensive smoke damage in a nearby theatre [26]. In Ireland in 2019 60 cars in an open car park were destroyed by fire [27]. It is worth noting that automatic fire extinguishing systems were not installed in any of the buildings where these fires took place

In 2017 there was a large fire in an open car park («Kings Dock car park») in Liverpool, Great Britain, where 1400 cars were destroyed. The evaluation report from the incident [28] points to the fact that:

- The fire will spread from vehicle to vehicle in a car park, both open and closed facilities.
- Sprinkler systems are effective both at controlling a fire during development and a fully developed fire. Without sprinkler systems the fire will probably spread from one vehicle to the next.
- Fires can spread from one floor to the next in an early phase of the fire, helped by water gutters
- Existing buildings regulations in Great Britain ought to be evaluated with basis in the incident.

Electric vehicles

As concern electric vehicles, the report « Charging of electric cars in parking garages» [29] refers to Norwegian statistics as well as international studies. It is stated that there is nothing to suggest that electric vehicles pose a greater fire risk than traditional cars (including probability of ignition as well as consequence of the fire). It is pointed out that the numerical basis is somewhat uncertain. Provided that the fire in an electric vehicle starts in a different part than the one used for charging, the fire will develop in the same way as in conventional petrol or diesel operated vehicles. Should the battery not be involved in the fire, the fire can be extinguished in the same way as in any other car. Battery cells are in general well protected, and there are barriers between the battery modules to prevent spread of fire. Should the battery be involved in the fire, a thermal runaway[5] in a battery cell will not be stoppable, and cooling is employed to the prevent thermal runaway from spreading. It may be tricky to get at the battery with water where required, since battery cells are well protected. Extinguishing such a fire will entail using water to extinguish visible flames, as well as monitoring and cooling by using water in periods without visible flames. The long duration of such battery fire gives a potentially high consumption of water to extinguish the fire. If the battery is involved in the fire, it is worth noting that this does not necessarily mean that the whole battery is included, and the rest of the vehicle can be extinguished in the usual manner. In each separate case it must be considered whether it is critical to let the burning vehicle remain where it is during extinguishing efforts. In some cases, it will be necessary to move the vehicle to a different location, for instance away from the parking facility.

4.2 The role of electric vehicles in the spread of fire

At a meeting with the County Authority of Rogaland 3 March 2020, the police informed the meeting that the first reports from the public suggested there was a fire in an electric vehicle. The police had informed as much to the media present at the incident. At start of the fire in particular, the media maintained a strong focus on the role of electric vehicles in the fire. This focused persisted for quite a long time, and media discussions on the theme were strongly divided.

However, at the inspection 23 January 2020 representatives of Avinor and the RBR stated that their impression from the fire was that electric vehicles had not impacted on the course of fire differently than what is to be expected in a fire involving conventional petrol or diesel cars. According to the RBR's evaluation report, no mentionable differences in intensity or duration of fire in the car park had been observed, and as of March 2020 no information had emerged «suggesting that thermal runaway occurred in electric vehicles» in the fire at Sola [1].

The different impressions held by the media and the RBR as to the involvement of electric vehicles in the fire, are in itself an interesting result of the incident.

No other information sources have been identified which can illuminate the role of electric vehicles in the spread of fire.

[5] «Thermal runaway» is uncontrollable heat generation in batteries over a short time

5 Handling of the incident in the emergency phase

A detailed timeline for the incident is provided in 0.

5.1 Basis for creating national learning after major incidents

Collection of information is vital in order to obtain a good and accurate picture of the incident. This part of the report employed a number of data sources to obtain an optimum picture of the course of fire and fire service response. Amongst others, six interviews with response personnel who had various functions in the response were carried out. Toward this goal the employees of the RBR were positive and committed, contributing with their experience, which is very useful to achieve national learning. When generating points of learning from an incident it is important that all available data be handed over to create learning from the incident. The fire service is also responsible for completing a so-called BRIS report (Norwegian acronym: Fire, Rescue, Reporting, Statistics) following an incident. We had access to this BRIS report, however, it contains very little information.

In working with this report, we were unable to access two data sources that we wished to review. These were a sound log and an unedited log from the emergency operations centre (vision log). It cannot be excluded that information (data) of importance to the evaluation might have appeared in these sources. Data that we wished to review are listed in Table 5-1.

Table 5-1 Overview of data basis collected from the fire service.

Doc.no.	Document name	Status
1.	Complete vision log (log kept by 110 operators based on reports from fire task leader)	Not handed over. Edited version received
2.	Timeline prepared by the fire service	Received
3.	Sound log (Digital sound recording of all communication traffic during the incident)	Not handed over
4.	Report "Evaluering av brann i parkeringshus. Stavanger lufthavn Sola."	Received
5.	Interview with fire/loss task leader (Avinor)	Completed
6.	Interview with police task leader	Completed
7.	Interview with brigadier	Completed
8.	Interview with incident commander (Chief fire officer on duty)	Completed
9.	Interview with emergency response leader	Completed

Doc.no.	Document name	Status
10.	Interview with duty officer at emergency operations centre	Completed
11.	Assistance agreement	Received
12.	BRIS report	Received

5.2 Response plan

Attachment 3 in the guideline to regulation on organization of fire service describes response plans, emergency preparedness plans and inspection, and how they should be designed (see appdenix A.1.3). Interviews and the fire service's evaluation report [1] show that there does not exist any response plan for the object or area.

The interviews reveal that the fire object is difficult to access for large vehicles. This was also the case for the first unit who encountered challenges during the deployment[6].

The fire service's report also shows that it was difficult to identify the ground hydrants around the airport. This was because they were connected to a privately owned water works, thus not being automatically stored in the system (Locus) to which RBR had access, independently of whether it was mapped in the fire safety design. A response plan would have mapped the location of and access to ground hydrants at the airport.

Moreover, the start of response was also challenging owing to a long response route[7]. The smoke divers entered with a so-called normal payout. Such normal payout has a 50m length from the branch pipe, but it turned out that the fire was more than 60m inside the building. As a result of this the smoke divers were forced to return to the outside of the building, without being able to start extinguishing. When the smoke divers came out, normal payout had to be extended by 25m. This took some time, since the payout first had to be depressurized and emptied of water.

> *"We agreed not to use the black hose, the medium pressure hose[8], as the response route was probably too long. Pulling it into the car park, only to find out that it's too short, we don't do that."*
>
> Interviewer*: "When you parked, from where did you take the water? Did you take it from the truck or did you hook up to the fire water supply?"*
>
> *Respondent: "No, we took it from our own truck ...and then we started at once, my driver and the driver in 1.2[9] to look for ground hydrants.[10]. This is a private area, which means the hydrants here are not on my map. On public roads, the hydrants are normally on the Locus maps[11].*

---

[6] Deployment – Access and setup for fire service response teams.
[7] Response route – Route selected by the response team in a real situation (kbt.no).
[8] Fire hose found on hose reel in fire truck, suitable for rapid water application from fire truck.
[9] Fire service vehicle, unit S.1.2. See appendix C for explanation.
[10] Fire water supplies.
[11] Data tools in fire engines.

They are marked with a sign on the walls, but I guess they're around ....12x15cm.. You'll have to be very close by to see it."

Interviewer*: "Was the fire water supply an encumbrance to you, did you fear running out?"*

Respondent: "Yes, it was a bit critical in the beginning. I guess that's normal. At that point we got round the Panter that was on the other side. It carries 12 000 litres. We hooked it up to our truck."

5.3 Exercise, interaction and common situational understanding

The interviews clearly show that the emergency service task leaders at all levels, and the emergency operations centre with a function in the incident, had a common understanding of the fundamental rules that apply to tactical prioritization (response theses, see section 5.4 below). They all concurred that lifesaving has first priority. In spite of this, misunderstandings arose in the communication between the police and the fire service as to whether there were missing persons inside the building.

The interviews revealed that no systematic exercises preparing for incidents had been performed with Avinor outside the air traffic area. There was therefore some uncertainty relating to common talk groups, capacity and striking power. An assistance agreement has been entered between Avinor and the RBR. Under the agreement the parties will exercise and interact in relevant actions. The agreement hardly mentions what is to be exercised, the frequency of exercises, and how interaction in a joint action is to take place.

5.4 Management tools and principles of task management

The training of fire and rescue personnel at the Norwegian Fire Academy has historically centred on four tactical basic rules (the four response theses). The four response theses are the basis of the technical and tactical training offered by the Norwegian Fire Academy to Norwegian fire and rescue personnel. Decision making tools taught at the fire academy are also based on the response theses:

1. Save lives: Saving lives and protecting health always have highest priority. Lifesaving is prioritized before material values. Eliminate the problem: If it is possible to extinguish the fire, this is to be carried out as early as possible, and with using maximum striking power.
2. Confine the problem: If it is impossible to extinguish the fire, the fire is to be controlled in order that harmful impacts on life, health and environment are reduced as far as possible.
3. Hold back: The risk of injury or loss of life of response crews must be in proportion to the expected gain of efforts. The assessment performed on site will principally consider whether the effort is lifesaving or not.

5.4.1 Tactical decision making models

The most central management tool in the training of leaders in the fire and rescue service has been «OBBO» [30] and the «seven-step model». Up until 2014 the Norwegian Fire Academy applied OBBO as a management tool for task leaders. It has now been replaced by the seven-step model with basis in the book on tactics written by Eriksson and Mattson [31].

OBBO is an associative word for a decision-making model used in Norway over a number of years, and which aims at helping personnel to remember an action pattern. The goal is to contribute to safe and efficient implementation of response.

O **Observe and find one's bearings at the incident scene.**

Lifesaving response, special hazards, etc.

B **Assess the situation at the incident scene.**

Is the risk of response in proportion to the lifesaving and damage-reducing potential?

B **Decide on organization of response.**

Determine tactics and protection of response personnel.

O **Orders to response personnel.**

Objective, distribution of tasks, particular hazards, and other safety measures, points of attack, and base points.

The seven-step model may be described as an extension of OBBO and will contribute to personnel remembering more details in an action pattern. The model is illustrated in Figure 5-1 below. In the sections below Figure 5-2, Figure 5-3, Figure 5-5 and Figure 5-7 to Figure 5-10 provide keywords relating to the various steps of the model.

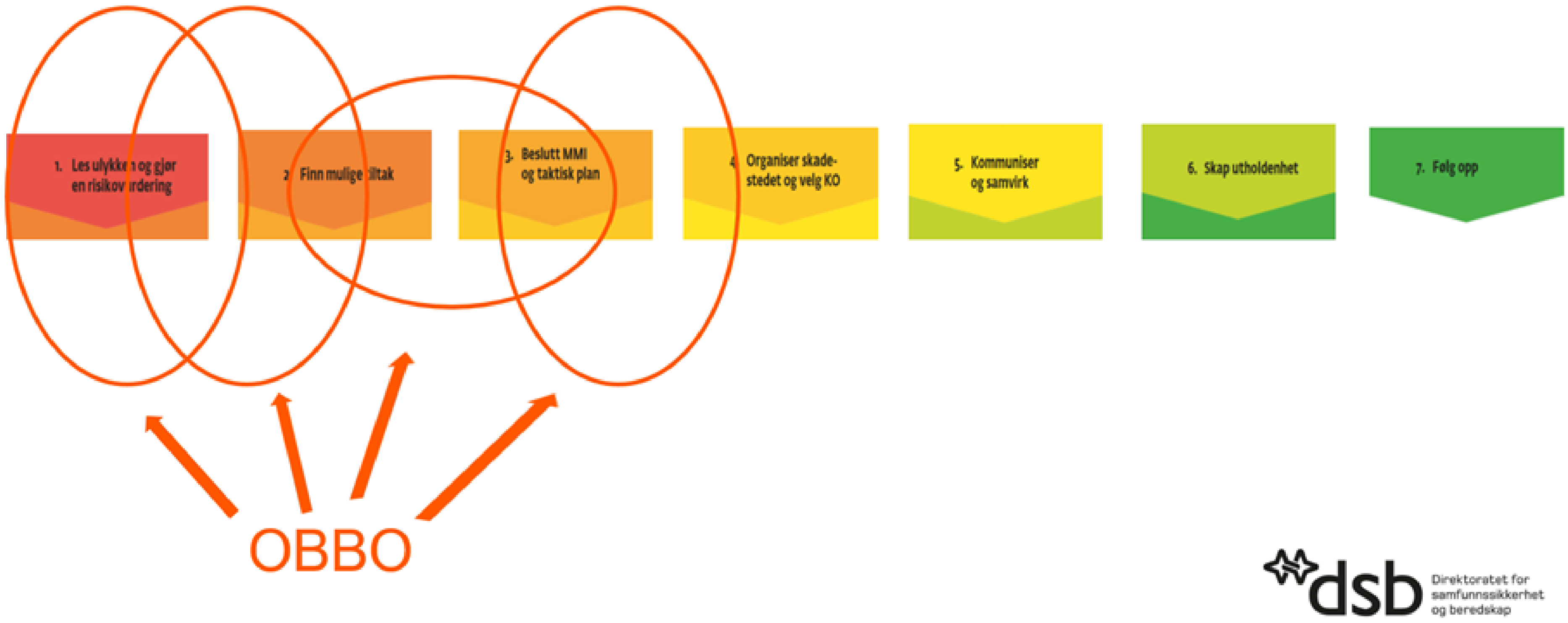

Figure 5-1 Figure developed by the Norwegian Fire Academy, based on the seven-step model (Taktikkboken, 2017). The various steps are: read the accident and make a risk assessment, identify potential measures, decide on MMI (purpose of response) and tactical plan, organize incident scene and select KO (Command point of task leaders), communicate and interact, create endurance and follow up [31].

Central in the seven-step model is MMI. MMI is conducted by the task leader with basis in steps 1 and 2, which are collection of information, processing of information, and an estimate of future status. MMI is communicated to response crews including the chief objectives of performing fire and rescue.

The models are not contradictory in any way, and both originate in approval-based decision-making models. The difference is that the seven-step model has a more proactive approach and uses other concepts than OBBO. It is a challenge that some task leaders received their training before 2014 and are trained within OBBO, while other task leader educated later are trained in the seven-step model. This may lead to confusion of concepts and misunderstanding when task leaders are working together during the operation. This aspect is supported in interviews with response personnel from the car park fire:

> *"I have a folder in the truck. I've got to use it one way or the other, but no one else grasps it."*

5.5 Call-out, sharing of information and arrival report in the emergency phase

The seven-step model is a central decision making and communication tool employed by the Norwegian fire and rescue service. The seven-step model describes an action pattern spanning from the point when the fire service is alerted about the incident, until the incident has transferred to the operating phase. The fire and rescue service rehearses and uses this model in fires and accidents, in particular where the situation requires a recognition-based decision making form. The seven-step model aims at helping task leaders to remember the chief elements in fires/accident when the situation requires quick decisions and actions, and it is therefore a suitable way of systematically evaluating the fire service's performance. In this chapter the seven-step model, step by step, is used as basis for the information that appeared about the fire service's handling of the incident, from which the points of learning will be derived.

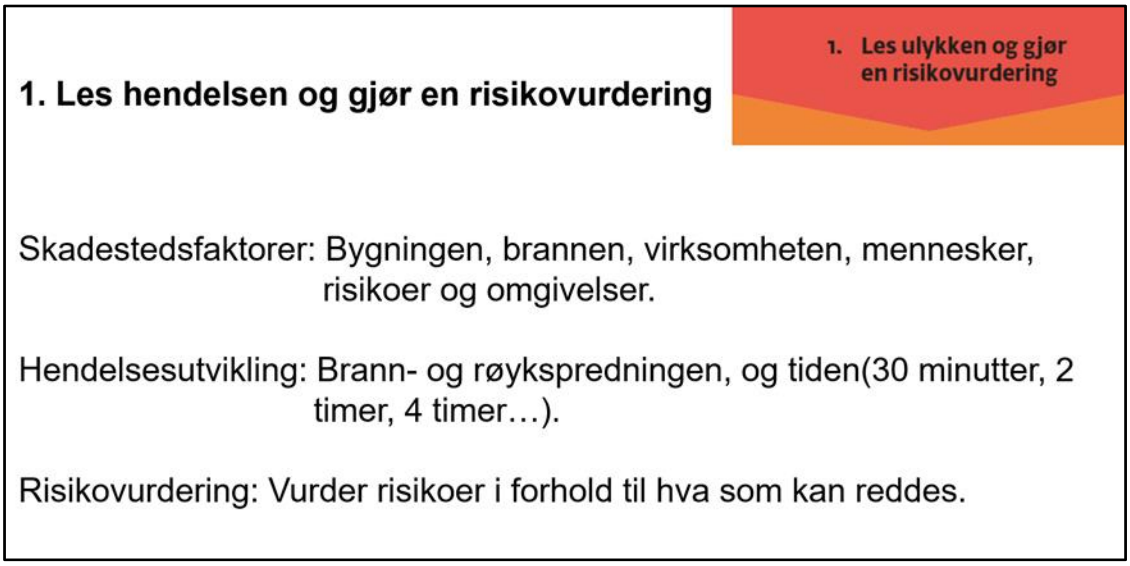

Figure 5-2 Step 1 in seven-step model [31].

5.5.1 Call-out

DSB and RISE did not get access to the sound log from the emergency operations centre. Nor did we get access to an unedited version of the vision log. According to the BRIS report, the incident type used on the first call-out was "car fire". According to several of those we interviewed, calling the type of incident a "car fire" led to the brigadier not being notified. When the type of incident was a car fire, only one crew unit was alerted. This is quite normal and in accordance with the pre-defined call-out instruction[12], but the 110-operator has the possibility of adding more units to the call-out. This was not done. Thereby a delay occurred in the call-out of the brigadier (S03) and Incident Commander (S01). Only when the emergency operations centre sent out a new call-out citing "fire in building" as type of incident, did all relevant units get a call-out. This point did not appear in the edited vision log that was submitted to us. According to interviewees the emergency operations centre in Rogaland changed this point after the incident.

According to interviewees there was confusion as to which radio channel Avinor could be reached on. The response leader was unable to contact Avinor in BAPS[13].

5.5.2 Arrival report and sharing of information

The police, the fire and health services must be able to interact with each other in an expedient manner [32]. In the arrival report, the police must provide information[14] about the scene and the incident relevant to the fire service, so that important factors for the response are identified as early as possible.

