Development of Safety Measures for Nightclubs

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Abstract
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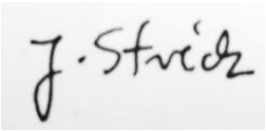
Read and approved

Lund, 30th April 2014



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Abstract

There have been numerous tragic incidents in nightclubs leading to hundreds of fatalities. This thesis attempts the current situation. Different nightclub fires from the past 17 years were analysed in order to identify the critical factors influencing these events. As most dominant factors the illegal operations of nightclubs; the use of pyrotechnics; the choice of materials; manual & automatic fire protection systems; the occupant load and the means of egress were identified. Additionally, the training of staff was found to be valuable, if present. It was never just a single factor influencing the events but always a combination. Additional input has been found by analysing two different evacuation experiments. The influence of staff and the fact that single rooms can become overcrowded before the maximum number of occupants of the venue is reached were identified. The critical factors are addressed in the regulations of the U.S.A. and the UK. It is recommended that countries with less developed codes adapt their codes to the more developed ones or completely adopt them, implement aggressive enforcement, fight corruption and improve their fire safety culture. Additional recommendations for future research are given.

Zusammenfassung

Immer wieder ereignen sich in Nachtclubs tragische Brandkatastrophen mit Hunderten von Toten. Diese Arbeit gibt Vorschläge zum Schutz vor solchen Katastrophen um damit die aktuelle Situation zu verbessern. Um die Faktoren, die den Verlauf einer Brandkatastrophe negativ, aber auch positiv beeinflussen, zu identifizieren, wurden Nachtclubbrände der letzten 17 Jahre analysiert. Als dominierende negative Faktoren wurden der illegale Betrieb von Nachtclubs, der Einsatz von Pyrotechnik, die Wahl von Baumaterialien, manuelle und automatische Schutzsysteme; die Anzahl von Gästen sowie die Fluchtmöglichkeiten identifiziert. Darüber hinaus wurde das Ausbilden der Angestellten als besonders positiv befunden. Nie war nur ein einzelner Faktor verantwortlich, immer eine Kombination mehrerer. Zusätzlich wurden zwei Evakuierungsexperimente von verschiedenen Nachtclubs analysiert, die weitere Erkenntnisse brachten: Das Verhalten des Clubpersonals hat großen Einfluss auf die Besucher und selbst wenn das Personenlimit des Nachtclubs nicht erreicht ist, können einzelne Räume gefährlich überfüllt sein. Sämtliche Einflussfaktoren werden von den gesetzlichen Bestimmungen der USA und Großbritannien behandelt. Vorgeschlagene Maßnahmen zum Schutz vor Brand-Katastrophen in Nachtclubs sind die Anpassung der Gesetzesgrundlage von Entwicklungs- und Schwellenländer an das Niveau entwickelter Länder wie USA und Großbritannien; die Verifizierung, dass diese Gesetzesgrundlagen ausreichend sind; die konsequente Durchsetzung und Kontrolle der bestehenden Gesetze und Kampf gegen Korruption sowie die Sensibilisierung für das Thema Brandschutz und Aufbau einer Sicherheitskultur. Darüber hinaus werden Vorschläge für zukünftige Forschungsgebiete gemacht.

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List of Acronyms and Abbreviations

ABNT	Associação Brasileira de Normas Técnicas
ASET	Available Safe Egress Time
BAC	Blood Alcohol Concentration
BBC	British Broadcasting Network
BS	British Standard
CNN	Cable News Network
DJ	Disc Jockey
FED	Fractional Effective Dose
INTI	Instituto de Tecnología Industrial
IT	Inspection Time
NFPA	National Fire Protection Association
NIST	National Institution of Standards and Technology
ppm	parts per million
P.A. System	Public Address System
PU	Polyurethane
RSET	Required Safe Egress Time
SART	Sustained Attention to Response Task
SOPT	Self-Ordered Pointing Task
U.S.A.	United States of America
UFOV	Useful Field of View Test
UK	United Kingdom

1. Introduction

Fire has and will always be a threat for humans and their environment. A fire can start due to several circumstances. In general, three things are necessary to start a fire; sufficient oxygen, combustible fuel and an ignition source [1]. Sufficient oxygen to at least start a fire is given in most environments that people can occupy. Combustible fuels can for example be building materials, interior finishings, cables or simply a stack of clothes. There are a high number of possible ignition sources. Electrical shortcuts, a pyrotechnic display and arson, just to name a few, can lead to an ignition. A fire can, in its early stages, be dangerous for people and in its later stages to the structure itself. For people, a fire becomes dangerous in an environment which makes it difficult to escape before the conditions reach a critical point. These environments can be isolated environments such as airplanes, ships or buildings. Most fires that led to fatalities or injuries occurred in residential buildings [2]. However, there have been many fires leading to a high number of fatalities occurring in non-residential but densely occupied buildings.