The police happened to be near Stavanger airport in connection with a different assignment. The police that were present dispatched a report in BAPS, but it contained little information about

[12] Call-out instruction is a pre-defined matrix prepared by the fire service which is submitted to the emergency operations centre. Call-out instruction describes which response the emergency operations centre should call out in a car fire, structural fire, traffic accident, etc.
[13] BAPS: (Fire - emergency medicine -police-interaction) (nodnett.no).
[14] E.g. information about the fire, fire spread, type of business, life/health, local conditions, etc.

incident scene factors, and was therefore not of much use to the other emergency bodies. From interviews it appears that the report was brief, and as follows:

> *"There is a fire. Call-out site – Heliport".*

5.6 Immediate measures

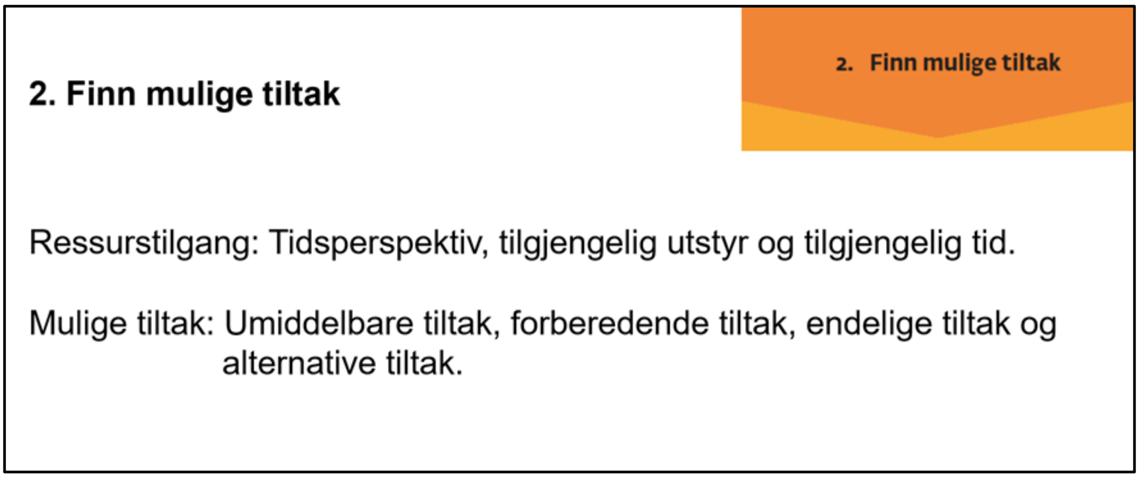

Figure 5-3 Step 2 in the seven-step model [31].

Immediate measures are often vital to the outcome of a fire. From interviews it appeared that the first unit from Avinor (Panter 1), decided that their immediate measure was to use extinguishing agent from the water cannon to suppress the fire. This is a cannon supplying up to 6 000 litres of water per minute. However, considering there were still people in the building who were being evacuated, this measure was considered risky to life and health. Other immediate measures were not evaluated. Avinor assisted the police in evacuating people from the building.

A flaming fire does not develop linearly along a timeline. It develops exponentially. The doubling principle is based on the fact that the flame height of fires in a combustible material has a given doubling time. If the doubling time is 60 seconds, the flame height will increase from 1m to 2m in 60 seconds. After another 60 seconds the flame height increases from 2m to 4m. After another 60 seconds the flame height increases from 4m to 8m, from 8m to 16m, from 16m to 32m etc. Examples are provided in Figure 5-4.

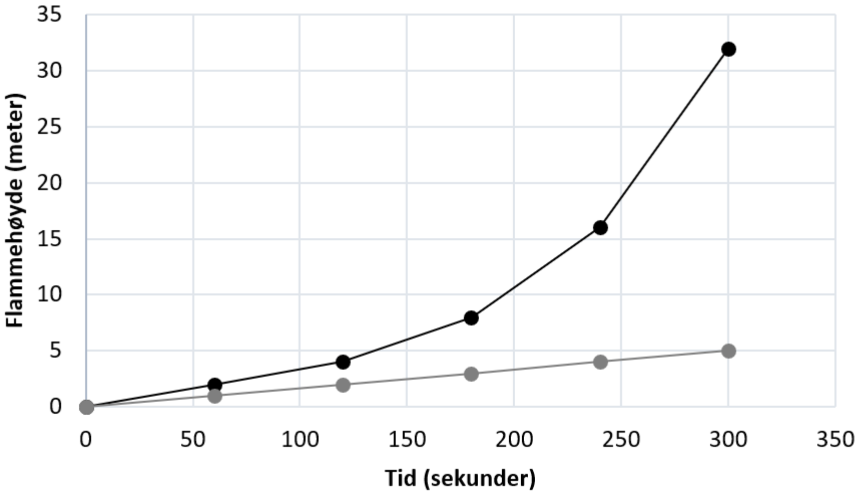

Figure 5-4 Illustration of how flame height can develop exponentially (black line), rather than linearly (grey line for comparison). The figure is based on the doubling principle described in text [33].

Two quotes from RBR respondents underline this aspect:

> *"When I look inside the car park….the moment I arrive, I get a slight feeling that … This is something we can actually manage to combat! Because at that point I see 4-5 burning cars. But then I go out, put on my jacket, two radios, BAPS and Brann 0, dressing takes a little time… I estimate...one minute, maybe two. When I walk towards the fire … I see ….ouf! This is lost!"*

> *"When you arrive at something as big as this…., you are the underdog. If I had all RBR's resources, to fight it from both ends, with the forces that were at play... there were 10 cars, after only a few minutes, 30... while we were setting up. It's maybe a bit arrogant to say so, but in order to achieve more, we should have arrived at the scene much earlier"*

Shortly after the arrival of the first Avinor unit, the first RBR unit arrived with a fire and rescue truck. This unit did not carry out any immediate measures. The assessment applied as basis that it was impossible to reach the fire with any kind of extinguishing agent. The initial measure made by this unit was to initiate smoke diver efforts using normal payout. This measure typically has a preparation time of 3-4 minutes. It is hard to determine the exact time of preparation, as the log to which we received access does not describe this point.

The interviews do not tell whether any preparatory, final and alternative measures had been assessed.

> *"It all happened so fast … No immediate measures were implemented."*

5.7 The goal of response and the tactical plan

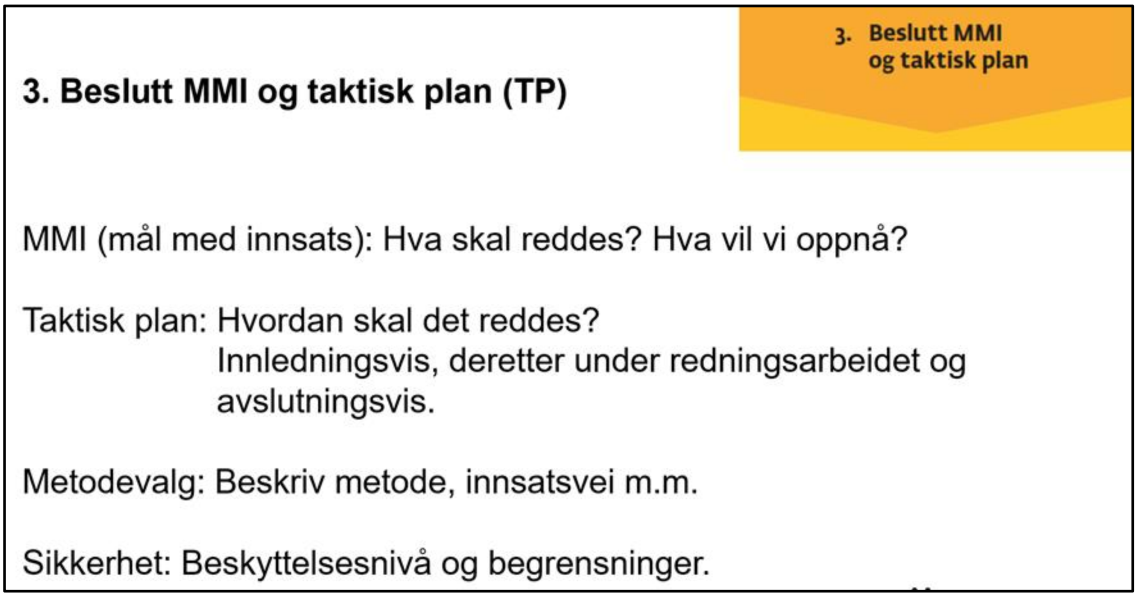

Figure 5-5 Step 3 in seven-step model [31].

The first RBR leaders who arrived, and the emergency response team leader from Avinor, maintained a definite focus on prioritizing life and health before extinguishing. However, misunderstanding arose between the police and the RBR on the status of evacuees and whether there where people inside the car park. It is important for emergency agencies to practice interaction and communication in the emergency phase. A common understanding of the situation may be vital to the response and the outcome of incidents. When time critical incidents occur, the decision makers (leaders) have room for manoeuvre only for a limited period of time. Owing to time pressure therefore, the leader is often forced to adopt an intuitive (recognition based) approach to the incident, in order that the room of manoeuvre does not disappear, because assessments and decision take too long. The problem of making quick, intuitive decisions is that the amount of impressions can be too small, see Figure 5-6. Defining the goals of efforts and the tactical plan are two tools that aim at helping the leader to make good intuitive decisions, and communicate these decisions clearly and unequivocally. These are further discussed below. The decision maker here has a dilemma. On the one hand one wishes to receive as much information as possible, on the other hand the decision needs to be taken as quickly as possible, in order to get several action alternatives. Management tools such as OBBO and the seven-step model are adapted to such dilemmas, and it is important that these tools be rehearsed and incorporated in the organization. It may seem as if the level of competence and use of management tools in general varies among leaders. Based on the interviews leaders do not have an equal understanding of the concepts and principles of the seven-step model. The challenge is typical for a number of fire services. Some have training in OBBO and others in the seven-step model. This means two decision making tools are used interchangeably. The organization ought to train leaders in the seven-step model, and make sure that everybody understands and is able to use the same concepts.

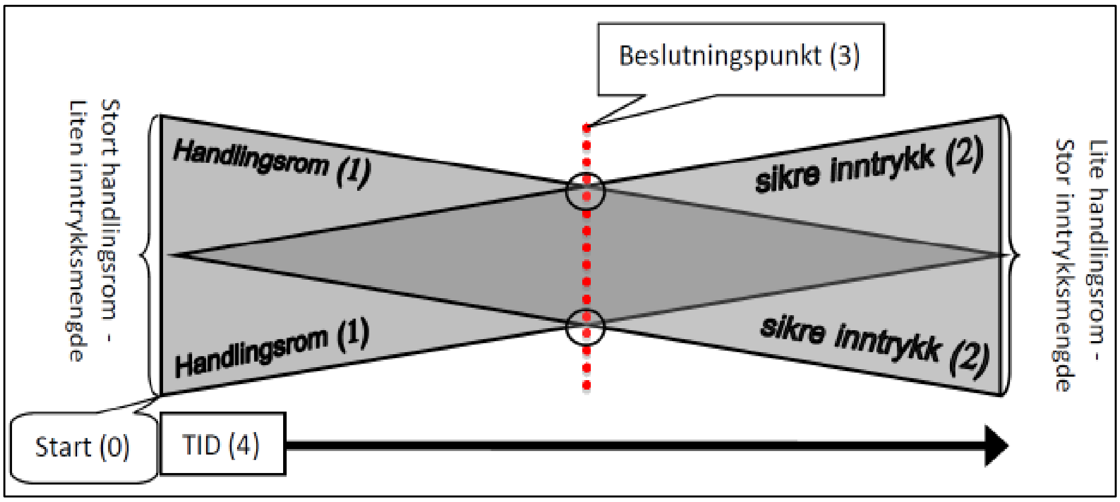

Figure 5-6 The relationship between room for manoeuvre (1), amount of information (2) and point of decision (3) along a time line [34].

The goal of response (MMI):

The purpose of deciding on and communicating MMI is as far as possible to ensure a common situational understanding and define the goal of response for the response team. This is particularly important when the incident is under time pressure and/or there are ambiguous circumstances, and/or much is at stake. In this incident the goal of response was not clearly expressed in the emergency phase.

Tactical plan (TP):

The purpose of a tactical plan is to help decision makers to assume a proactive pattern. A tactical plan is to obey the IDA mnemonic rule: (based on Norwegian Capital letters)

- «Initially we will…»
- «Then we will …»
- «Finally, we will …»

When the decision maker needs to consider a 3-point tactic relating to the future, the decision maker will adopt a proactive pattern. In a number of incidents one has seen that the decision maker acted reactively, because of considerable time pressure, complexity of the incident, and because the brain basically is reactive in terms of problem-solving. A tactical plan according to the IDA model was not expressed in this response.

5.8 Incident scene organization and task leaders' command point (ILKO)

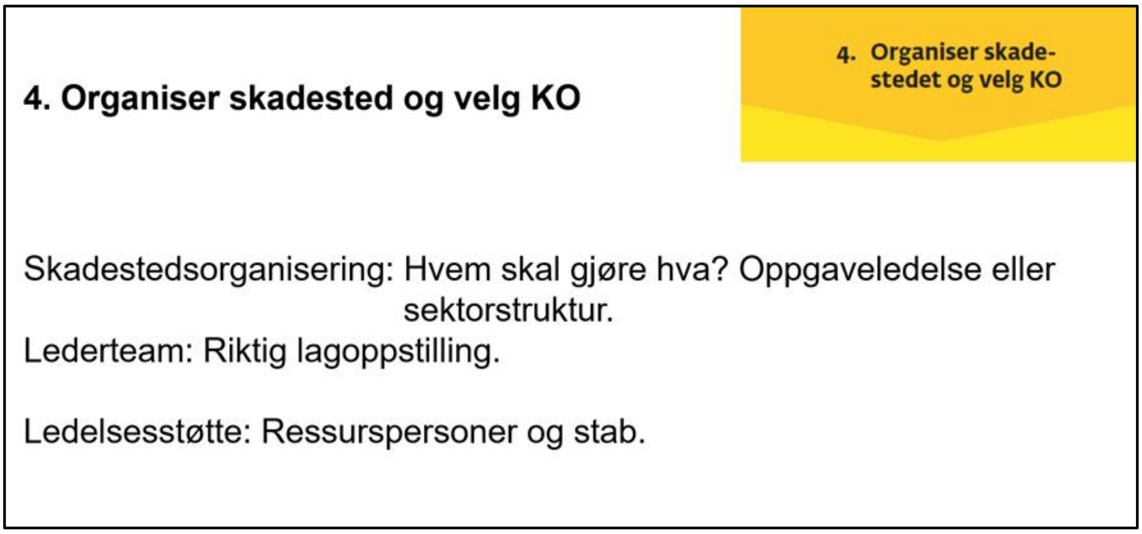

Figure 5-7 Step 4 in seven-step model [31].

Respondents were asked during interviews whether ILKO worked. There were diverging answers as to whether ILKO worked in an expedient manner. Some of the things that did not work, were that ILKO had too many participants, which made communication in ILKO a challenge. ILKO is normally led by the police task leader. It is important that the information flow in ILKO has a tight structure since there is a time pressure in the majority of cases where ILKO is established. Everyone staying in and near ILKO should have a good flair and timing for sharing information. In a structural fire the fire service's representative in ILKO is technical resource. It is important that there is room for the fire service's assessments and decisions in ILKO.

> *"In this case KO[15] was inside a restaurant, where almost everybody had access."*

In a major fire there will be several fire service leaders with roles in the fire scene (emergency response team leader, brigadier/task leader, Incident Commander/task leader). It is common for leaders to arrive at the fire scene at different times. It varies in fire departments who has the role of task leader. E.g. in some fire services it is the emergency response team leader, in others the Incident Commander. There must be no doubt as to which fire service leader is in charge of task management at any time. This ought to be clarified on the telecommunication circuit to ensure that the entire response team knows it, and that the emergency operations centre logs who is in charge, and logs any transfer of task management.

> *"We ought to be clear on this point. Because it's a typical thing...if there's one person in charge....and then someone else comes in who is*

[15] Editor's note: ILKO.

16.

ranked several grades[16] above...between myself and him there are many grades. So people tend to think, okay, now he has come, he's the chief. Then we must be clear on that point, that he's[17] still in charge of task management, and that N.N[18] is assisting him. We were not clear on that point."

5.9 Communication and interaction

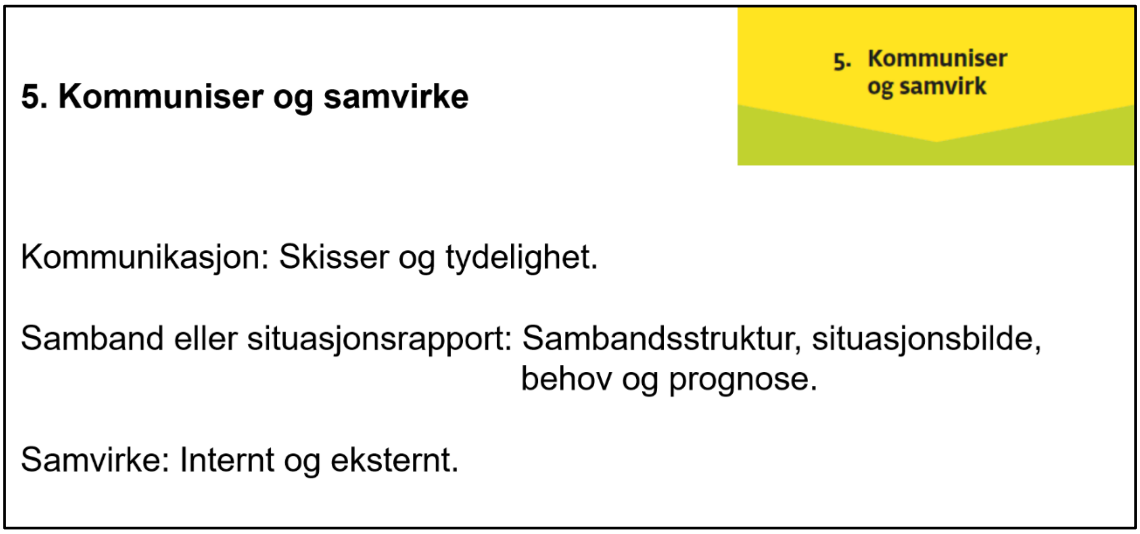

Figure 5-8 Step 5 in seven-step model [31].

The response team experienced considerable challenges in communicating with smoke divers. It appeared in interviews that the smoke divers were unable to receive or send information. This failure is ascribed to the fact that the telecommunication circuit equipment (microphone and loudspeaker) did not handle the noise level at the fire scene. This again meant that the smoke divers had to spend time in going in and out of the car park, to communicate and interact internally.

"They had to go out to her[19] when they needed to report on the telecommunication circuit, for it was useless talking on the telecommunication circuit."

"Were they not able to report on the smoke divers' telecommunication circuit"?

"No, there's so much noise, you don't hear a thing."

[16] Editor's note: Position rank.
[17] Editors' note: Brigadier.
[18] Editor's note: Incident Commander.
[19] Editor's note: Smoke diver leader.

"What takes time is that you can't communicate on the telecommunication circuit."

Interviews revealed that at one point during the incident it was uncertain whether there were people remaining inside the burning car park at the point when the RBR arrived on the scene.

"What the police said in the phase when we were able to start suppression ... at one point or other they said: The people are out of the building, or we have managed to get people out of the building. We were two leaders who thought the people were out of the building. At that point we initiated smoke diving. My orders were, start throwing water on it. Own safety first. But I should have understood that they couldn't have checked the building. After all it's 50 000 m ^{2} ... and the building hadn't been checked."

From the interviews it appears that Avinor and the RBR worked well together once the response had been properly started.

5.10 Logistics and depot

Figure 5-9 Step 6 in seven-step model [31].

Both the interviews and the RBR's evaluation report reveal there were challenges relating to logistics and depot. Set up and control of logistics and depot are decisive in the fire service's handling of major responses. Personnel and material get worn out and spent. It is not unusual for large fires to last up to 24-48 hours. This makes it all the more important that there is always access to breathing air, food, drink, extinguishing agent, and so on. It is usual for fire services to have storage and systems for replacement of personnel and material at the main station. Good logistics will be to make material and rested personnel available on the fire scene at an early stage.

"We should've done better, when it comes to sector 6[20]*. It's been an area where.... That's to say, logistics flowed, but it was very messy. For example, the loss-control dep. arrived*[21]*, where there were 12 smoke diver sets*[22]*. Of course, we didn't know anything about that... In my head the logistic division should've been called out"*

"*Which of the leaders had responsibility for sector 6?"*

"No, that never became quite clear."

5.11 Handling uncertainty and follow up

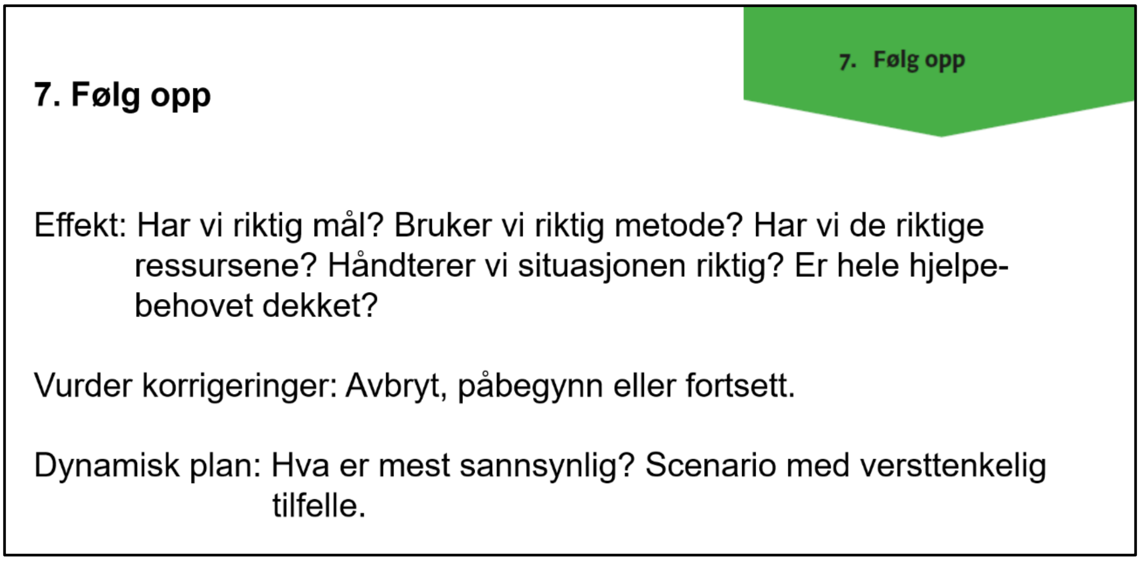

Figure 5-10 Step 7 in seven-step model [31].

In interviews it appeared that RBR task leaders were adept at and willing to evaluate themselves and the fire service during the incident. An example is the decision to change suppression tactics by using foam instead of water. The point when this was altered is not logged. Several vehicles in the car park were melting with subsequent leakage from fuel tanks, which resulted in the fuel from the vehicles going astray. This led to degassing of the fuel which ignited new areas. By using foam as extinguishing agent, "a cap" is paced on the fuel, and thereby the combustible degassing is eliminated. The decision to use foam might perhaps have been evaluated earlier. Foam has an inferior throw length compared to water. Avinor and RBR took advantage of the wind during the application of foam, to get an optimum effect of the foam. As it turned out, this had a good effect on suppression efforts. Several RBR respondents stated that it was not until foam was used as an extinguishing agent, that they succeeded in eliminating the problem, i.e. extinguishing the fire, gradually.

[20] Editor's note: Logistics and depot.
[21] Editors' note: Loss-control dep.
[22] Editor's note: Breathing air.

> *"There was no elimination until we decided to use foam instead of water. It was an interaction that we made in ILKO after a while. We lined up the trucks with the wind in our back. Then we managed to get an effect."*

Moreover, boundary lines were established at quite an early stage, which were evaluated and adjusted underway. The boundary lines were set with the purpose of keeping the fire within a tactically limited area. It occurs often that boundary lines are set which the fire service has to give up. In this fire it may appear that the boundary lines were appropriately set.

> *"Actually, we didn't need to take out as much as we did*[23]*. It's always better to give it a little extra....and have a plan B...which is what we did."*

[23] Editor's note Boundary lines

6 Environmental impacts resulting from the fire and suppression efforts

This chapter presents the environmental impacts resulting from the fire and suppression efforts, with a focus on emissions to air, water, and the ground. Environmental impact embraces the effects on the natural environment as well as neighbours. **Error! Reference source not found.** shows an aerial photo of the airport and adjacent areas, where the following points of interest are marked:

- Water treatment park with sediment basin and purification dam for overwater (H)
- Discharges to sea from a treatment park, in an open stream on Solastranden (I)
- Protected landscape area at Solavika with sand dune beach (J)
- Neighbours noticed in scattered and densely populated areas north and east of the airport (area outlined in map)

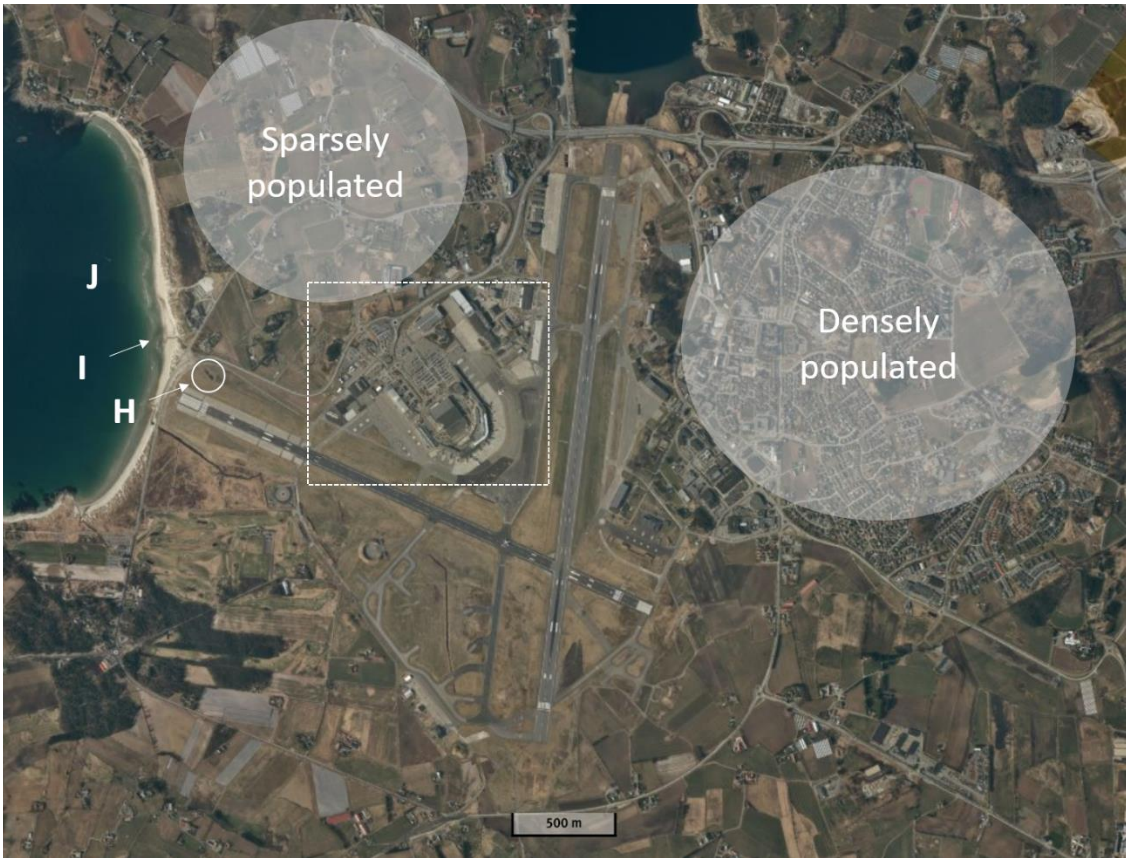

Figure 6-1 Overview of airport area, scale 500 m is indicated at the bottom. Section of Figure 2-1 is shown in frame. Map section from www.norgeskart.no (© Kartverket, CC BY 4.0), points of interest are indicated with letters, see explanation in the text. Image is oriented toward the north.

6.1 Water discharges

According to the municipality's impact analysis for Stavanger Airport [35], the airport borders on the protected landscape area Solavika with a sand dune beach in the west (item J in Figure 6-1). A plant protection area part of this protected area is located within the airport area. The airport area consists of filling compounds and levelled soil deposits, and the bedrock in the area is diorite-granitic gneiss and migmatite [35].

Avinor has a water treatment park connected to the airport area (item H in Figure 6-1). Drains from the parking facility are discharged here, amongst others. The treatment park has a treatment tank with two chambers, which also acts as an oil separator. Discharges from the treatment park go through a discharge point (item I in Figure 6-1), which makes it easier to control the water discharged. During the incident, oil film was observed in the treatment park at approximately 21:30, according to Avinor. As an immediate measure, a vacuum truck was ordered to remove oil the next morning, but at that point there was only a thin oil film in the sedimentation chamber and nothing to remove. There were reports of heavy precipitation that night and consequently high water levels in the treatment park. The municipality was notified of the oil film situation and placed oil booms in a stream at Solastranden (item I in Figure 6-1), according to the municipality's report on the incident [36].

Avinor has carried out regular inspections of the treatment park, streams and at Solastranden from the evening of the fire, up until and including 10 February, 2020 [37]. At the time of the inspection on 23 January, 2020, Avinor informed that daily samples were taken after the fire. Samples of sediment, ash and water were also taken near the parking facility to be checked for per- and polyfluorinated alkyl substances (PFAS) as well as lithium (with regard to fires in electric car batteries). The purpose of taking samples both of discharges from the treatment park and near the parking facility was to determine whether any effects on environmental toxins in the water can be linked to this incident, or whether it should rather be linked to background noise from previous discharges, for example from training grounds at the airport or the fire station of the airport (item G in Figure 2-1) from the time when foam with AFFF[24][25] content was used.

According to Avinor, they used two types of foam during the incident. Approximately 3.900 litres of foam of type RE-HEALING FOAM™ RF3 3% [38] was used, and approximately 760 litres of foam of type MOUSSOL®-FF 3/6 F-5 #7942 [39]. On the product data sheet of the former there is information about the level of acute and chronic toxicity, and it states that the foam is *harmful* to fish and invertebrates, *not very harmful* to algae and *not harmful* to activated sludge. Biodegradability in water is provided, and it is indicated that the foam does not contain bioaccumulative components. The product data sheet of the latter foam states the level of acute toxicity to fish, crustaceans, algae and cyanobacteria. The product is stated to be readily biodegradable. *Chemical oxygen demand* and *biochemical oxygen demand* are given (corresponding respectively to chemical oxygen demand (COD) and biological oxygen demand (BOD)).

According to interviews with the RBR and at a meeting with the County Authority of Rogaland on 3 March, 2020, the fire service brought approximately 200 litres of foam (assuming that this is foam concentrate, not pre-mixed foam liquid). According to an e-mail correspondence between the RBR and Avinor, the fire service has both A foam [40] and B foam [41] in the trucks, but it

[24] AFFF is an abbreviation for "Aqueous Film Forming Foam" [7], and is an example of firefighting foam that may contain PFAS.

is reported that only A foam was used from their trucks. The amount of foam used is not stated in the RBR's evaluation report [1]. According to interviews with the fire service, they were unsure whether the amount of foam they brought with them was enough for the effort and what the possibilities for refilling were.

The A foam product data sheet states that the product is physiologically harmless and easily biodegradable[25]. The product data sheet of the RBR's foam that was made available for the project, gave no information about fish toxicity, chemical oxygen demand (COD), biological oxygen demand (BOD), PFAS or details about biodegradation (such as rate of degradation). A product data sheet should as a minimum contain information on COD and BOD, as well as PFAS content [42]. The lack of information in product data sheets can make it difficult to evaluate the potential environmental impact of foam.

On an assignment from Avinor, COWI in the aftermath of the fire conducted water analyses from discharges from the treatment park. From this work analysis reports for dioxins and PFAS [43,44] and the report from COWI [37] were made available to RISE by Avinor. COWI's report provides details on analyses of dioxins and furans in water, an analysis of various PFAS, chemical oxygen demand, different metals (lithium, arsenic, lead, copper, zinc, iron), manganese, total hydrocarbons, various polyaromatic hydrocarbons (PAH) as well as BTEX (benzene, toluene, ethyl benzene and different xylene isomers).

Regarding firefighting foam, the report provides details on the content of BOD and COD in Avinor's foam, and the assumed content in the RBR's foam is stated. Based on the chemical composition of the types of foam used, COWI concludes that *no* significant amounts of PFAS were added during the extinguishing. However, PFAS was found in all the water samples analysed, and a possible explanation for this is stated to be "older deposits in infrastructure and ground that may have been mobilised by the large amounts of water used during the extinguishing work" [37]. COWI also studied oxygen consumption and based on this assessed whether the foam had an impact on nearby water bodies. Solavika is considered to be a robust water body, and the discharge would therefore not have had a negative effect on marine life. The release of firefighting foam is nevertheless considered to give the expected local toxic effects.

When it comes to the investigation of electric vehicles' involvement in the fire, analyses were made of metals particularly relevant for electric car batteries. Lithium was not found in the water samples, and only low concentrations of cobalt were found. Based on this, COWI states as a preliminary conclusion that "batteries in burnt out electric vehicles have not contributed to pollution". Other types of metals show low concentrations, which are not considered critical to the environment or to have toxic effects.

Overall, COWI considers that it was only the first days after the fire that the acute discharge had toxic effects. Measures to limit pollution in connection with the demolition or rehabilitation of buildings are also proposed. For more details about the environmental impact on water bodies, see COWI's report [37].

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[25] The following is stated on the product data sheet under "Environmental acceptability": "physiologically harmless and easily biodegradable".

6.2 Smoke emissions

Of nearby residential areas around the airport, there are scattered houses north and south of the airport and a more densely populated area in the east (Figure 6-1). As described in section 2.3, at the start of fire the wind came from the south-southeast, before it turned in the direction of the more densely populated area northeast of the airport throughout the evening.

According to the municipality's report on the incident [36], there was a lot of smoke north of the fire during the incident. No evacuation was carried out there. No closure of ventilation systems in Tananger-hallen, Haga primary school or Tananger lower secondary school was initiated, and the municipality informs that there is no reason to believe that this had health consequences for the users. At night, ventilation systems at schools and kindergartens in the centre of Sola (in the densely populated area east of the airport) were closed as a preventive measure.

The municipality further states that the police were in the process of evacuating the Scandic hotel (E in Figure 2-1) approximately 40 minutes after the start of fire [36]. This hotel is situated close to the incident site, north-northeast of the parking facility. During an on-site inspection on 23 January, 2020, it was informed that fire smoke probably triggered the fire alarm at the hotel, automatically opening the doors to the emergency exits. This caused smoke to enter the hotel. At a meeting with the County Authority of Rogaland on 3 March, 2020, it was announced that RBR during the afternoon carried out information rounds to nearby neighbours to inform about the incident. A resident of Rolighetsvegen (north-northwest of the airport) contacted the municipality's emergency manager after the incident, submitting the following report [45]:

> *"The cloud of smoke was literally right above the houses. You could see there was black smoke in the air one meter in front of you. We called the police around 17.00 hours and asked how we should act. They replied that they didn't know. It's strange that no one identified the location of the massive cloud of smoke and contacted the persons living in the worst affected area".*
>
> - Resident north-northwest of the airport

An emergency warning to the population was sent out by SMS at 20:10 (details about the entire timeline of the event in Appendix C). A warning to the population can be sent out to predefined districts (based on the national register), emergency action groups or to anyone within a geographical area (based on position in relation to base stations). The message sent out read: *"Due to a fire at Stavanger Airport, people have to stay indoors. Close doors and windows. Close ventilation systems. Stay tuned for information from the authorities"* [1]. According to a report from the municipality [36], it was the police who, in consultation with RBR, sent out the warning to the population via SMS to 21.500 mobile phones in an area around Stavanger Airport, based on mobile phones connected to the base stations. In the afternoon, in the hours following the fire, many in the municipality's emergency management were busy handling the centre for evacuees and relatives (EPS)[26], according to the municipality's emergency manager [45]. Whether the warning to the population should have been sent out earlier will be assessed in the municipality's

[26] For more details on handling of the centre of evacuees and relatives, see separate report prepared by the advisor for living conditions and EPS manager in the municipality [46].

evaluation of the incident. RBR's evaluation report concludes that the warning to the population should have been sent out earlier [1].

In total, the EMS communications centre in Stavanger had 11 consultations as a result of the incident, of which a handful were sent on to hospitals [36]. It is assumed that these were checked for possible smoke exposure, as no other physical injuries have been reported.

RBR points out that the wind direction this day was favourable and the consequences would probably have been greater if the wind had blown in the opposite direction, with fire smoke against terminal buildings, aircraft and helicopters [1].

We have not found any information indicating that measurements of the composition of smoke or other smoke analysis have been carried out in connection with the incident. It is therefore not possible to state anything about the environmental impacts on the natural environment as a result of emissions of fire smoke.

7 Discussion

7.1 Building engineering and execution

This section discusses whether the building's engineering, execution, and operation were in compliance with current regulations. The car park was built in three building stages which were put to use in 1991, 2001 and 2014, respectively, which means that current regulations were amended during the period. Building B from 2001 was designed according to TEK97 and building C from 2014 according to TEK10.

With fire protection measures are meant active measures (such as automatic fire extinguishing systems or fire alarm systems), or passive measures (such as use of non-combustible building materials and fire restricting structures with fire resistance). Given the buildings' overall base of 18 500 m^2 (and 13 800 m^2 for step B and C combined), more fire protection measures should have been implemented under the regulations.

Pre-accepted performance level provides a fire section limit of 10 000 m^2 on each level when the building is sprinkled.