Densely occupied buildings can be office complexes, like the World Trade Center or industrial facilities as well as assembly buildings such as nightclubs. This thesis will focus on the nightclub environment. Throughout history there have been several fatal nightclub fires such as the Cocoanut Grove nightclub fire in 1942 resulting in 442 fatalities [3]. In the years 2000-2004 1350 fires in clubs in the U.S.A. were reported [4]. In the United States, 27% of the analysed fires of the time period were reported in clubs, excluding eating and drinking establishments as well as religious and funeral properties.

A nightclub is, as any other company, profit-orientated and therefore the owner tries to maximize his profit. Obviously the regulations have to be fulfilled in order to reach a minimum safety standard.

1.1 Research Aim and Purpose

The aim of this master thesis is to develop safety measures for nightclubs. In order to be able to do so, critical factors regarding nightclub safety in a fire situation are identified, by analysing past nightclub fires as well as experiments and, on that basis, give recommendations on how to create safer nightclub environment.

1.2 Method

In order to understand human behaviour in response to a fire emergency, the theoretical background is given in chapter 2. In order to identify critical factors that are negatively and positively influencing an evacuation in case of an emergency, nine different nightclub fires from the past 17 years are evaluated in Chapter 3. Chapter 4 focuses on evaluating two different evacuation experiments carried out by the Lund University and the University of Ulster. Chapter 5 focuses on the current state of the art in nightclub safety, mainly by verifying whether the determined factors are addressed in the regulations of the NFPA and the BSI. In chapter 6, recommendations to create a safer nightclub environment as well as limitations of the study are given. Suggestions for future research are given in chapter 7.

1.3 Definition of a Nightclub

A nightclub is an entertainment venue that is open until late at night. A nightclub usually has a dance floor and plays loud live or amplified music. Some nightclubs have *"showy décor and elaborate lighting"* [5]. A nightclub usually serves drinks, both alcoholic and non-alcoholic, and sometimes food [6], [7].

2. Human Behaviour in a Fire Situation

Human behaviour in a fire situation depends on a lot of things such as the individuals experience and training regarding fire situations [8]. If people are inexperienced they can underestimate the growth rate of a fire and its severity, even experts can fail to estimate fire growth or severity [9]. People who have had prior experience with a similar threatening situation before tend to be highly sensitized and react very fast upon cues similar to those already experienced [10].

Other important factors are the affiliation of occupants with familiar places or people as well as the question if patrons of whether staff stay in their original role during a drastically changing situation such as a fire.

The degree of focus can also be important. For example are the occupants ignoring a fire alarm because they are still dancing, are they influenced by alcohol and therefore have a slower reaction time or they perceive danger differently [11], [12], [13]? It is possible that people are not committing to an evacuation because they paid a lot of money to enter the club or do they just not want to accept that their fun night out has ended [14]. Additionally, occupants can be influenced by the behaviour of others [15], [16]. Other aspects that can influence human behaviour are age and gender [8].

2.1 Risk Perception and Fire Growth

In a fire situation, the correct approximation of fire growth can be of vital importance. Fire growth is normally described by the energy that is released: $Q = \alpha * t^2$, where Q is the released heat, α is the growth factor [kW/s] and t is the time from established ignition [s] [17].

From witness statements, as well as experiments, it was found that people are not very good at estimating fire growth or the severity of a fire. In the aftermath of the Stardust nightclub fire in the Republic of Ireland in 1981 people watched the fire grow as well as the extinguishing attempts [18]. During this incident 48 people died and 214 were injured. Similar behaviour was reported for the Beverly Hills Supper Club fire in the U.S.A. where almost everybody had underestimated the severity of the fire even after evacuating the building and looking back at the fire. This fire resulted in 164 deaths and 70 injuries [15].