7.1.1 Fire class

While fire classes 1, 2 and 3 are to be used for buildings where the consequence of fire is relatively *small*, *medium* or *large*, fire class 4 must be used where the consequence may become *very large*. VTEK10 underlines in the guideline to § 11-3 that «Buildings where the consequences of fire become very large to life and health, the environment or society in general, are to be placed in fire class 4». Further, it is underlined that the pre-accepted performance level that may be used for fire classes 1-3 cannot be applied in fire class 4 without verifying the safety level through analysis. As examples of buildings that should be placed in fire class 4, buildings where a fire may constitute a large risk to significant public interests are mentioned, e.g. infrastructure. An airport is an infrastructure which should be called significant public interests, a point which is also emphasized in VTEK10, under §11-1, fourth subsection.

In this case the car park is not the critical the object, but rather the adjacent buildings. The car park in this case represents the fire load and a risk, also in terms of smoke spread, to the adjacent buildings, which should trigger a requirement for fire class 4. In our opinion the car park should therefore have been placed in fire class 4.

By defining the building into fire class 4 a requirement for verifying safety by means of analysis would have been triggered, at the same time as the pre-accepted performance level would no longer be valid. It is therefore reasonable to believe that by conducting a thorough analysis a design for the building with a higher fire resistance rating than R 15 would have been selected (which incidentally VTEK10 for the selected fire class does not open for, see section 7.1.8).

7.1.2 Area

The fire strategies for buildings B and C refer to the fact that 50 % of wall areas will be open. This fact is used as an argument to show that flue gases will be vented out, and that the building can be designed with a lower fire resistance rating. The guideline to TEK97 allows this, but not the guideline to TEK10, where this option only applies to car parks in fire classes 1 and 2.

None of the guidelines state anything specifically about which base areas this applies to, but there is a requirement for each level to have a design that ensures good ventilation. Buildings B and C had bases of 7 800 m^2 and 6 000 m^2 respectively. The fire strategies state that the total base for buildings A, B and C combined was 18 500 m^2, which gives an estimated base for building A of 4 700 m^2. The fire strategies do not provide any assessment of the significance of the buildings' (which in this connection must be considered as one building) total base or shapes (including distance to facades) for ventilation of flue gases, and how this may affect the structure. Depending on where the fire starts, when the building base increases, there may potentially be a long distance to the point where flue gases can be vented. More about this point in section 7.1.5 Ventilation and wind.

7.1.3 Fire load

The fire strategy for building C states that the car park's fire load is 50-400 MJ per m^2 of total surface area. In this connection reference is made to SINTEF Byggforskseriens byggdetaljblad 520.333: «*Brannenergi i Bygninger – Beregninger og statistiske verdier*» [47]. This detail sheet has later been renamed 321.051: «*Brannenergi i bygninger. Beregninger og statistiske verdier*» (Fire load in buildings. Calculations and statistical values) [48]. The fire strategy does not indicate how a fire load between 50-400 MJ/m^2 has been arrived at, nor does the detail sheet give any specific indication for car parks or parking garages. What appears to be most relevant, is the value for a car dealership, which is stated at 200 MJ/m^2 (per floor space), even though there are differences between a car dealership and a car park. In a car park there will potentially be more cars, and they will be standing closer. Because of this fire load in a car park will probably be higher. Additionally, a car park with vehicles may have high concentrated loads (in series), which to a large extent exceed the average value which is specific fire load. This should have been evaluated in the fire strategy.

7.1.4 Spread of fire

As discussed in chapter 4, after 1985 a number of studies have been performed and published on the issue of fires in half-open car parks. The fire strategies should therefore have employed newer references in order to reflect the knowledge front related to spread of fire between vehicles, and structure response at the point when engineering was carried out.

This being said, the majority of studies performed and mapped in this report are coincident: spread of fire between vehicles may occur (even if this according to statistics seldom occurs), but it poses no risk of building collapse. It is conspicuous that the mapped studies merely discuss the results of fire in the experiments using a limited number of vehicles, without evaluating and problematising the consequences and effects of the presence of more vehicles, which expectedly will be found in a real car park. An exception is the BRE's report, which states:

> *There were only a limited number of cars in each of the tests (a maximum of four); however escalation to many cars within a specific proximity in an actual car park must be expected under these conditions).* [16]

The BRE's report does not discuss the potential effects of heat development on the car park structure in such a case, but it must be assumed that the structure would have become more damaged than what is seen in the mapped studies.

Nor do any of the studies to any large extent problematise and discuss the way in which winds might have impacted on the fire development. Anon [22] mentions, e.g., that winds may have contributed to an acceleration of the fire development they noticed in the trial in an open parking garage, but there is no discussion as to what this may signify for a fire in a real car park.

Building details, such as gutters to collect rain water and wash water, may also have contributed to fire spread by spreading liquid fuel. The RBR mentions this point in its evaluation report [1], and it appeared in our interviews with response personnel from the RBR (section 5.11) that liquid, non-ignited fuel floated to other rows of vehicles, and that ignited degasses from fuel contributed to the spread of fire.

7.1.5 Ventilation and wind

Wall openings will prevent build-up of pressure in the event of fire, but potentially long distances between the fire and the ventilation point will lead to smoke being trapped over a longer period of time, and covering a larger area, which again leads to build-up of temperature.

When the fire at Sola erupted, wind from the south-southeast was blowing with a gust speed between 11 m/s – 19 m/s. This corresponds to winds ranging from a fresh breeze to a gale. When walls are partly open, the wind may impact on the fire development in that more oxygen is carried to the fire zone, making the fire more intense than what it would have been without wind. Moreover, the wind might impact on the fire so that spreads easier to combustible materials downstream. In this case one saw visible evidence that this had happened, a fire fan, in the damaged car and the collapse of parts of building C, see Figure 2-2 on page 12. In a smaller car park, where the smoke is vented out much faster, and where there is a limited number of parked cars, the wind will probably have a smaller impact. As far as we can see, previous studies have not investigated at which base areas this starts to be become a problem, and research is required in order to provide a better decision-making basis for fire safety engineers. In case of Sola, with a base of approx. 18 500 m^2, the wind will act as a bellows. This accelerates the spread of fire and enables the fire to maintain a high intensity throughout the entire course of fire, only limited by a potential lack of combustible materials. A car park at an airport will typically have a high occupancy rate, so that there is good access to combustible materials (cars). The fire strategies did not look into this aspect.

If the wind direction on the day of incident had been from the west or the north-west, more smoke would have blown toward the densely populated area in the east, potentially resulting in more severe consequences for the population. It would also have resulted in more smoke blowing in the direction of the terminal buildings, which could have led to larger consequences for the terminal, even damaging aircraft. It is not improbable that this might have happened, since these are two of the most prevailing wind directions at the airport (Figure 2-3). It might therefore be relevant to use climate data in the risk analysis relating to the car park's location compared to the terminal buildings, and whether one may expect fire smoke to have consequences for airport operations. Climate data was not evaluated, neither in the fire strategies nor the risk mapping prepared by Multiconsult (see section 3.2.1)..

The heavy wind did not *only* have a negative impact during the incident. Even if the wind contributed to the spread of fire, it also helped the RBR and Avinor to use the foam more effectively, by making it possible for them to exploit the wind during application of foam (see section 5.11).

7.1.6 Arrangements for firefighters

Point 4 in the fire strategies' argumentation for allowing deviations states as follows:

> *4. The safety of firefighting crews is ensured through the given prerequisites. Whether the load-bearing structure holds out for 10 or 15 minutes does not change the fire service's response strategies. They need to take the same precautions in both cases.*

The wording in the guideline to TEK97, allowing the fire resistance rating of the main load-bearing system to be reduced from R 90 to R 15, assumes that the building has sufficient stability and load-bearing capacity in order to ensure *the necessary time for escape and safety of firefighters.*

Floor height in the building is 2.86 m including floor separator. This gives an effective ceiling height of around 2.5 m. The response trucks are typically 3.1 – 3.3 m high, according to the Norwegian Fire Academy. During response it is not common for the fire service to drive its own trucks into a burning building, but the low ceiling height in combination with the angle of the water jet coming from the response truck, limited the amount of extinguishing agent that hit where it was intended.

All response internally in the building was done manually. The RBR's smoke drivers had a very long response route. Interviews revealed that the response route was approx. 60-70m long, which became an obstacle to the application of extinguishing medium. What is more, the evacuation route for smoke divers was long as well, which lead to an enhanced risk in terms of collapse. The RBR chose at an early stage to withdraw its crews to ensure their safety.

Since the guideline to TEK97 allows fire resistance of the load-bearing structure to be reduced from R 90 to R 15, it signifies a relaxation of the performance requirement. There is no longer a demand for the building to hold up during the whole course of fire, but to hold up sufficiently long in order to allow persons to evacuate the building. Regulations thus accept that structural fires may result in building collapse. This must be seen against fire service safety, and whether it was ensured. The load-bearing capacity, however, must be seen in the light of which expectations or assumptions were made with a view to the fire service's response tactic.

The fire strategy for building B refers to e-mail communication with the fire service, where the RBR confirms that concerns relating to their response have been taken into consideration. The fire strategy for building C refers to the same communication and argues that the fire service's acceptance also must apply to building C, the buildings being quite similar, but that this was not confirmed. It thus appears that the RBR was not given an opportunity to give a specific statement about building C, in spite of there being differences of execution (steel instead of concrete etc.). It should be added that by carrying out building stage C, the base area is increased by 43 %, which might affect the fire service's response prerequisites.

The argument that firefighting crews need to take precautions regardless of whether fire resistance rating is R 15 or R 10, suggests that the fire strategy does not expect the fire service to be able to, or need to, perform any particular extinguishing efforts, and therefore that the fire resistance rating may be reduced further. This view is probably based on the fire consultant's assessment, which did not find very likely that the fire would spread from the origin (car) of fire, and that the total structural load would not be critical.

7.1.7 Active fire protection measures

The fire strategies for building B and C underline that there is no requirement for sprinkling of the building or for fire alarm systems to be installed. In the regulations the purpose of an automatic sprinkler system is to prolong the available time for escape. Similarly, the purpose of a fire alarm system is to reduce the time needed for escape. Installation of fire alarm systems may also entail a reduction in the need for compartmentation. Further, a risk analysis or cost-utility analysis may identify that installation of a fire extinguishing system or fire alarm system is appropriate for financial reasons, but there is no requirement for this in regulations.

However, for building C the fire strategy recommended that the building owner consider the installation of a fire alarm system owing to the size and content of the building. Whether this recommendation was motivated by personal safety concerns or safety for material values is unknown. Considering that the fire safety engineer applies the building's size and content as basis for this recommendation, it suggests that the fire safety engineer saw a certain risk of a major car park fire. However, this is incompatible with the argumentation for reducing the resistance of the load-bearing structure, where the argument is that the car fire will not spread, and that the car fire is not sufficient to weaken the structure to a degree where there is a risk of collapse. The fire strategies are therefore inconsistent, which suggests that the risk of fire was not fully mapped and evaluated in connection with preparation of fire strategies, neither as concerns personal safety nor safety for material values.

Automatic sprinkler systems

Under TEK10 with guideline, the pre-accepted performance level is basically a fire alarm system or automatic fire extinguishing system, in order to increase the available-, or reduce the required time of escape. This performance level is however dropped, both when it comes to fire alarm system and fire extinguishing system, if more than 1/3 of the wall area is open and openings are located in a way that gives good ventilation.

The corresponding text in the guideline to TEK97 has a different wording. It provides that *either* a fire alarm system *or* an automatic fire extinguishing system must be installed, but if at least 1/3 of walls are open, and provided the location of openings gives adequate ventilation, a fire alarm system may be dropped. No exemption is here given for a fire extinguishing system. This means that if a fire alarm system is not installed, an automatic fire extinguishing system nevertheless needs to be installed, in order to meet the «either or» requirement.

Independently of the actual regulatory requirements as concern fire extinguishing systems, previous studies have shown that automatic fire extinguishing systems, both sprinkler systems and water mist systems, would have had a good effect when it comes to reducing the risk of the fire spreading to other cars. This is presented in section 4.1. An automatic fire extinguishing system would therefore probably have given firefighting crews a better starting point for their efforts than in this case where there was no fire extinguishing system. If an automatic fire extinguishing system had been installed at the Sola car park, the consequences of the fire would probably have been limited to the origin of fire, or to the cars in the immediate vicinity of the origin of fire.

Fire extinguishers

For building B the fire strategy recommends that arrangements for manual extinguishing be made so that all areas are *covered by the equipment*. The strategy for building C has a similar recommendation, with the wording «suitable number of fire extinguishers». This signifies that the fire strategy is not specific when it comes to the number of fire extinguishers required, or how closely they are to be placed, nor is this provided in regulations .However, the regulations have a requirement for the extinguishing equipment to be located in a way that allows for effective extinguishing efforts. In this connection one would therefore expect to find an evaluation of how specifically to achieve an effective extinguishing effort given the specific prerequisites applying in a car park. There were a defined number of fire extinguishers (6 kg powder extinguishers) per floor in each of the buildings. Neither the fire strategy nor the risk assessment conducted by Multiconsult in 2016, made any evaluation as to how fast a fire in a car park may develop, and whether the number and type of fire extinguishers to be found in the car park was suitable for being used by visitors to the car park. Questions may be raised as to whether the average visitor to an airport car park may be expected to have the ability required to handle a car fire well enough to avoid an escalation of the fire. Research on human behaviour in an early phase of fires has shown that the *perceived danger* in a fire cam make the public believe it will be impossible for them to extinguish a fire by using a fire extinguisher [49], which may lead to an ineffective handling of the fire in an early phase. For car fires no studies specifically on human behaviour have been found, but it is not unreasonable to assume that some visitors might believe that car fires quickly may escalate into explosion (the way they do in movies), and that they would therefore focus on evacuating rather than fire extinguishing, even though it was not identified that this is what happened in this specific fire.

Fire alarm systems

Under TEK10 with guideline, the pre-accepted performance level is basically a fire alarm system or an automatic fire extinguishing systems. This performance level is however dropped, both when it comes to fire alarm system and fire extinguishing system, if more than 1/3 of the wall area is open and openings are located in a way that gives good ventilation. Identical performance level and exemption as concern fire alarm systems are provided in the guideline to TEK97.

There was no fire alarm system installed in the car park at Sola. However, manual fire alarms linked to the airport's alarm centre were installed. The RBR was alerted about the fire, on the phone, 8 minutes after start of fire, and the car park's manual alarm was activated 13 minutes after start of fire. The RBR arrived at the airport around 19 minutes after start of the fire.

The fire strategy for the car park assumes a 10-minute response time for the fire service, which is close to the time used by the fire service from the initial alert of fire. However, some time was lost from when the fire started until the alert, in particular considering the fact that the start of fire actually was observed. This might have been critical considering that fires often increase exponentially in intensity during the growth phase, and that the fire in fact had already grown to large proportions before the RBR arrived at the airport.

The question is whether a fire alarm system would have managed to detect the fire and alert the fire service at an earlier point in time. In a partially open car park, where occasionally there is a lot of draught, it is not certain that conventional smoke detectors (photoelectric sensors) would be the most suitable to use. Air flows may thin out the smoke in the fire's early phase, which may lead to delayed detection. If, however, air flow in the car park is low, faster detection may be achieved. Alternatives also exist that may give early detection, which are not affected by changes in ambient conditions (e.g. temperature fluctuations, wind etc.) to any mentionable extent. Examples are flame detectors, thermographic camera, and heat detecting cables. The selected technology must also be able to tolerate the car park's environment (varying temperatures, condensation, exhaust, etc.).

Depending on which solution is used, it will take some time after fire eruption until the fire is detected. For a fire alarm system to have had any significant impact on the outcome in this specific incident, the system would have had to react faster than the time it took from start of fire until the RBR received notification about it (i.e. faster than 8 minutes), and preferably with a good margin in order to have been of any practical importance. This signifies that fast-responding sensors should have been in place, e.g. thermographic camera, which not only reacts to flames, but temperature increases in general. However, such a system requires good coverage (view) of all areas in the car park, but it would probably have shortened the time it took to alert the fire service, enabling it to arrive earlier and initiate suppression efforts at a point where the fire was smaller. It is however uncertain whether this would have led to a different outcome of the fire, but it cannot be excluded that the societal consequences, such as disruption of infrastructure (airport), might have been reduced, which is to be taken into consideration for buildings (that should have been) designed according to fire class 4.

7.1.8 Passive fire protection measures

Load-bearing capacity and stability

The fire strategies for buildings B and C (building where the fire started and the collapsed building, respectively) carried out a deviation analysis relating to the fire resistance rating of the main load-bearing system being designed according to R 10 instead of R 15.

According to the guideline to TEK97 and TEK10, the main load-bearing system for a building in fire class 3 must have a fire resistance rating of R 90 and fulfil A2-s1, d0 (non-combustible materials). Both guidelines open for reducing the fire resistance rating to R 15, provided at least 1/3 of the wall area is open, and provided that openings are distributed in a manner that gives good ventilation, see sections 0 and A.2.2. The difference is that in the guideline to TEK97 this rule applies generally to car parks in all fire classes, while in the guideline to TEK10 it only applies to fire classes 1 and 2. This is linked to the performance requirement providing that a building in fire classes 1 and 2 must have sufficient stability and load-bearing capacity in order to ensure sufficient time to escape, while the requirement for buildings in fire classes 3 and 4 provide that they must be designed so that they hold up throughout the entire course of fire.

Under certain prerequisites, therefore, VTEK97 allows the fire resistance rating of main load-bearing systems to be reduced by 75 minutes, but not according to VTEK10. This ought to have been revealed in connection with preparing the fire strategy design for building C. One prerequisite for being able to reduce the fire resistance rating to R 15 under VTEK97 was that good ventilation could be ensured. Because of the large base area of car parks and the potential for major financial and material losses, there was a requirement for compartmentation, which may be an obstacle to good ventilation. Unless one may allow for the compartmentation requirement, as the same time as at least 1/3 of wall surfaces in sections are open and good ventilation can be ensured, there is no permission for reducing the fire resistance rating to R 15, neither under VTEK97 nor VTEK10.

Additionally, the fire strategies for building B and C argue for a further reduction, from R 15 to R 10, i.e. an 80-minute reduction from the pre-accepted performance level of R 90 in buildings in fire class 3. It appears strange to argue for a 10-minute fire resistance rating, at the same time as stating in the fire strategies that the fire service's response time is approx. 10 minutes. In practical terms this means giving the fire service a difficult basis for its extinguishing efforts. Of course, a 10-minute fire resistance rating does not entail that the structures will fail 10 minutes after the start of fire, but that parts of the structure have been tested in a standardised setup where they are exposed to a fire load simulating a fully developed fire. Nevertheless, both a 10-minute and 15-minute fire resistance rating for load-bearing building components is deemed to be very low.

In term of the structural design this reduction signifies that one may avoid protecting the steel in load-bearing structures, or avoid increased steel dimensions, which is a financial gain. As concerns whether this reduction contributed to the collapse of parts of building C, it is doubtful that the outcome would have differed if the load-bearing structure had been erected with a fire resistance rating of R 15. However, if the pre-accepted performance level had been used (R 90), the RBR probably would have had better opportunities for fighting the fire actively, which might have led to a different outcome.

The argument that the deviation fulfils the functional regulatory requirement for a satisfactory load-bearing capacity and stability throughout the entire fire is provided in eight points that are identical in the fire strategies for buildings B and C respectively.

Summarized, one can say that the conclusions of this argumentation become erroneous with basis in the following circumstances:

1. The effect of open walls was misjudged.
2. It is applied as basis that a car fire will not spread to neighbouring cars.
3. It is not taken into consideration that the base area increases by 43 % from building stage B to building stage C, becoming 18 500 m^2.
4. It is assumed that the fire service is able to access floors with a low ceiling, and with considerable thermal stress and fume emission, 10-20 minutes after the start of fire.

Compartmentation and measures to prevent spread of fire between buildings

TEK97 and TEK10 prescribe that buildings must be divided into separate parts, so that the fire within each part does not give unreasonably large consequences or material loss. The appurtenant guidelines indicate maximum permitted gross area per floor without compartmentation. For a specific fire load between 50-400 MJ/m^2 per total surface area without fire alarm systems or sprinkler systems, but with smoke ventilation, maximum area is 4 000 m^2 per floor. With basis in the building's lack of compartmentation and insufficient distance between buildings A and B, buildings A, B and C combined must be considered as one large building, and the area limitation is thus exceeded. This also applies when considering each building separately. There is no connection either between open walls and the compartmentation requirement, such as alleged in the fire strategies. The building should therefore have been sectioned. This applies even if the building had been sprinkled, as the pre-accepted performance level for the maximum non-sectioned base area permitted is 10 000 m^2 with sprinkler systems.

The guidelines to the building regulation underline that the person(s) responsible for design must conduct a special assessment of the requirement for compartmentation of buildings that represent social values of a large magnitude, or that are of great significance to major public interests (e.g. infrastructure). The guideline to TEK97 further emphasises that the area limitation in such cases should be set lower. A car park is in itself not an infrastructure of significance to major public interests. But when a car park is built in association with an international airport, and is surrounded by buildings connected to operation of the airport, one should be able to argue that this cark park is a piece of infrastructure that makes this rule apply.

7.1.9 Control of fire safety strategies

We do not have access to documentation showing whether an independent control of the engineering of fire safety strategy was made. Nor was this a requirement in the Building Application Regulation SAK10 (Norw. *sakbehandlingsforskriften)* before 1 January 2013, but it was nevertheless implemented in some building cases before that date. The guideline to the Building Application Regulation SAK from 2003 describes fire safety as an important and critical control area, and states that independent control must be employed in all cases where this is necessary in order to ensure satisfactory control. The guideline recommends municipalities to consider using an independent control in building cases.

If an independent control had been implemented, there is a larger probability that deficiencies in fire safety engineering would have been detected and corrected. An independent control could have been proposed by the engineering party or by the municipality.

7.1.10 Organisational fire protection measures

Organisational fire protection measures appear as being well taken care of, in accordance with regulations. The fire service expressed they were satisfied with the measures implemented by Avinor related to deviations identified through inspections over the years, and adequate systems were in place for follow-up of operation, maintenance, and emergency preparedness. Assistance was brought in when needed, and deviations were handled and closed.

7.1.11 General learning points related to engineering

- **An holistic safety philosophy is important**
  A review of the two fire strategies for building B and C showed some weaknesses that should be highlighted as learning points. Section 7.1.7 shows that one argument is employed to recommend installation of a fire alarm system, whereas the opposite argument is used to reduce the fire resistance rating to R 10. This shows that an holistic understanding of the fire risks associated with the building was lacking, and that there was excessive focus on pre-

accepted performance levels without considering the functional requirement that the performance level had to meet. On the contrary, it appears as if one is trying to meet the various requirements in TEK97 and TEK10 separately, instead of establishing an overall safety philosophy. Similar findings were uncovered when we examined the fire strategy prepared for playground and activity centres [50], which means this is not an issue of concern unique to this incident, but something that is possibly repeated in numerous cases.

- **Assessment of the consequences of fire on adjacent buildings and infrastructure**
  In addition to mapping the actual risks relating to the building being planned, it is also important to assess the consequences that a fire might have for adjacent buildings and infrastructure. In this connection there will be vast difference between car parks erected on an open area, and one being erected e.g. in a town centre or inside an airport area.

- **Reuse of assessment and updates to new regulations**
  In this case we see that the fire strategy for building C largely copied the fire strategy for building B. This was done without taking into account that building B already had been built, and without considering the impact the increase in base area would have on fire safety. Nor were the expired references to the various sections of TEK97 updated, which should have referred to TEK10. The latter is an example of details being overlooked, which can have a great impact on fire safety if an earlier fire strategy is reused.

- **Fire safety engineering**
  An overall assessment of the building seen in connection with the surroundings may show that pre-accepted performance levels do not provide a sufficient fire safety, in which case fire safety engineering might identify challenges and measures that should be deployed. In Norway today, there should be more focus on using fire safety engineering, and there is a need to focus on fire safety from a more overall perspective rather than only using pre-accepted performance levels.

7.2 Regulations

This case has shown that fires in car parks with large openings in wall areas may develop into unacceptable proportions, if the wind conditions are unfavourable. As concern the building regulations with guideline, we believe that the pre-accepted performance level allowing a reduction of fire resistance rating in fire class 1 and 2 car parks should be amended. As mentioned above, it is a provision that more than 1/3 of the wall area is open, and that the design allows good ventilation. In this connection it should be examined to which the extent of openness (size, shape and distribution of openings) impacts on the fire development, and what may be considered as adequate and suitable ventilation, and whether any limitations to the base area and design of car parks should be introduced in order for this provision to apply.

Beyond this, no potential weaknesses in regulations were found, including the reviewed regulations with guidelines relevant to this incident. The mistakes pointed to in section 7.1 relating to the preparation of fire strategies, would probably not have been different if regulations had been amended

However, some points in the guideline to the building regulation contain ambiguities that may seem confusing. One example is VTEK10 §11-4, third subsection, which deals with buildings in fire classes 1 and 2. This guideline also refers to pre-accepted performance levels for buildings in fire class 3, which may lead to confusion as to whether the remaining text on this point also applies to fire class 3. This point has however been rectified, and the table removed in the 2017 edition of the guidance (VTEK17). There are multiple examples of minor adjustments and corrections that have been made from one version to the next, which may have a great impact on the way regulations are interpreted. Unless the party preparing the fire strategy is vigilant, it is easy to make mistakes. By uncritically reusing old fire strategies such changes will not be discovered, and it is therefore important for regulation users to keep updated on potential changes. It is also important that the authorities bring forward and clarify such changes when they are made.

7.3 Learning points regarding handling of the incident in the emergency phase

7.3.1 The basis for creating national learning in the wake of major incidents

The evaluations of the fire services' handling of the response, had as an overall goal to examine whether national learning points could be drawn from the incident. The Norwegian Fire Academy (NBSK) is the educational institution for national fire and rescue education. With the NBSK's experience as a national competence supplier, we see that the majority of learning points identified from this incident are learning points that it also would have been possible to identify from other incidents, and by other fire departments. This means that the learning points do not appear to be typical for the RBR.

This section will present a number of learning points, related to a number of functions in the response team. Three main factors are applied as basis to show that the fire service's response team had small or no opportunities for extinguishing this fire in the initial phase:

1. It took 8 minutes from start of fire until the emergency operations centre was alerted (there was no direct alert from the car park to the emergency operations centre).
2. No active fire protection measures were in place.
3. Persons present in the car park did not use the available fire extinguishers during the start phase of the fire.

BRIS-reports following incidents are potentially of both national and local value, in particular in risk-based preventive work and in evaluation work. However, in this evaluation specifically, information in BRIS related to the incident was very limited. The BRIS-report should answer all questions in the form completely and precisely.

Summarized learning points - The basis for creating national learning after major incidents:

- Sound-logs after an incident should be handed over when national learning is the purpose.
- Vision-logs should be handed over in an unedited version, when national learning is the purpose.
- BRIS-reporting (in-data) should be increased in quality and volume.

7.3.2 Response plan

The guideline to the regulation on organization of the fire and rescue service provides that work on the response plan should start with an inspection. Through the inspection owner and fire service together may agree on which of the above-mentioned points that should be part of a plan. The value of an object and response plan is not necessarily only to have documents and drawings available for the response, but the preparation of the response plan itself could also prove to be valuable, in particular if prepared in collaboration with response crews and the fire safety department. The inspection may uncover conditions that make extinguishing efforts difficult, allowing these conditions to be rectified before a potential fire occurs. A number of the challenges related to turnout and early suppression efforts in the car park fire at Sola, might have been avoided if a response plan for the object had been prepared.

It appears that access to the fire object was exacting for large vehicles, and that start of the response became challenging owing to a long response route.

Both these examples may have delayed the suppression efforts during the time critical early phase. A response plan might have remedied these challenges.

Emergency preparedness plans should be divided into incident based and function-based checklists. The purpose is to standardise the response by assigning the various functions their adapted check lists. The checklist should clearly state who is responsible for decisions and tasks. Another advantage is that the functions during response will be familiar with each other's checklists. There is no information to indicate that function-based checklists were used during the response.

Summarized learning points - Response plan:

- The response plan should be prepared for objects posing particular challenges in fire fighting efforts and/or high risk in a fire.
- The response plan should be prepared in collaboration between response personnel (emergency preparedness department), fire safety department, and building owner.
- The response plan should be prepared with basis in inspection. Deficiencies identified through inspection may be adjusted in collaboration with the owner, fire safety department and response personnel.
- The response plan should contain the points proposed by attachment 3 to the guideline to the regulation for organization of the fire and rescue service.
- The response plan should be rehearsed and made available for proactive use during response.
- All imaginable players performing service during the response should rehearse the response plan together.

- Fire service should have emergency preparedness plans for exacting and /or complicated response.
- Emergency preparedness plans should include both incident based and function based check lists.

In its work to determine a uniform language within the fire services, the Norwegian collegium for fire safety terminology (KBT) has arrived at a somewhat different definition of the "response plan" concept compared to what is used in the regulation on organization of the fire and rescue service. The terms will probably be coordinated in a regulation revision at a later stage.

7.3.3 Exercises, interaction and common situational understanding

On a general basis, exercises interacting with other response units and other emergency agencies will identify and uncover deficiencies preventing interaction from working. Deficiencies and items with potential for improvement appearing during exercises represent a good opportunity for adjusting routines, checklists, and procedures. Repeated exposures increase the degree of common situational understanding between emergency agencies. Simulator training, and desktop exercises are simple but good rehearsing methods.

7.3.4 Management tools

The fire service should provide for a standardisation of decision making models and terminology, such as e.g. the seven-step model, OBBO, ELS, and the names used for the different sides of the building (front, back, etc.). With this purpose in mind simulator training and desktop exercises are suitable for identifying concept confusion and clarifying terminology.

The Norwegian Fire Academy should offer refresher courses for emergency response team leaders who have emergency response team leader training from before the seven-step model was introduced.

7.3.5 Call-out, sharing of information and arrival report

Such ambiguities that arose in connection with which radio channel Avinor could be reached on, should be avoided. The RBR and Avinor between them should have clarified and rehearsed such aspects in advance. As mentioned above the police’s arrival report in the BAPS interaction system was very brief, «There is a fire. Call-out site – Heliport». The precision level and extent of such arrival reports ought to be more comprehensive. An arrival report should contain the following:

- Approach path
- Meeting point
- Response area
- Extent of damage
- Notifier, witnesses, etc.
- Dangerous area
- Important information for further planning of extra resources, in the form of material, personnel, emergency preparedness, etc.

Time critical information must be communicated through the talk group[27] as soon as it is available.

Summarized learning points - Call-out, sharing of information and arrival report in the emergency phase:

- More units should have been called in the initial call-out from emergency operations centre. With basis in potential-based tactical management, the incident should be scaled with basis in the incident potential with called-out resources (Most likely/Worst case).
- Since all response players do not have access to BAPS, the use of interaction communication with the fire service should be part of a channel plan and rehearsed.
- Interaction between emergency agencies should be rehearsed, in particular during the emergency phase, in order that a precise arrival report including critical information is communicated from the first emergency unit arriving on the scene.
- The first unit should also send an arrival report. If this is not available, emergency operations centre should ask for it.

7.3.6 Immediate measures

It is conceivable that the use of immediate measures would have retarded the fire development. Nevertheless, it is hard to see that this could have been achieved given the long distance between the lined-up fire trucks and the fire scene.

Knowledge on how fires develop and fought is a basis with which all fire and response personnel at all levels should be familiar. But even with sound knowledge on fire development principles, response personnel have challenges in obtaining an exact understanding of the situation. It may be challenging to select the right extinguishing agent and application technique. The properties of a substance may vary from one time to the next, because conditions are different (temperature, oxygen supply, volume, etc). It is therefore important for response personnel to have acquired a number of firefighting methods based on general knowledge on how fires develop. This understanding entails that tactical firefighting must be founded on a strategy based on the following learning points:

Summarized learning points – Immediate measures:

- Preventive measures: When a fire occurs, active and passive fire protection measures will "curb" the exponential fire development. This will lead to the fire developing at a slower pace for as long as possible. The purpose is to give the response team time for turnout, driving time, and preparation prior to the fire being eliminated or restricted by using a suitable extinguishing agent. The response team should be familiar with how preventive measures work, and the opportunities these provide for suppression.
- The response team must use a short time in performing immediate measures: Nothing must be allowed to delay the application of water (or other suitable extinguishing agent) to the fire. Even tiny amounts of extinguishing agent will retard the exponential development of fire.

[27] Joint telecommunication rules for emergency network

7.3.7 The purpose of response and the tactical plan

There is no empirical basis for claiming that an absence of purpose of response (MMI) and tactical plan (TP) affected the outcome of this incident. All the same, the purpose of the response and a tactical plan is to provide task leaders with adequate tools for making proactive reflection and obtaining a good way of communicating clearly to response crews. It is therefore important for response crews as well as fire service leaders to know the same concepts. When it comes to using management tools it seems that the level of competence amongst managers in general is varying. The challenge is typical for a number of fire services. Some are trained in OBBO and others in the seven-step model. This means the two decision making tools are being used interchangeably. The organisation should train leaders in the seven-step model, and make sure that everybody understands and is able to use the same concepts.

Summarized learning points – The purpose of response and tactical plan:

- Emergency agencies should practice establishing a common situational understanding in the emergency phase.
- Emergency agencies should practice interaction and communication in the emergency phase.
- The fire service should introduce and train the organization in the use of **one** management tool.
- MMI and TP must be trained on management level.
- The fire service should practice making meta decisions[28], enabling leaders to give a good estimate of the intersection between information volume and the room for manoeuvre.

7.3.8 Incident scene organisation:

Who should have onsite responsibility during an incident depends on the size and character of the incident. In minor incidents the emergency response team leader on the personnel carrier often has onsite responsibility. In middle-sized and major incidents fire services of some size have a brigadier function who coordinates emergency response team leaders and who acts as representative in ILKO. In major incidents the incident commander is called out, who has authority from the chief fire officer. Ergo in this incident the emergency response team leader is first onsite leader. The brigadier (S03) is the second onsite leader. The incident commander (S01), who arrived last, could then have been named third onsite leader. S01 and S03 agreed that S03 would continue acting as leader for the response, even though S01 had arrived. It is a positive thing that these evaluations are made, and it seems appropriate with the view of obtaining a good continuity of leadership. It also appeared rational for S01 to assume the role as leader support, and handling of the media. What is lacking relating to responsibility in this case is a logged transfer of responsibility. Who carried the responsibility at any time should have been made clear in the logs and on the telecommunication circuit. Even though the leaders made adequate agreements on responsibility between them, it is important for the entire response organisation and emergency operations centre to know who carries responsibility. In this incident this point was not understood by everyone. After a while, the fire scene was redefined from being task-

[28] Meta decision – decision on the decision

oriented into sectors (according to the ELS-principle). This appears as a suitable move, as the response area was large, and so was S03/S01's span of control.

Summarized learning points - Incident scene organisation and task leaders' command point:

- Emergency agencies should limit the number of participants and observers in ILKO.
- Emergency agencies should be conscious about "flair" and "timing" for sharing of information in ILKO.
- It is very good that the fire service's task leader is allowed to "set the agenda" in ILKO.
- There should be clear transfer of responsibility and leadership when more leaders arrive on the fire scene. This should be communicated and logged.
- Leader support provided by the incident commander is a good idea, instead of transferring leadership and responsibility.
- An appropriate ELS-organization of the fire scene is important in large and lingering incidents.
- A diminished span of control with division into sectors is recommended in major and complex incidents.

7.3.9 Communication and interaction

The fact that there were uncertainties as to whether there were people inside the burning car park at the point when the RBR arrived might have resulted in highly unfortunate outcomes. A common situational understanding in ILKO should be established, where task leaders understand the same thing, at the same time. An issue is whether the use of time in clarifying such information was so demanding as to make the room of manoeuvre for making decisions smaller than necessary. Critical information, such as e.g. status on life and health, must have a high precision level.

The telecommunication circuit between smoke divers and the smoke diver supervisor did not work. Response crew personnel pointed out that the microphone and loudspeaker did not handle the noise level present at the fire scene. Firewater pumps, engine noise, and noise from the fire typically give high noise levels. Microphones and loudspeakers should be dimensioned to handle a high ambient noise level.

It appears that Avinor and RBR worked well together once the response had started. To obtain good and effective collaboration, it may be wise to work up knowledge on each other's procedures, equipment, striking power, etc. This is best achieved though rehearsing together.

Summarized learning points - Communication and interaction:

- The telecommunication circuit needs to work, in order that smoke divers do not lose valuable time and are exposed to unnecessary risk.
- The fire service should practice ways for improving the common situational understanding with the other response players. A good way of practicing is using simulation tools.
- The assistance agreement between the fire service and Avinor should describe the number exercises and content.

7.3.10 Logistics and depot

The interviews as well as the RBR's own evaluation report go to show that there were challenges relating to logistics and depot. In this context it is important to bear in mind that the leader's control span should not be too large. As soon as establishing that the incident will be long lasting, a separate logistics leader should be appointed. If S01 and S03 use function-based checklists, it is natural that the task of appointing a logistics leader should lie with one of these. Some logistics material is critical, which requires a proactive leader. It is too late ordering air bottles when smoke divers run out of air, or ordering more foam fluid the moment it runs out. Good and precise descriptions of the logistics function can make it easier to manage this function. It is also a good idea to consider the potential, which means it is incident potential that decides how logistics and supplies are scaled. It is better bringing oversupplies of material back rather than running out at the fire scene. This also applies to the highest degrees as concerns personnel resources. Smoke diving in situations with a long response route and high temperatures is very demanding and gives an acute requirement for rested personnel. By degrees internal staff with the RBR was deployed, who provided assistance to the task leader in handling the media, logistics, logging and registration. This provides good leader support in demanding fires.