This inability to estimate fire growth is being supported by two experimental studies which have been carried out by Lund University [9], [19]. In the first experiment 535 people, mainly students participated. The 141 participants for the second experiment were students as well and therefore representative of a nightclub population. In the experiments the participants were expected to estimate the time difference between two video sequences from two different growing fires. In the first experiment, a chair and a popcorn machine fire were shown and in the second experiment a popcorn machine and a kitchen fire were shown. Both studies show that young adults' estimations of fire growth are very poor. For the second experiment it was found that the majority of participants underestimated the time difference for the videos of the popcorn fire, thus overestimating the fire growth. The majority of participants overestimated the time difference for the kitchen fire, thus underestimating fire growth. This is connected to the fire growth itself. A fast growing fire is more likely to be underestimated. In reality, a dangerous situation occurs when the fire growth or severity are underestimated [9]. In a different study, it was found that out of the people that are exposed to a fire, those closest perceive it as more dangerous and are more likely to evacuate earlier than those further away [20]. This can be a problem since people further away do not necessarily understand the immediate danger and therefore not only block the way for those already being exposed to danger but can also delay their own evacuation until it is too late to do so safely.

2.2 Models & Theories

In this section, a description of different human behaviour models and theories is given. These theories are vital to understand human behaviour in fire situations, such as in nightclub fires, and to be able to avoid future tragedies by designing.

2.2.1 The Behavioural Sequence Model

In order to develop the Behavioural Sequence Model Canter, Breaux and Sime carried out interviews with fire victims [20], [21]. They found that in the developing phase of a fire people had to deal with a lot of uncertainty. The information the fire victims had was very limited and ambiguous. The first cues of being in a fire situation were "*strange noises, unaccustomed behaviour of others, such as running, and […] direct encounter with smoke or flames".* It was found that the fire victims constantly became involved in an investigation in

order to determine what threat they had faced during the fire. In many cases it was found, that in the early stages of a fire, the motivation to reduce uncertainty was stronger than the motivation to evacuate. They developed the following behavioural model that shows the different steps people go through in a fire scenario, from receiving information, to interpreting, to preparing to take action.

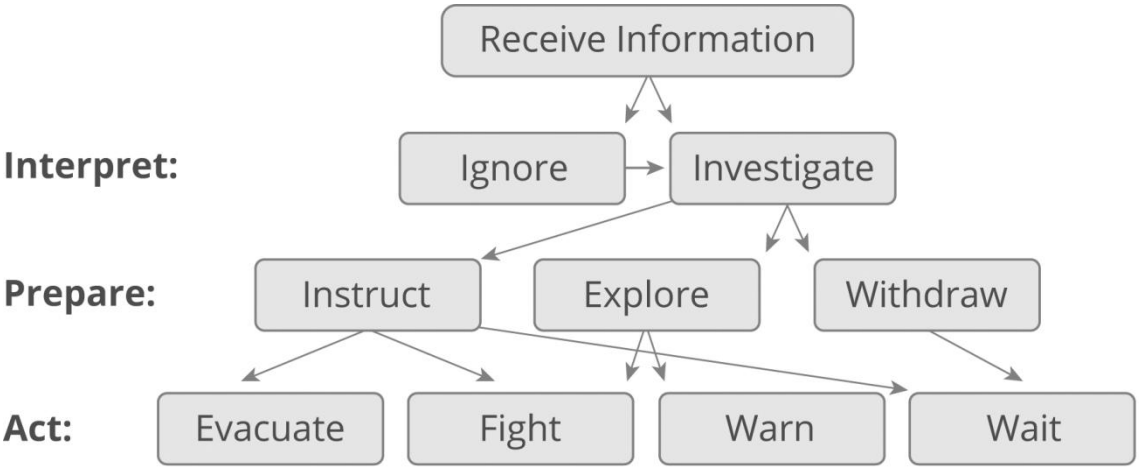

Figure 1: The Behavioural Sequence Model; Figure based on [21]

2.2.2 The Egress Time-Line Model

The Egress Time-Line Model describes the different time steps of a fire situation. It defines the Required Safe Egress Time (RSET) as well as the Available Safe Egress Time (ASET). The RSET includes every step from ignition and detection until the occupants have safely left the building. The different steps are the ignition, the detection time, the alarm time, the recognition, the response and the movement time. The recognition and response time are defined as the pre-movement time. The ASET is the time from the ignition of a fire until conditions in the building become untenable for humans [22].