Summarized learning points - Logistics and depot:

- The incident commander or brigadier should have a permanent responsibility for appointing a person responsible for logistics.
- Logistics and depot should have a potential based approach, to prevent "lagging behind".
- Plans and procedures must be prepared for resupply of critical material, e.g. foam liquid.
- Function based checklists should be prepared for depot and logistics.
- Task leader should be early in establishing staff, to make the required leader support available.

7.3.11 Handling of uncertainty and follow up

A number of measures that did not work out as planned, were evaluated and modified by the RBR during the incident. It is important that this be done early on in the incident, parallel to reducing uncertainty. Moreover, boundary lines were established at an early point, and evaluated and adjusted during the process. The principle of following up and evaluating own measures was followed at the same time as task management in RBR worked to reduce uncertainty.

The most important approach in response follow-up is to reduce uncertainty first. A research-based method for handling uncertainty is RAWFS-model [51]:

- Reduction – Collect more information
- Assumption – Employ assumption as compensation for lack of information
- Weighing – Weighing pros and cons
- Forestalling – Generate, simulate multiple options
- Suppression – Ignore uncertainty by suppressing negative information

Summarized learning points – Handling of uncertainty and follow up:

- Fire service task leaders should evaluate own measures and decisions. Do they work or not?
- Task leader should work systematically to reduce situational uncertainty.
- Boundary lines should be determined in understanding with building competence.

7.4 The impact of electric and modern vehicles on the extent of fire

There were conventional petrol and diesel vehicles, hybrid vehicles and electric vehicles in the car park, and many vehicles were involved in the fire. The spread of fire and its course can amongst others be affected by the age of the vehicle fleet and by electric car batteries if these are involved in the fire. In addition, ignited, flowing fuel contributed to the spread of fire, as described in section 7.1.4.

Modern vehicles

Modern vehicles have higher fire load and are on average wider than older vehicles. Modern vehicles therefore contribute to a more intense course of fire than older ones, and the risk of fire spreading to other vehicles is greater [16]. There is no sharp distinction between what we describe as modern and older vehicles; the change has taken place over time. As mentioned earlier, research results from 1985 were used as an argument for the deviation whereby the fire resistance rating of the load-bearing system in the car park was reduced. We have previously argued that one should generally use recent literature to ensure that up-to-date knowledge is used. In this case however, using recent literature would not have helped, as the literature has shortcomings (at least the one mapped in this study). Research should therefore be conducted on the spread of fire between vehicles in car parks with different degrees of openings in the façade and different geometry, ceiling height, and any compartmentation, in order to improve the basis for risk analyses in connection with engineering of car parks in the future.

Electric vehicles

One objective of the project is to assess the impact of electric vehicles on the extent of the fire, and it is of interest to clarify whether battery packs were involved in the fire development. This question has arisen partly due to the extent of the fire and partly due to media focus, especially in the initial phase of the fire.

The Norwegian car fleet has a significant share of electric vehicles per inhabitant, with a market share of new car sales of up to 50 % as of March 2020, according to the Norwegian Electric Vehicle Association [52]. This is higher than many comparable countries, and we therefore expect that a larger proportion of the vehicles involved in this incident were electric or hybrid vehicles, compared to fires in car parks in other countries.

Observations made by the RBR regarding the intensity and duration of car fires during the incident indicate that electric car batteries were not involved in the fire (see section 4.2). If the battery is not involved, the course of fire in an electric vehicle is expected to be approximately the same as in a conventional petrol or diesel vehicle (as described in chapter 4).

When it comes to the fire's environmental impact, analyses of water samples in nearby water bodies provide indications on the contribution of electric vehicle batteries (analyses carried out by COWI, see details in section 6.1). The analyses included lithium and cobalt, main components of an electric car battery. Lithium was not found in any of the water samples, and the analyses showed low concentrations of cobalt. This indicates that batteries from burnt out electric vehicles have not contributed to the pollution of nearby water bodies.

Observations made during the fire, as well as water analyses in retrospect, thus imply that electric car batteries were not involved in the fire. However, technical investigations of the actual batteries of the burnt-out or partially burnt-out electric and hybrid vehicles are necessary to substantiate this point and provide a definite answer. This will involve extracting batteries from the vehicles, opening them up and studying them in detail, and putting the extent of damage on the electric vehicle batteries in connection with the fire exposure. This has not been implemented in this evaluation.

The fire at Sola provides a unique opportunity for a large-scale investigation of the involvement of electric car batteries in a fire. Such a study could provide very valuable information to automotive manufacturers about how different types of batteries and enclosures work, to designers, engineers and owners for the engineering of car parks, and to authorities formulating regulations related to electric vehicles. This is therefore recommended for further work.

Environmental impact

Analyses of water samples carried out by COWI (see chapter 6) provide information on the environmental impact of the firefighting foam. The type of firefighting foam used is said not to have added significant amounts of PFAS during the extinguishing. Nevertheless, PFAS was found in all water samples, which is linked to previous discharges. Oxygen consumption due to discharges of firefighting foam is considered having local toxic effects, but no general negative effects on life in the sea at Solavika. Overall, this shows that even though a lot of firefighting foam was used during the incident, it led to limited pollution of the aquatic environment. The choice of firefighting foam, a permanently established treatment park, combined with close follow-up of the environmental impact following the incident on Avinor's part, are considered to be solid consequence-reducing measures to limit water pollution.

Even though the use of firefighting foam in this case only led to limited pollution of the aquatic environment, our assessment is that there should be a stronger focus on the use of firefighting foam in the future. Logistics for logging the amount of firefighting foam brought to the incident scene, and the amount of firefighting foam used, should also be in place. Here we can learn from Sweden, which has a much stronger focus on the use of firefighting foam. The amount of firefighting foam used during efforts should always be included in the fire service's evaluation of the incident.

8 Conclusions

Why did the fire become so extensive?

This evaluation shows that the fire became so extensive due to a combination of factors:

- It took a relatively long time from the fire started until the fire service was notified.
- There was no automatic fire alarm system in the building.
- There was no automatic extinguishing system in the building.
- There was no fire compartmentation in the car park.
- Fire extinguishers in the car park were not used to try to extinguish the intial fire.
- The fire spread rapidly to several vehicles.
- Strong wind helped accelerate the spread of fire.
- The leakage of fuel from burning vehicles contributed to the fire spreading.
- A response plan with corresponding object plan for the car park was lacking. This could have helped the fire service with the road, assembly, and other effort organisation.

Was the structure designed and constructed in accordance with current building regulations?

The engineering of the car park did not take into account that a fire could develop and spread at the speed and extent experienced in this fire.

- The car park was placed in fire class 3. Our conclusion is that it should have been placed in fire class 4 due to its location close to the airport, which is considered a socially important infrastructure. Placement in fire class 4 would have required fire safety engineering (analysis).
- Building C: The fire resistance rating for load-bearing structural parts in a car park in fire class 3 should under TEK10 with guideline have been designed as R 90, not R 10.
- Due to the large area, the car park should have been divided into fire compartments to prevent large material losses. The building was not designed with fire compartmentation.

On this basis, we conclude that the structure was not designed in accordance with current building regulations. We have no information indicating that the construction of the building was not in accordance with the design.

Could additional fire safety measures have limited the extent of fire?

The review shows that the organizational fire safety measures probably worked well and as intended.

The following fire safety measures would probably have had an effect on the development of the fire and led to less extensive consequences:

- An automatic fire alarm system would probably have led to the fire service being notified earlier.
- An automatic extinguishing system would have contributed to mitigating the fire and limiting the fire spread.

- Compartmentation of the car park would probably have limited the extent of damage.
- A higher fire resistance rating in the structure of building C would probably have prevented the building from collapsing less than two hours after the start of fire.
- Facilitating the use of fire extinguishers will increase the likelihood of being able to control and extinguish manageable fire outbreaks (e.g. general information, training, dissemination of knowledge, dedicated responsible personnel). This must not compromise the personal safety of those who are expected to use such fire extinguishers.

The pre-accepted performance level that allows reducing the fire resistance rating in car parks in fire classes 1 and 2, providing that more than 1/3 of the wall area is open and that the design allows for satisfactory ventilation, should be changed. In this connection, one should investigate in what way the degree of openness (size, shape and distribution of openings) might impact on the fire development, what can be considered good, appropriate ventilation, and whether restrictions should be placed on the car park's base area and design in order for this provision to apply.

We have not seen a need for modifications of the Building Application Regulation, the regulation on fire prevention, the internal control regulation, or the regulation on organization of the fire and rescue service, as a result of the experience gained in this incident.

Implementation of extinguishing efforts

Although areas were identified that may provide a basis for learning, these areas are not considered decisive for the outcome of the fire. Learning points are described and summarized in a separate chapter.

What impact did electric vehicles have on the extent of fire?

There are no findings giving reason to believe that electric vehicles affected the fire development differently than petrol-powered and diesel-powered vehicles would have done. No evidence was found that fires in electric vehicles led to the pollution of nearby water bodies either.

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Appendix A Summary of regulations

The below sections provide an overview of the requirements relating to organizational and building related fire protection measures, with basis in the:

a. Fire and Explosion Prevention Act with regulations
b. Planning and Building Act with regulations

The overview is not exhaustive, but provides a summary of the regulations that are most relevant for the evaluation of this fire, with basis in the mandate of this project.

The car park was built in three stages:

A. 1991: unharmed after the fire
B. 2011 (concrete structure): damaged
C. 2014 (steel structure): collapsed

As concern building regulations, building regulation TEK97 with guideline (building B), and TEK10 with guideline (building C) were used as basis. TEK10 was replaced by TEK17 in July 2017.

The regulations relevant for building application processing is the building application regulation from 2010 (SAK10), and regulation on procedures and control in building applications from 2003 (SAK).

A.1 The Fire and Explosion Prevention Act

The Act on protection against fire, explosion, and accidents involving hazardous substances and on the rescue tasks of fire services (The Fire and Explosion Prevention Act) has as its object to protect life, health, the environment, and material values against fire and explosion, against accidents involving hazardous substances and dangerous goods and other acute accidents, as well as unintended incidents. Under the Fire and Explosion Prevention Act, § 6, the building owners has an obligation to ensure that the necessary safety measures are in place to prevent and curb fire, and the owner and user of buildings have an obligation to keep structures and all safety measures in an appropriate condition, in order that they work as intended. [53]

Under § 11 of the law, the fire service is amongst other responsible for carrying out inspections to prevent fire and act as a response force in fires.

A.1.1 Regulation on fire prevention

The statutory basis of the regulation on fire prevention is the Fire and Explosion Prevention Act. The regulation is to contribute to reducing the likelihood of fire, and limiting the consequences that fires may have on life, health, the environment, and material values [54].

What is relevant in this case, is the obligation that the owner and users of the building have to prevent fire, as well as the municipality.

The regulation, § 4, provides that the owner must have knowledge about the building components, installations, and equipment that are in place to detect or curb the consequences of a fire. Requirements relating to control and maintenance are provided by § 5, and will clarify whether safety installations fulfil the fire safety requirements that apply to the building, and whether these installations function separately or together with each other.

§ 9 of the requirements provides that an enterprise owning a building must pursue systematic safety work, which amongst others includes routines for identifying, correcting, and preventing deficiencies of building components, installations, and equipment set to discover the fire or restrict its consequences. Further, routines must be implemented in order to identify, correct, and prevent deficiencies of systematic safety work. Systematic safety work will be adapted to the building's size, complexity, use, and risk.

The municipality has, under § 14, the responsibility for mapping the probability and potential consequences of a fire on life, health, the environment, and material values in the municipality, and must, according to §16, implement measures in accordance with the plan for preventive work, and on basis of incidents, notes of concern and similar providing new knowledge on the risk of fire. Supervision must be carried out amongst others with basis in the risk of loss of material values and social consequences (§18).

A.1.2 Internal control regulation

The internal control regulation applies amongst others to enterprises comprised by the Fire and Explosion Prevention Act [55]. The object of the regulation is to promote the enterprise's improvement effort within work environment and safety, prevention of health injuries, and environmental disturbance caused by products or consumer services, and to promote protection of the exterior environment against pollution, and improved processing of waste in order that safety regulation objectives relating to health, the environment and safety are reached.

§ 5 poses requirements for written documentation on systematic work relating to health, the environment, and safety. The following points and requirements for written documentation are particularly relevant in this evaluation:

….

4. determine goals for health, environment, and safety
5. have an overview of the enterprise's organization, including the distribution of responsibility, tasks and authority relating to work on health, environment, and safety
6. identify hazards and problems and on this basis assess risk, and prepare appurtenant plans and measures to reduce risk conditions
7. implement routines to uncover, correct, and prevent transgressions of requirements determined in or pursuant to legislation relating to health, environment, and safety
8. conduct systematic monitoring and review of internal control to ensure that it works as presupposed

A.1.3 Regulation on organization and scaling of fire services

§ 1-1 Purpose

The regulation is to ensure that all municipalities have a fire service that is organized, equipped and manned in order that tasks imposed through law and regulations are carried out in a safe manner [56]. Further, the regulation will ensure that the fire service is organized and scaled with basis in existing risk and vulnerability.

§ 4-1 Collaboration

The regulation provides that the municipality must seek to collaborate with other municipalities and emergency preparedness organizations in order to exploit resources in the region. In cases where a community is common to numerous municipalities, these will collaborate on emergency preparedness for this community [56]. The guideline underlines that «the most common form of emergency preparedness collaboration is agreements on fire extinguishing where a different municipality or a private business takes over responsibility for response in entire of parts of the municipality. Assistance agreements are intended for simpler forms of collaboration between municipalities, other emergency preparedness organisations or private businesses». [57]

On the coordination of emergency preparedness and response plans the guideline specifies [57]:

«With basis in the overall resources, identified risk and any collaboration agreements, the chief fire officer must prepare emergency preparedness plans for tasks under the Fire and Explosion Prevention Act, and other tasks assigned to the fire service by the municipality, cf. § 2-6. Fire services' emergency preparedness plans must be coordinated with other emergency preparedness plans in the municipality, the police and other emergency preparedness organisations. In municipalities where there is an airport, the chief fire officer should contribute to the coordination of response in air accidents/air crashes. Interaction exercises of the airport's damage restoration plan and a potential takeover of task management should be drilled. The chief fire officer should seek collaboration with owners and parties responsible for fire protection in large risk objects in the preparation of response plans. Response plans make it easier to obtain a coordinated, effective, and secure response in accident situations, see attachment 3 on emergency preparedness and response plans.»

On alert arrangements the guideline states [57]:

The emergency operations centre should be an initiator in establishing suitable routines for alert. The emergency operations centre must at all times be updated with worked-in routines that handle collaboration agreements on emergency preparedness in the region. The agreement on alarms should contain the duties of emergency operations centres, procedures, authorities, etc. as concerns the individual fire service/municipality. The agreement must ensure that the emergency operations centre is able to alert the closest task force, in order that the distressed get help from the task force with the shortest response time. The municipalities have the responsibility for entering collaboration agreements that take care of the distressed. The emergency operations centre should all the same seek to identify areas where collaboration is needed, but the emergency operations centre must at all times relate to the municipality in charge and the emergency procedures that have been agreed. Assistance is a particular form of collaboration in an emergency situation. This is further addressed under § 4-2. Procedures relating to the request for and provision of assistance should also be facilitated through the emergency operations centre.

§ 4-2 Assistance

According to the regulation, the municipality or the fire protection region, «in addition to any collaboration agreements, must enter agreements that provide for receiving and giving assistance when needed in severe fires and accident situations, through involving the neighbouring fire service, industrial defence, airport and damage restoration emergency preparedness, civil defence, the Armed Forces, etc. where such forces are available. The agreement is also to regulate the mode of approach in assistance requests.» Guideline text: «In all municipalities fire and accident situations may occur that develop differently or become more extensive than imagined. In such situations it is vital that the fire service has established collaboration agreements or assistance agreements comprising the resources available in a reasonable proximity.

To enable the fire service to carry out an optimally effective response, it is important for assistance opportunities to have been identified. For the same reason, municipalities must also enter agreements with other public authorities or emergency preparedness institutions to provide assistance in the event of extensive fires and accidents. This is to be facilitated through agreements to ensure that everyone is prepared in the cases where this becomes relevant.

§4-13 Emergency preparedness exercises

The regulation §4-13 states that all personnel that are part of emergency preparedness must regularly rehearse the tasks they expectedly may be faced with in fire and accident situations. The overall emergency preparedness within the municipality or the fire protection region must be rehearsed so that the telecommunication circuit and command lines work safely. [57]

In guideline [57] on additional drills and exercises when emergency preparedness is extended [57]: «Additional exercises should be carried out when municipalities or fire protection regions have: – risk objects requiring particular competence – personnel where special competence is required, such as e.g. smoke divers and hazmat divers (see Guideline for smoke divers and hazmat divers). The bulk of drill and exercises should be part of ordinary exercises. Exercises with individual or particular content should be additional to the recommended number of exercises. In fire services with particular emergency preparedness, the chief fire officer should make sure that the municipality/fire protection region determines an extended number of exercises for relevant personnel. Particular emergency preparedness may be relevant for: – acute pollution – traffic/occupational accidents larger than "normal" – use of turntable ladder – long/deep tunnels – natural disaster – response at sea – water diving – ambulance service – call-out to social alarms/ remote control safety alarms – residual value rescue

Collaboration on exercises

Exercises and training are activities that are technically and economically suitable for collaboration schemes. Personnel having completed essential courses, may be assigned the responsibility for organizing exercises and further at their fire department, in neighbouring fire departments and in the fire protection region, see under §§ 2-1 and 4-1. It is assumed that fire departments that have entered an agreement on emergency preparedness collaboration with a different fire department have agreed on joint plans for drilling and exercises. The number of joint exercises and their scope depends on the basis of the collaboration agreement and risks found in the area. The chief fire officer should take the initiative toward leaders of industrial defence, airport/damage restoration preparedness, civil defence, the Armed Forces, the police, and ambulance service in order to facilitate and coordinate training of response plans unless this has already been done by the police. At least once a year leaders of relevant task forces, regardless of the size of the municipality or fire protection region, should come together to discuss response relating to "current" incidents, and, if relevant, carry out table-top exercises based on emergency preparedness and response plans.»

§ 4-8 Response time

In densely populated areas with a particular risk of fast and extensive spread of fire, hospitals/nursing home etc., neighbourhoods with concentrated and extensive industrial activities etc., the response time must not exceed 10 minutes.

In some cases the response time may take longer if measures have been taken to compensate for enhanced risk. The municipality must document how this has been done.

Response time in built up areas is not to exceed 20 minutes. Response outside built area is distributed between forces in the region, in order that complete coverage is secured. Response time in such cases does not exceed 30 minutes.

§ 4-9 Smoke or hazmat diving

Before smoke or hazmat diving is initiated, the emergency response team leader or smoke diver supervisor, and a required number of qualified smoke divers or hazmat divers, and sufficient equipment, must have arrived at the incident scene, and the safety of personnel through implementing the response must have been considered.

§ 6-1 Outfitting for firefighting and accident response

The fire service must have suitable and sufficient equipment with a high operational reliability to employ in anticipated fires and accidents, including means of transportation, pumps, hoses and other extinguishing equipment, as well as equipment to be used for acute pollution.

In areas where sufficient water for fire extinguishing efforts is not immediately available, the fire service will bring water for extinguishing efforts.

Attachment 3 in the guideline (Emergency preparedness plans, response plans and inspection) [57]

Response plans should contain a situational plan of the area with the following drawn in: – main access and any alternative access –any risk zones requiring evacuation – water supplies for extinguishing - rough floor plan of buildings showing: – access – escape routes – fire sections – location of fire alarm systems – location of automatic extinguishing equipment – hand-held extinguishing equipment – areas/rooms with special hazards – areas with high-voltage switch gear

– current technical rooms etc. – current retreat routes for smoke divers – and overviews of: – object owner and user – fire safety manager - current local experts – resource persons – other relevant persons – current material resources

Emergency preparedness plans

An emergency preparedness plan is to ensure that all resources have been mapped beforehand, that routines for various incidents are described and tasks distributed between different personnel and material. For approximately identical incidents emergency preparedness plan(s) should be prepared to be used by or coordinated with all relevant task forces. For some incidents it may be relevant to prepare separate plans, and if needed, tailored for individual task forces. With basis in the total resources and existing risk in the area, the chief fire officer in collaboration with the police and other authorities should contribute to preparing coordinated emergency preparedness plans. These emergency preparedness plans can be used by several bodies, (emergency operations centres, leaders and response personnel) in various incidents, also see under § 2-1, § 4-1 et al. Such plans must be documented according to § 2-4. The most current situations requiring adaptation of plans are: – large industrial/structural fires – fire/explosion in hazardous warehouse/explosive storage – city block/city fire (densely connected wooden houses) –forest fire – road traffic accident, work accidents, air crash, railroad accident – accident/fire in tunnel (road/railroad /power station) – avalanche, flood, storm – acute pollution – ship's fire – provisional water supplies – special risk objects with basis in local conditions.

A.2 Planning and Building Act

The Planning and Building Act provides how national areas are to be used and regulated, and applies to all types of activities and businesses relating to real property [58]. The act contains a planning part and a building application part, and provides rules on the liability of developers and the authorities, including liability for damages, and the authorities' overseeing of measures and building operations.

A.2.1 TEK10 building regulation

The statutory basis of the building regulation is the Planning and Building Act . This paragraph describes the provisions in the building regulation (TEK10) with guideline [59].

§11-1 Safety in case of fire

Chapter I *General safety requirements in case of fire provide the* following requirements:

(1) Structures must be designed and constructed to ensure the attainment of an adequate level of safety in case of fire for people present in or on the structure, for material assets, and for environmental and social factors.

(2) There must be an adequate opportunity to rescue people and domestic animals and for effective fire extinguishing.

(3) Structures shall be sited, designed and constructed to ensure the probability of fire spreading to other structures is minimal.

(4) Structures where a fire may pose a serious environmental hazard or affect other material community interests, shall be designed and constructed to ensure the probability of harm to the environment or other material community interests is minimal.

The guideline to the first subsection (1) underlines that safety requirements in case of fire in structures, also must ensure safety for rescue crews and firefighters.

The guideline to the second subsection (2) provides that facilitating for effective rescue and extinguishing efforts must be made. This includes manual extinguishing in an early phase of the fire.

The guideline to the fourth subsection (4) amongst other cites structures connected to transport -- concretized with airports – as an example of structures that constitute a major part of society's infrastructure, and which must be placed in fire class 4. Car parks in airports are not mentioned specifically.

§11-2 Hazard classes

Chapter I *General safety requirements in case of fire* provides how structures, or different areas of use in a building, must be categorized in hazard classes according to the «Hazard class» table, with basis in the potential threat of damage to life and health. Hazard classes must be applied as basis for design and construction to ensure escape and rescue in case of fire.

The six hazard classes 1 to 6 are characterized with basis in assessments as to whether

- the structure is only intended for sporadic stops
- people in the constructions work are familiar with opportunities for escape, including escape routes, and can get to safety unattended
- structures designed for overnight stays
- provided that the intended use of the structure does not represent a serious fire hazard

Structures in hazard class 6 require the highest level of fire protection measures.

According to the guideline text on hazard classes in VTEK10, pre-accepted performance level for car parks with two or more floors or levels is hazard class 2. Parking basements and underground garages are also placed in hazard class 2.

§11-3 Fire classes

Chapter I in *General safety requirements in case of fire* states that structures, or the different parts of structures, are placed in fire classes according to the potential consequences of a fire for damage to life, health, societal interests, and the environment. Fire classes will be used as basis for design and construction to secure load-bearing capacity etc. in case of fire.

The division into fire classes BKL 1 to BKL 4 is based on whether the consequences can be characterized as slight, moderate, serious or very serious. VTEK10 has three divisions, BKL 1, BKL 2 and BKL 3, based on hazard class and number of floors. For such structures the pre-accepted performance level may be applied as basis.

Structures where the consequences of a fire may become very large for life and health, the environment or society in general, must be BKL 4, which means the pre-accepted performance levels in VTEK10 are inadequate. VTEK10 gives the following examples of such structures:

- structures with more than 16 floors
- structures where fire may pose a large risk to significant public interests (e.g. infrastructure)
- structures mainly located underground (mountain halls, etc.)
- structures with specific fire load above 400 MJ/m^2
- structures for chemical industry and environmentally dangerous production
- structures storing inflammables and environmentally dangerous substances

According to § 11-3 Table 1 the pre-accepted performance level for a car park with five or more floors is BKL 3. Should assessments suggest that a fire may pose a serious risk to significant public interests (where airports may be an example of significant infrastructure), it may become necessary to place the building in fire class 4. Airports are also particularly mentioned in the guideline to the fourth subsection in §11-1, see the above section.

§11-4 Load-bearing capacity and stability

Chapter II *Load-bearing capacity and stability in case of fire and explosion* provides the following requirements:

(1) Structures shall be designed and constructed to ensure that the structures as a whole, as well as its individual parts, attains an adequate level of safety with regard to load-bearing capacity and stability.

(2) The thermal load from the energy of a fire and the expected progress of a fire in the structure must be taken into account when designing for adequate load-bearing capacity and stability in case of fire.

(3) Load-bearing systems in structures in fire classes 1 and 2 shall be designed to maintain adequate load-bearing capacity and stability for the minimum of the time necessary to escape and rescue persons and domestic animals in and on the structure.

(4) Main load-bearing systems in structures in fire classes 3 and 4 shall be designed to maintain adequate load-bearing capacity and stability for the complete duration of a fire, insofar as this can be modelled.

The guideline to the first subsection (1) specifies that the main purpose of these requirements is to achieve sufficient load-bearing capacity and stability to withstand an anticipated fire load. This is to ensure that the building does not collapse during the fire, but maintains its stability and load-bearing capacity during the time required for escape and rescue.

The guideline to the second subsection (2) provides that a computational demonstration of load-bearing capacity in a fire may calculate or decide the fire load with basis in relevant recognized statistics in accordance with NS-EN 1991-1-2 Eurocode 1: Actions on structures. Part 1-2: General actions. Actions on structures in a fire [60]. For construction parts which according to table 1 must have fire resistance rating R 90 or higher, design fire load must be used which is characteristic for the fire load multiplied with factor 1.5. The 1.5 factor corresponds with the transfer from fire resistance rating R 60to R 90 when using a pre-accepted performance level. (Table 1 is given in the guideline to the third subsection).

In § 11-4 Table 1 in the guideline to the third subsection (3) also applies to the guideline to the fourth subsection (4). Main load-bearing systems in fire class 3 must have fire resistance rating R 90 A2-s1 d0 [A90][29] (90 minutes fire resistance rating, constructed of non-combustible materials or materials with limited flammability). Secondary, load-bearing building components, floor dividers and roof structures that are not part of the main load-bearing systems or stabilizing, must have 60 minutes fire resistance as a minimum (R 60 A2-s1,d0 [A60]).

The guideline to the third subsection provides the following: *Provided that the required time for escape and safety of firefighters is ensured, car parks with more than 1/3 of wall surfaces open may be built with fire resistance rating R 15 A2-s1,d0 [non-combustible material]. Openings must be dispersed and the individual levels must have a design that allows good ventilation. The building must not be too high for firefighter crews to be able to access with their vehicle aerial apparatus. This design assumes that an assessment is made by the person(s) responsible for design. The assessment must be documented.*

Since this guideline text is indicated under the point applying to fire classes 1 and 2, it must be assumed that it only applies to car parks in fire classes 1 and 2.

The guideline to the fourth subsection (4) provides that the requirement for documenting the fire resistance rating for the complete duration of a fire applies to structures in fire class 4. For structures in fire classes 3 the regulatory requirements are fulfilled if the fire resistance rating is in accordance with table 1 provided in the guideline to the third subsection. One exception is structures in fire class 3 with maximum 8 floors, where floor dividers with fire resistance rating R 60 A2-s1,d0 [A 60].

§ 11-6 Measures to prevent the spread of fire between structures

Chapter III *Measures to prevent ignition, development and spread of fire and smoke* provides requirements for measures to prevent spread of fire to other buildings:

(1) Fires shall be prevented from spreading between constructions works in order to maintain the safety of people and domestic animals, and so that a fire does not cause unreasonably large financial losses or societal consequences.

The second and third subsections address spread of fire between low structures, and are therefore not repeated here.

(4) High-rise structures shall be a minimum distance of 8.0 m from other structures, unless the structures are constructed to ensure that fire will be prevented from spreading throughout the full duration of a fire.

(5) Structures that, either due to their inherent properties or the activities taking place in them, entail a particularly high probability of fire spreading, shall be designed, constructed, protected

[29] Text in brackets gives the classification designations that were formerly used in Norway, and that were still being used when this regulation was valid. A indicates that the building component are made in non-combustible materials, and 90 is 90 minutes fire resistance.

or sited so that the particularly high probability of spread of fire to other structures is reduced to an acceptable level.

The guideline to the first subsection (1) provides that the spread of fire between structures may be prevented through establishing sufficient distance between structures, in order that heat radiation, flame exposure and fall-out of burning building components do not ignite neighbouring structures, or by using fire walls with sufficient fire resistance, load-bearing capacity and stability. When the distance between structures is 8.0 m or more, the risk of fire contagion is considered to be low, and usually there is no need for exterior walls or roofs to be fire resistant.

The guideline to the fifth subsection (5) specifies that the risk of spread of fire will be particularly high in structures with a high fire load or where the fire service has a long response time. Such structures may be remotely located hotels, barracks, agricultural structures or lumber yards The longest distance given under paragraph *Pre-accepted performance level* is 25m, and applies to big lumber yards.

§11-7 Fire sections

Chapter III *Measures to protect against ignition, development and spread of fire and smoke* provides the requirements for compartmentation. The first subsection states the following:

(1) Structures shall be divided into fire sections so that a fire within one fire section does not result in unreasonably large financial or material losses. Given the anticipated extinguishing efforts, it should be possible to limit the fire to the fire section in which it started.

The guideline to the first subsection (1) provides that for structures placed in fire class 4, cf. § 11-3, special assessment must be made of the need for compartmentation. Correspondingly, the person(s) responsible for design must conduct a special assessment of the need for compartmentation of structures representing public interests of a particularly large value, or structures of major importance to significant societal interests (e.g. infrastructure). This needs to be clarified with the developer.

Pre-accepted performance level for compartmentation is based on gross area and specific fire load is provided in §11-7 Table 1 as follows:

Specific fire load [MJ/m^2]	**Largest gross area [m^2] per floor without compartmentation**			
	Normally	**With fire alarm system**	**With extinguishing system**	**With smoke ventilation**
Over 400	800	1 200	5 000	Unsuitable
50-400	1 200	1 800	10 000	4 000
Under 50	1 800	2 700	Unlimited	10 000

The guideline text states that specific fire load can be calculated or decided with basis in relevant recognised statistics in accordance with NS-EN 1991-1-2 Eurocode 1: Actions on structures. Part 1-2: General actions. Actions on structures in a fire.

Specific fire load in table 1 is indicated as fire load per m^2 total surface area.

§11-8 Fire compartmentations

Chapter III *Measures to protect against ignition, development and spread of fire and smoke* provide requirements of fire cell partitioning:

(1) Structures shall be appropriately divided into fire compartments. Areas posing differing risks to life and health or in which the risk of fire occurring differs, shall be separate fire compartments unless the same level of safety can be obtained by other means.

(2) Fire compartments shall be constructed in a manner that prevents the spread of fire and conflagration gases to other fire compartments during the time necessary for escape and rescue.

Provisions with relevance to car parks: The guideline to first subsection (1) provides that the following spaces must be separate fire compartments:

- Staircases, even when the staircase is not part of the escape route
- Garage
- Rooms linking the garage with other rooms
- Lift shafts and technical installation shafts. Exemptions apply to lift shafts located in staircases

The guideline to the second subsection (2) contains a table (§ 11-8 Table 1) indicating the pre-accepted performance level for fire resistance of building components. For fire class 3 pre-accepted performance level is EI 60 A2-s1,d0 for building components which is part of fire compartments – in general, for building component surrounding staircases, lift shafts and installation shafts across multiple levels and for lift machine rooms.

§11-12 Measures affecting escape and rescue times

In chapter IV *Facilitating for escape and rescue* the following requirements are relevant for car parks:

(1) In structures that are designed for activities that could result in escape and rescue taking a long time, proactive measures shall be implemented that increase the available escape time.

(2) Structures shall have equipment enabling early detection of fire, so that the necessary escape time is reduced. The following shall as a minimum be complied with:

a) Structures designed for activities in hazard classes 2 to 6 shall have a fire alarm system.

The guideline to the second subsection, letter a, provides in point 1 under pre-accepted performance level that «Fire alarm systems shall be constructed in accordance with fire alarm categories given in table 3 with the exemptions given below». Point 3 states that «For car parks, garages and parking basements, the requirement relating to fire alarm systems applies when the total gross area is larger than 1 200 m^2. As an alternative automatic sprinkler systems may be installed. Car parks with more than 1/3 of wall surfaces on each level open to the outdoors above finished grade and top parking space less than 16m above average finished grade, may nevertheless still be erected without fire alarm systems or automatic sprinkler systems when the openings are located to allow good ventilation.»

According to § 11-12 Table 3 structures in hazard class 2 with 2 or more floors must have a fire alarm system in category 2, if the exemption criteria in point 3 are not fulfilled. This entails all-covering fire alarm systems with optical smoke detectors in all areas.

§11-16 Facilitating manual extinguishing of fires

Chapter V, *Facilitating the manual extinguishing of fires* provides the following requirements:

(1) Structures shall be designed for the effective manual fire extinguishing of fire.

(2) In or on all structures where a fire may occur, manual fire extinguishing equipment must be in place that facilitates effective extinguishing efforts in the fire's initial phase. This is additional to any automatic fire extinguishing system.

(3) Fire extinguishing equipment shall be sited to ensure effective extinguishing efforts. For small structures with activities in hazard class 1, equipment may be located in neighbouring structures.

(4) The location of fire extinguishing equipment shall be clearly marked, unless it is only intended for people in a single housing and the people must be expected to be well acquainted with its location.

The guideline to the first subsection (1) provides that it must be possible for people in the structures to use the extinguishing equipment to extinguish a fire outbreak in an early phase. Further, that fire hoses and hand-held extinguishers are suitable extinguishing equipment in most fires. In the event of extraordinary risks such as fire in cooking oil, fire in metals etc., other types of extinguishants means may be required.

The guideline to the second subsection (2) provides that structures must have fire hoses or hand-held extinguishers. Structures in hazard class 2 must either have hand-held extinguishers or suitable fire hoses reaching into all rooms. Hand-held extinguishers can either be powder extinguishers of minimum 6 kg with ABC-powder, or foam and water devices of minimum 9 litres or minimum 6 litres and with efficiency class minimum 21A according to NS-EN 3-7 Fire material - Portable extinguishers Part 7: Properties, performance requirements and testing methods.

The guideline to the third subsection (3) specifies that the requirement must be met by using practical solutions within each fire section. Fire extinguishing equipment must be lcoated so that users may easily find it, and so that they have a chance of suppressing fire outbreaks in the initial phase before it develops into a major fire. The location must be considered in each case with basis in the activity and the need for fast suppression efforts to protect life, health and material values. The following pre-accepted performance level is given:

1. The number and coverage area of fire hoses and hand-held extinguishers must be such that all rooms in the entire building are covered.
2. Fire hose cabinets must not be placed in staircases. Doors that remain in an open position because of fire hoses being pulled through them, can lead to spread of smoke and fume gasses to the rest of the building.
3. Fire hoses must not be longer than 30 m at full deployment

The guideline to the fourth subsection (4) provides that the sites where manual extinguishing equipment is located must be clearly signed. Signs should be retroflective or illuminated with emergency lighting. Directional signs for extinguishing equipment must be located across the direction of traffic. For material requiring user instructions, these must be found on or at the material, and be in the most relevant foreign languages.

§ 11-17 Facilitating the work of rescue and firefighting personnel

Chapter V *Facilitating the work of rescue and firefighting personnel* provides the following requirements:

(1) Structures shall be sited and designed to ensure rescue and firefighting personnel, and their required equipment are able to gain useful access to and inside the constructions works for rescue and firefighting efforts.

(2) Structures shall be designed to ensure that fires can be easily located and fought.

(3) Technical fire installations of importance for escape and firefighting efforts shall be clearly marked.

The guideline to the first subsection (1) provides that structures up to 8 floors are assumed to have adequate availability for the fire service' aerial apparatus (fire truck equipped with turntable ladder or snorkel), so that all floors and fire sections can be reached, and preferably so that all fire compartments intended for people can be reached. To obtain accessibility the top floor must not be higher than 23m above the lower point on the line-up spaces for the fire service's aerial apparatus. In low structures arrangement for use of portable ladders may be made. Point 5 under paragraph *Pre-accepted performance level* prescribes that it must be possible to reach all parts of a floor using maximum 50m hose line deployment. The distance is calculated from the nearest fire barrier.

The guideline to the second subsection (2) has a separate section headed *Pre-accepted performance level – parking basements*. It states that fires in large parking basements have proven difficult to handle for the fire service, and for this reason special measures need to be implemented to facilitate for rescue and extinguishing efforts in such objects. Measures described include smoke ventilation, location of attack routes for the fire service and a mimic plan for the building. Some of these guidelines may also be of relevance for car parks above ground level.

The guideline to the second subsection also contains section *Pre-accepted performance level – automatic garage facilities.* Such garage facilities are described as a closed and compact facility which is not available to the public

The guideline to the third subsection (3) provides that for large structures in hazard class 2, there must be a mimic plan at the entry to the main attack route containing information about fire dividing building components, escape and attack routes, extinguishing equipment, fire safety installations (alarm and fire extinguishing systems, fire chief, and other important personnel, as well as an overview of particular hazards relating to fire and accidents.