Occupants should have an adequate time for evacuation before these conditions are reached. An adequate time for evacuation means that people in an evacuation process *"[...] are not exposed to falling structural elements, high temperature, high levels of heat radiation, toxic gases or reduced visibility [...]"* which would make a person incapable of safely evacuating [23]. In a standard fire situation, smoke is the biggest threat for humans. Smoke can have irritant effects as well as obscure vision and therefore slows down the walking speed. A more complex approach regards the Fractional Effective Dose (FED). This dose is the comparison

between the dose received by the occupant and the dose necessary for incapacitation [24]. In order to ensure a safe egress the RSET should be smaller than the ASET [22].

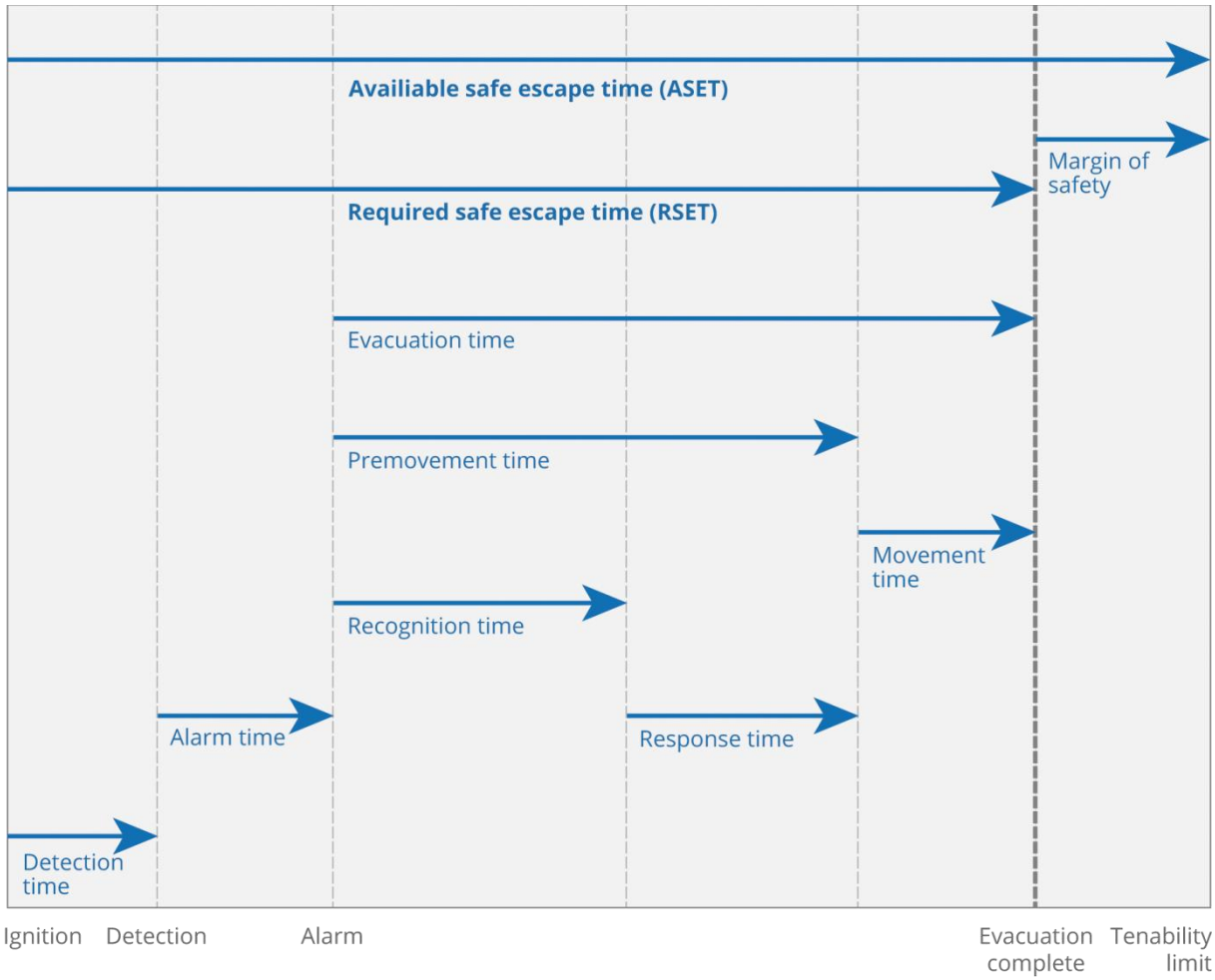

Figure 2: The Egress-Time-Line Model; Figure based on [22]

2.2.3 The Affiliation Model

The Affiliation Model was introduced by Sime who studied human behaviour in fire on the basis of witness statements [25]. He found that in a threatening situation people *"[...] seek security with the familiar [...]"*. He states that in an emergency *"[...] attachment takes precedence of escape behavior"*. Furthermore, he states that the direction of flight will not only be related to the location of the fire but also to the location of familiar people or places. In case of *"[...] an emergency people are even more likely to be drawn towards familiar places or people than under normal conditions"*.