A.2.2 Technical regulations to the Planning and Building Act 1997

The regulations on technical requirements for constructions works (Norw. *Byggteknisk forskrift)* are based on the Planning and Building Act. This paragraph describes the provisions in TEK97 [61] with guideline [62]. Any amendments in TEK10 are commented for each provision.

§ 7-22 Risk categories and fire classes

The division into risk categories is the same as in TEK10. The tabular text on risk categories has been somewhat amended from TEK97 to TEK10, without this being of significance to the classification itself (e.g.: «Only intended for awake persons» in TEK97 is changed to «Buildings intended for overnight stops» in TEK10).

The system for fire class classification is identical for TEK97 and TEK10 with guidelines.

§ 7-23 Load-bearing capacity and stability in a fire

TEK97 §7-23 point 2b provides the following requirements:

Main load-bearing systems in buildings in fire classes 3 and 4 shall be executed so that the building maintains its stability and load-bearing capacity throughout the entire course of fire.

Secondary structures that only are load-bearing for one floor, or for the roof, shall remain their stability and load-bearing capacity during the time necessary for escape and rescue in and on the building.

§ 7-23 table 1 in the guideline to TEK97 provides the pre-accepted performance level for fire resistance of load-bearing building components in fire class 3. The performance level for main load-bearing systems and for secondary, load-bearing building components, floor dividers and roof structures is the same as in the guideline to TEK10.

The following guideline is specifically provided for car parks:

Buildings with median fire load (maximum 400 MJ/m²) with open wall surfaces toward the outdoors so that fire and flue gases are easily vented, not contributing to a rapid fire growth, may be built with a lower fire resistance rating than indicated in § 7-23, table 1. Provided that the time necessary for escape and safety for firefighters is taken into account, a car park with more than 1/3 of wall surfaces open may be built with fire resistance rating R 15 A2-s1,d0 [non-combustible material]. Openings must be dispersed and the individual levels must have a shape that allows good ventilation. Buildings must not be higher than allowing firefighters access with their ladder material.

This is on the whole identical to the text in VTEK10 to §11-3. third subsection, except that the guideline to TEK97 does not specify that the assessment must be documented. TEK97 does not indicate that this guideline text contains some limitations as concerns the building’s fire class.

§ 7-24 Ignition, development, and spread of fire and smoke

Requirements for fire cell partitioning and compartmentation are provided in point 3. *Spread of fire and smoke in buildings.*

The wording relating to fire cell partitioning is roughly identical to the corresponding text in TEK10. The guideline to TEK97 provides the same requirements for the fire resistance rating of building components in fire class 3 as the guideline to TEK10.

The wording relating to compartmentation is identical to the corresponding text in TEK10. The guideline to TEK97 gives the same area restrictions for compartmentation based on fire load as the guideline to TEK10.

§ 7-25 Fire extinguishing arrangement

General requirements are provided in item 1 of the provision; requirements for fire extinguishing equipment in item 2 and marking requirements in item 3. Requirements in TEK97 are in principle the same as in TEK10, but TEK97 does not emphasize that it is a matter of manual extinguishing equipment, such as in TEK10.

The texts in TEK97 and TEK10 provide the same guideline as concerns arrangements for manual extinguishing of fires in an early phase.

§ 7-26 Spread of fire between buildings

The content in provisions on spread of fire between buildings is in principle the same in TEK97 and TEK10, however, there are some minor changes to the wording. Therefore the regulation text of TEK97 is rendered below.

1. General requirements
Risk of spread of fire between buildings shall be prevented so that personal safety is ensured and so that the fire does not lead to excessively large financial or public loss or damage.

The second subsection addresses spread of fire between low buildings, and is therefore not rendered her.

3. Spread of fire between tall buildings
Tall buildings shall have minimum 8m distance to other buildings, unless the building is designed so that spread of fire is prevented for at least 120 minutes.

4. Buildings posing a large risk of spread of fire
Buildings which either by themselves or by the activities performed in them, entail a particularly high risk of spread of fire, must be planned, executed, secured or placed so that the particularly high risk of spread of fire to other buildings is reduced to an acceptable level.

The guideline to TEK97 provides the same recommendation as the guideline to TEK10.

§ 7-27 Escape of persons

TEK97 provides the following requirements:

2. Measures affecting escape times
If a safe escape is not ensured through physical design of the escape route, the building shall have sufficient fire protection equipment to reduce the necessary escape time.

…

The guideline to TEK97 provides that *Buildings where fire may threaten a large number of people, and buildings that are large and over-complex, shall have fire alarm systems providing rapid information about fire.*

Further, for car parks *buildings or parts of a building being used for parking of cars shall have fire alarm systems or automatic fire extinguishing systems, when the total gross area for the purpose is larger than 1 200 m². Car parks/garages with more than 1/3 open wall surfaces and the top parking space less than 16 m above average level terrain may nevertheless be built without fire alarm systems, when openings are located to provide good ventilation.*

§ 7-28 Arrangements for rescue crews and firefighters

The regulation text in TEK97 is identical to the text in TEK10. The requirement for marking of fire safety installations provided in TEK10 §11-17, is in TEK97 provided in item 3 in *§ 7-25 Fire extinguishing arrangement* (see above).

A.2.3 Building Application Regulation

Building Application Regulation (SAK10) [63] with guideline [64] is statutorily based in the Planning and Building Act . SAK10 became effective 1 July 2010, replacing regulation on building application and control in building matters (SAK) from2003 [65].

The introduction of SAK10 gives the purpose of the Planning and Building Act as *amongst others, to promote sustainable development to the benefit of individuals and society, and to ensure that building application procedures in building projects are in accordance with the law, regulation and planning decisions, cf. pbl. § 1-1. The regulation shall contribute to ensuring implementation of the purpose of the law through requirements relating to applications, procedures, responsibility in building matters, implementation of supervision, control, and provisions on penalty for violations.*

After the fire there were media discussions as to which fire class the car park should have been placed in. This is a natural topic for discussion in a pre-conference.

Pre-conference is described in the Planning and Building Act § 21-1:

§ 21-1 Pre-conference

To get a further clarification of project framework and contentt, a pre-conference may be held between the developer, municipality and other affected technical bodies. Other affected bodies may also participate. The developer or the planning and building authorities may demand that a pre-conference be held.

The ministry may provide regulations on the preparation, implementation, and keeping of minutes of the pre-conference.

The description of the pre-conference is in principle the same in SAK and SAK10 The following renders the text of SAK10.

SAK10 §6-1 first subsection describes the pre-conference as follows:

Pre-conference under the Planning and Building Act § 21-1 shall clarify the assumptions and framework of the further procedures.

The guideline to the first subsection states introductorily:

The purpose of a pre-conference is to establish early contact between the developer and the municipality. A clarification meeting between the parties will illuminate relevant issues of concern relating to the project, allowing the developer to become familiar with relevant requirements and assumptions for further procedures.

SAK10 poses requirements for reciprocal information to be conveyed between the developer and municipality in connection with the pre-conference:

SAK10 §6-1 fourth subsection:

The developer shall as far as possible account for project content, scope, location, progress, current responsible parties, and assumptions. The developer must in advance give the municipality the information required for pre-conference preparation. The municipality may demand that such information be given in a specified form.

SAK10 §6-1 fifth subsection:

The municipality shall provide the necessary information on framework assumptions and requirements relating to area plans, infrastructure, current laws, regulations and guidelines, documentation requirements, requirements relating to project location, need for coordination with relevant authorities, cf. § 6-2, municipality practice, procedural routines, opportunity for divided application procedure, independent control, supervision, responsibility rules, requirements relating to enterprises with liability, and other matters of importance. The municipality shall give information about the further procedure and assumed processing time.

Independent control

SAK from 2003, with guideline, describes project control in chapter VIII. The guideline states that as a rule all projects subject to application are to be controlled. The control may either be performed by the executive party (internal control) or other enterprise (independent control). The municipality shall in each building case consider whether an independent control is needed. Fire safety is mentioned as an important and critical control area. The guideline also provides that

> *Independent control is no exemption from the rule, but shall be employed in all cases where this is required in order to ensure satisfactory control. It is recommended that municipalities to a large extent evaluate using independent control to ensure that the project are in accordance with provisions provided in or pursuant to pbl.* (Planning and Building Act)

The control must be documented. Documentation will not be sent to the municipality, but retained by the enterprise to be available in any municipality inspection.

January 2013 saw the introduction of requirements for mandatory independent control of fire safety for building works in enterprise classifications 2 and 3. Project control is described in § 14 in SAK10. The control requirement according to SAK10 § 14-2, second subsection, letter d) is limited to *engineering of fire safety strategy*. The requirement became effective to applications received by the municipality as of 1 January 2013 [66].

Appendix B Interview program

Function	Theme of interview
Emergency response team leader (First UL on site)	- Call out - Turn-out (Collection of information) - Arrival report submitted - (OBBO) - Immediate measures - Risk assessment - Goal of response - Tactical plan (IDA) - Internal interaction
Fire task leader	- Call out - Arrival report received - Potential based management - Scaling of response organization - Risk assessment - Goal of response - Tactical plan - Interaction ILKO - Create endurance - Revaluate: MMI, TP, IDA
Incident commander	- Call out - Arrival report received - Potential based management - Evaluation of leader support /ELS - Assigning/distribution of tasks with 0.1 - Fleet management/Overall outline - Internal-Liaison-staff - Collaboration with AVINOR/Sola municipality/Other - Revaluate MMI/TP - Interaction internal/External - Create endurance
Avinor task leader	- Call-out - Turn-out time - Arrival report submitted/received - Initial measures - MMI and TP? - Safety network/contact with fire task leader - Airport operation
RBR-110 guard	- When was assistance request received - Arrival report received - When did callout go off (which vehicles) - When was link request sent (Incendium) - Does airport have TETRA (interaction) - Number of coincident incidents

	- Time of incident command - Evaluation of need for extra resources - Incident updates
Police task leader	- Arrival report - Interaction ILKO - Organization of incident scene - Distribution of work and responsibilities - Endurance - Management system

Appendix C Response timeline

A timeline for the incident is shown in Table C-1. In the *incident* column, the different types of vehicles at the fire service's disposal are referred to as «S 4-1», «S 2-1» etc., where the first digit indicates the station from which the vehicle comes, and the second digit is the type of vehicle (1 and 2 are personnel carriers). When the first digit is 0, e.g. «S0-1» and «S0-3», the vehicle belongs to the command unit.

Table C-1 Incident record put together and reported by RBR

Hour:	**Incident:**	**Source:**	**Other:**	**Hours**
---- *07.01.2020* ----				
Ca. 15:25	Vehicle starts burning.	Tactical information from the police and assessment of information.		0 min
15:33:39	Call received by the emergency operations centre. Fire in vehicle.	Incident record, emergency operations centre		8 min 39 sec
15:33:49	AMK calls emergency operations centre. They have a caller reporting a car fire at the airport.	Tel. record 110.		8 min 49 sec
15:34:06	The police call the emergency operations centre. AMK is also on the line reporting a car fire at the airport.	Tel. record 110		9 min 6 sec
15:34:29	S 4-1 and S 1-2 are assigned tasks.	Incident record, emergency operations centre		9 min 29 sec
Around. 15:34	The operations centre receives a call from the Heliport.	The heliport		Around 9 min
Around 15:35	The operations centre at Avinor assigns tasks to the fire and emergency service.	Avinor		Around 10 min
15:35:34	New caller to the emergency operations centre. Reports a car fire at the airport. The emergency operations centre requests a video stream.	Tel. record 110		10 min 34 sec
15:35:57	Notice stating that it is an Opel Zafira burning.	Incident record, emergency operations centre		10 min 57 sec
15:36:18	Notice stating that the vehicle is all aflame.	Incident record, emergency operations centre		11 min 18
15:36:23	S 4-1 starts off from Vestre Svanholmen 13	Incident record, emergency operations centre		11 min 23 sec

Hour:	Incident:	Source:	Other:	Hours
15:37:07	S1-2 starts off from Brannstasjonsveien 2	Incident record, emergency operations centre		12 min 7 sec
15:37:50	Manual call point is pressed in car park. Alarm bells at car park are activated.	Alarm response, emergency operations centre		12 min 50 sec
Around15:38:00	S0-3 listening in on Brann 0; perceives real incident. Calls emergency operations centre, requests more resources.	Tel. record to S0-3		Around 13 min
15:40:40	Electric vehicle slams. Risk of fire spreading to three to four vehicles.	Incident record, emergency operations centre		15 min 40 sec
15:41:15	S0-3 is assigned task.	Incident record, emergency operations centre		16 min 15 sec
15:41:18	Notice stating that car park is full. High spreading risk. Flames, large bangs and several vehicles on fire observed.	Incident record, emergency operations centre		16 min 18 sec
15:41:36	S2-2 was assigned task.	Incident record, emergency operations centre		16 min 36 sec
15:41:45	Police are on site. Everyone who was in the vehicle is out.	Incident record, emergency operations centre		16 min 45 sec
15:43:17	Around 10 vehicles on fire.	Incident record, emergency operations centre		18 min 17 sec
Around15:44:00	Panter 1 from Avinor arrives at car park.	Avinor and S4-1 (observation)		Around 19 min
15:44:21	S4-1 arrives at car park.	Audio record		19 min 21 sec
Around15:45:00	Panter 1 lines up at car park exit to start extinguishing. Cannot extinguish due to people/vehicles in the way.	Avinor		Around 20 min
Ca15:47:00	S4-1 parks the truck and starts advancing fire hoses	Conversation with response leader on S1-2. Observed S4-1 at site when they arrived.		Around 22 min
15:48:03	S1-2 arrives at car park.	Incident record, emergency operations centre		23 min 03 sec
ca15:48:30	Panter 1 from Avinor lines up at S4-1 to function as a tanker until S4-1 is connected to tank.	Avinor		23 min 30 sec

Hour:	Incident:	Source:	Other:	Hours
15:50:26	The police close the road to the airport.	Incident record, emergency operations centre		25 min 26 sec
15:51:21	S0-3 arrives at car park.	Incident record, emergency operations centre		26 min 21 sec
15:51:23	Meeting place is Heliport.	Incident record, emergency operations centre		26 min 23 sec
Around15:52:00	S0-3 receives information from the police task force leader that people are out of the building.	Conversation with S0-3		Around 27 min
15:57:47	ILKO is at Heliport. Large smoke development. Panter is at the scene to assist.	Incident record, emergency operations centre		32 min 47 sec
ca15:58:34	S2-2 arrives at car park.	Incident record emergency, operations centre and conversation with brigadier general S-03		33 min 34 sec
16:01:27	S0-3 requests more personnel carriers.	Incident record, emergency operations centre		36 min 27 sec
16:01:37	S0-3 needs more personnel carriers due to hotel nearby. Requests two personnel carriers.	Incident record, emergency operations centre		36 min 37 sec
Around 16:02:00	Police with smoke diver equipment have begun evacuation of Scandic Hotel.	Conversation with S.0-3		Around 37 min
16:02:33	S1-1 was assigned task.	Incident record, emergency operations centre		37 min 33 sec
16:03:34	ILKO established at the Heliport.	Incident record, emergency operations centre		38 min 34 sec
16:09:15	S9-1 was assigned task.	Incident record, emergency operations centre		44 min 15 sec
Around 16:10:00	S1-3 starts off from the main fire station.	Conversation with driver at S1-3.	Did not receive call-out from emergency operations centre. Confirmation of arrival time at destination.	Around 45 min
16:15:00	The airport is closed for air traffic. Available resources from fire and emergency services start off heading for car park.	Avinor		50 min
Around 16:20	S0-3 reports spread to 1st floor.	Audio record		Around 55 min

Hour:	Incident:	Source:	Other:	Hours
16:21:10	S1-1 arrives at car park.	Incident record, emergency operations centre		56 min 10 sec
Around16:23:00	Panter 2 and 3. Superbuffalo arrive at car park.	Avinor		Around 58 min
16:28	RBR requests more water pressure at Sola.	SIM		1 hour 3 min
Around16:30:00	S1-3 arrives at the car park.	Conversation with driver on S1-3.	Did not receive call-out from the emergency operations centre. Confirmation of arrival time at destination.	Around 1 hour 5 min
16:30:37	S1RVR was assigned task.	Incident record, emergency operations centre		1 h 5 min 37 sec
16:31:48	Sola municipality increases water network pressure.	Incident record, emergency operations centre		1 h 6 min 48 sec
16:35:45	S0-1 on its way out as leader support for S0-3.	Audio record		1 h 10 min 45 sec
16:36:24	S9-1 arrives at the car park.	Incident record, emergency operations centre		1 h 11 min 24 sec
16:37:23	S4-4 is on its way to Sola.	Incident record, emergency operations centre		1 h 12 min 23 sec
Around16:41:00	S0-1 arrives ate car park.	Audio record and conversation with S0-1		Around 1 h 16 min
16:41:47 16:43:46	Incoming message via Police that building might collapse after 1-1.5 hours at high temperature. 110 sends out a 98 notice regarding this in BABS.	Incident record, emergency operations centre Audio record		1 hour 16 min 47 sec 1 hour 18 min 46 sec
16:45:13	S1RVR arrives at car park.	Incident record, emergency operations centre		1 hour 20 min 13 sec
16:47:00	S0-3 reports that all crew must withdraw from the building.	Audio record		1 hour 22 min
16:47:02	It is burning fiercely on the 1st floor.	Incident record, emergency operations centre		1 hour 22 min 2 sec
17:02:50	Parts of the building are beginning to collapse.	Incident record, emergency operations centre		1 hour 37 min 50 sec
17:20:09	Building stage 3 collapses.	Incident record, emergency operations centre and audio record		1 hour 56 min 51 sec
17:39:12	Full blaze on 1st floor above fire site.	Incident record, emergency operations centre		2 hours 14 min

Hour:	Incident:	Source:	Other:	Hours
17:54:08	Established 25m safety distance around car park of 25 meters.	Incident record, emergency operations centre		2 hours 29 min
19:30 – 21:00	At this point Avinor's Panter extinguishing efforts have a gradually increasing effect. They are located on the southwest side (the heliport).	NRK's live broadcast		4 hours and onwards
20:10:06	Emergency warning to the population sent out.	Incident record, emergency operations centre		4 hours and 51 min
20:40 – 21:10	Excavator in place to tear down façade panels.	NRK's live broadcast		5 hours and onwards
		---- 08.01.2020 ----		
01:27:49	It is still burning inside building. Some fresh outbreaks occasionally. Significant fire development.	Incident record, emergency operations centre		
18:13:26	S0-3 reports that crews are finishing up at incident, and Avinor takes over security.	Incident record, emergency operations centre		1 day 2 hours 50 min
		---- 09.01.2020 ----		
12:03:34	S1-2 sets out after smoke alarm notification on 2nd floor. Overheating in the collapsed pile.	Incident record, emergency operations centre		1 day 20 hours 38 min
14:33:16	Incident terminated.	Incident record, emergency operations centre		1 day 23 hours

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