Another behavioural aspect he discovered is that individuals tend to respond faster to ambiguous cues of a potentially dangerous situation than groups. Latané and Darley give a

possible explanation by stating that the presence of a group gives the feeling of having an increased ability to cope with a fire [26]. They stated that *"[…] subjects in groups may have been less afraid of fire […] than solitary subjects"*.

People unfamiliar with a place will most certainly use the main entrance, whereas staff entering through side entrances on a daily basis, prefer to use those during evacuations [20]. If a close relationship between patrons and waiters/waitresses exists and they know alternative exits this relationship can lead to a use of exits being closer than the main entrance. The patrons assume that the waitress working in the same location every day has a profound knowledge of the evacuation design and can guide them to safety. This is exactly what happened in the Beverly Hill Supper Club fire [15].

2.2.4 Social Influence

In a fire emergency social influence can play an important role, especially concerning pre-movement time [16]. When speaking about group influences there are mainly two cases which need to be distinguished. The first one is the *normative influence* which means that people do not want to make a fool out of themselves and be different from the rest. In an uncertain situation for example with very little cues of what is going on and what should be done nobody wants to move first. The second one is the *informational influence* which goes hand in hand with the above mentioned behaviour. People are observing what the other people around them are doing. When the first person starts evacuating it is likely that others will follow since are no longer responsible for setting an example. They cannot make a fool out of themselves anymore.

2.2.5 The Role-Rule Model

In general, everybody has a certain role. This role is associated with a certain set of rules. There are for example waitresses working behind the bar who are allowed to serve alcohol while the ordinary occupant is not. People's behaviour in a fire situation is influenced by their own expectations that they have of themselves. During the Beverly Hills Supper Club fire the staff still perceived themselves as being responsible for the occupants. Prior to the fire waitresses were assigned to serve certain patrons. When the fire broke out each waitress

instructed *"[…] those patrons for whom they had had responsibility prior to the fire"* [15], [20]. They actively guided them out. Care needs to be taken since this model cannot be used as a precise predictive tool and does not apply in every situation. Not such a close relationship between staff and patrons existed in the Summerland fire. The patrons mainly exited through the main entrance whereas the staff mainly exited through the alternative exits, which they use on a daily base to enter the premise [20].

2.2.6 The Theory of Affordances

According to The Theory of Affordances every object, such as an emergency exit, has 4 different affordances: a cognitive, physical, sensory and functional one [27], [28]. The Theory of Affordances can be used to understand why for example some emergency exits function better than others [29]. It is important to understand this theory in order to avoid conflicts. All information given to people in a fire situation should be as simple as possible [30], [31].

Sensory affordance refers to the ability to see or sense an object [28]. This means for example the visibility of an emergency exit. An emergency exit should be visible in any given condition. This can be achieved by luminescent cues or a painting that is in contrast to its surrounding environment. Another possibility would be flashing lights catching the attention of the occupants in case of an evacuation alarm. These measures have to be applied individually and adapted to each situation [27].

Cognitive affordance refers to the ability to understand an object [28]. Understanding of an emergency exit begins with signage. The signs should be easily understood and leave no room for interpretation. Experiments carried out by Lund University have shown that the use of green flashing lights attract the attention of occupants and can help in a fire emergency [27]. The test participants stated that the colour green helped to convey the message of the emergency exit leading to a safe place. Complexity should be kept out of a design. An emergency exit should be designed as simple as possible in order to avoid misunderstandings.

Physical affordance refers to the physical possibility of using an object [28]. An emergency exit that is difficult to open, opens against the direction of the egressing flow, is blocked by obstacles or is locked and therefore hinders/inhibits a safe evacuation should be avoided. The usage for people with disabilities should be considered [27].

Functional affordance describes how the individual's goal can be fulfilled in conjunction with the other affordances [28]. Sometimes this goal can be difficult to describe. In case of a fire or other situations demanding an evacuation a possible goal is to evacuate as fast as possible. The functional affordance combines all other affordances. If an emergency exit is easy to see, understand and use, it is functional. An emergency exit should therefore be provided with a powerful combination of sensory, cognitive and physical affordances [27].

It is important to mention that *conflicting affordances* can occur and should be avoided. An example for a cognitive conflict can be that an emergency exit is marked as such but has a sign on the door saying "staff only" or "no admittance". Occupants might misinterpret the use of the door. A conflict between physical and cognitive affordance could be the use of a push handle while the door needs to be pulled to be opened. Conflicting affordances are named misaffordance [32].

2.3 Panic

The word "panic" often appears in the media when describing a fire emergency. In the field of fire safety it was stated that *"the concept of panic is a myth meant to blame the outcome of a tragedy on the occupants when in fact the building design or its management were possibly at fault"* [33]. Experts claim that panic occurs very seldom and that the term panic is often misused by society and media as well as by some people closely concerned with the concept [30], [34], [35]. Quarantelli even questions *"whether there is still any scientific justification for the continuing use of the concept in any technical sense"* [34]. In order to get a better understanding of the concept of panic it first needs to be defined. In the literature several different definitions can be found. Quarantelli defines panic as *"an acute fear reaction marked by loss of self-control which is followed by non-social and nonrational flight"* [10]. Goldenson (as cited in [33]) defines panic as a *"reaction involving terror, confusion and irrational behaviour precipitated by a threatening situation"*. Another definition is given by Keating who states that there are four elements of panic: *"a) hope to escape through dwindling resources; b) contagious behaviour; c) aggressive concern about one's own safety; and d) irrational, illogical responses"* [30].

In [33] different examples and case studies where the word panic was used for describing logical or rational behaviour are presented. In some cases people are described as panicky by

others. Sometimes people describe themselves as panicky. One example is the Beverly Hills Supper Club fire in the USA of 1977 in the in which 164 people died [15]. The newspaper headlines described the reason for the large loss of life as *"people trapped in panic"*. Interviews with the survivors clearly indicate that their behaviour was far from irrational or nonrational. The staff rationally informed the customers of the danger and guided them towards the exits. They were untrained for fire emergencies and there was no evacuation plan. In the interviews several people have been described as panicking when smoke or heat penetrated them which led to a rush towards the exits. This seems to be a rational action under these circumstances [3], [15], [33]. For a fire in a nursing home where five people died it was reported that the fire alarm was shut off to prevent people from panicking [33]. According to [36] this is not an uncommon practice.

Panic is often used to describe a person's behaviour after an incident after acquiring more information than the person had at the time [35]. In a fire emergency decisions need to be made quickly based on the available information. For an observer these decisions can look irrational but maybe were rational considering the information the person had at the time [33]. Experts state that information is important for an early decision making and weighing of options by the occupants. With early received information it is possible to realize the seriousness of an incident much faster [37].

2.4 The Influence of Alcohol

Alcohol does not only impair the reaction time but can also impair cognitive abilities and decision making significantly, depending on the dose [11], [12], [13]. Even small amounts can lead to impaired ability and/or functionality. When people consume a large amount of alcohol they make more mistakes when performing simple tasks [38]. The amount remains unspecified in the report.

A two day experiment on cognitive functioning under the influence of alcohol was performed in 2012 and is presented in [39]. In this experiment, six different tasks were performed by 56 different participants, 32 males and 24 females. The participants were between 18 and 45 years old. On the first day these tasks were presented to and completed by the participants three times without the intake of alcohol. On the second day another training session was followed by the performance of the tasks with different Blood Alcohol Concentrations

(BACs); 0.048%, 0.082% and 0.1%. Three out of the six tests showed a significant sensitivity towards alcohol, already under the effect of the lowest tested BAC of 0.048%. The results for the so called Inspection Time (IT) task as well as the Self-Ordered Pointing Task (SOPT) show a clear correlation between the BAC and degree of impairment. The IT task is a measure for the speed of information processing whereas SOPT can be used to measure the working memory function. Another test, the Sustained Attention to Response Task (SART-CO) showed impairment under the effect of the lowest BAC as well. The change of degree of impairment with increasing BAC was very little. SART-CO measures the *"vigilance for and inhibition of response to rare events"* [39]. Also the results for the Useful Field of View Test (UFOV) show a clear relation between the BAC and the degree of impairment. The degree of impairment with the lowest tested BAC is not as significant as for the previously addressed tasks. The UFOV is a measure for the speed of processing as well as divided visual attention. The results show that all cognitive abilities that have been tested suffer under the effect of alcohol. Some are more sensitive than others, but all are being negatively affected [39].

3. Evaluation of Selected Nightclub Fires

In this section the following nine past nightclub fires are analysed with the goal of identifying the critical factors that influenced the outcome.

- Kiss, Brazil, 2013
- Lame Horse Club, Russia, 2009
- Santika, Thailand, 2009
- Luna, Scotland, 2009
- República Cromañón, Argentina, 2004
- The Station, U.S.A., 2003
- The Fine Line Music Café, U.S.A., 2003
- La Goajira, Venezuela, 2002
- Gothenburg Dancehall, Sweden, 1998

Those fires have been chosen for several reasons. Firstly, they represent a wide range of different types of nightclubs. They range from rural to inner-city venues. Secondly, the incidents are from all over the world and therefore from countries with different regulations and a different state of the art concerning fire safety. Thirdly, the incidents happened relatively recent, the oldest one in 1998, and therefore provide a good basis for improving the current situation regarding nightclub safety. There were some disastrous incidents leading to a high number of fatalities earlier in history like the Cocoanut Grove Nightclub fire in 1942 resulting in 492 fatalities [3]. These cases will not be regarded here since some adjustments of regulations have already been made after those fires occurred and the goal of this thesis is to improve the safety of currently existing nightclubs and those that will be built in the future.

However, there have been more recent nightclub fires than those that are analysed. For some the information is very limited and that is why they have been discarded in the analysis. In December of the year 2000, 309 people died in the Chinese city of Luoyang. The nightclub was located on the 4th floor. A welding accident in the basement led to the tragic incident [40], [41]. In 2008, 43 people died in the reportedly overcrowded Wuwang Club in Shenzhen in China. Both nightclubs have been reported to have operated illegally [41]. These are just two examples of less well documented incidents that have not been analysed. Another incident worth mentioning is the crowd crush in the E2 nightclub in Chicago which happened on February 17th 2003 [42]. There was a fight and a security officer used pepper spray

intending to end the fight. Some occupants shouted “terrorist attack” and “poison gas”. Some occupants saw others vomiting or passing out which prompted people to rush toward the exit. A subsequent crowd crush on the staircase led to 21 deaths and 50 injuries. The most recent documented nightclub fire happened on New Year’s Eve 2013 in the Neighbours nightclub in Seattle [43]. An arsonist set fire to gasoline he had poured over the staircase leading to the upper bar. However, sprinklers and fire extinguishers were able to control the fire and no one was killed or injured.

3.1 Kiss, Brazil, 2013

On the 27th of January 2013, a fire occurred in the nightclub “Kiss” in the city of Santa Maria in Brazil. The venue was hosting a popular rock band. The fire started due to the use of pyrotechnics and led to 241 fatalities, mainly students, and over 600 injuries [44]. The information presented is based on newspaper articles.

Description of the Building and the Situation Prior to the Fire

The one storey venue had two adjacent buildings, one on the left and one on the right side. No connection that could be used as an escape route existed. The nightclub had only one exit, it was a dead-end configuration. In front of this exit there were metal barriers designed to let people in slowly and in a controlled way. The nightclub had no windows. After the main entrance the occupants could go directly to the stage area on the left or to the main area of the nightclub, straight ahead. The area in front of the stage was elevated and could be reached via a stair or ramps. The difference in height to the rest of the venue is unknown. In the main area there were some possibilities to sit as well as two bars and two toilet areas. Another bar area was located in the back [45].

In the newspaper articles it is not mentioned that the nightclub had a fire alarm, an automatic suppression system, a smoke and heat control system or emergency lighting. The nightclub was equipped with fire extinguishers. The number is unknown. The one that was used on that night was malfunctioning. The fuel load mainly consisted of the wooden stage itself, polyurethane foam and curtains [46].

According to the police and witnesses the nightclub was overcrowded [47], [48]. The exact number of occupants varies from source to source. In [44] and [49] it is stated that the venue had a capacity of 1000 occupants while more than 2000 were in the building. Also [47] mentions 2000 occupants. In [50] it is stated that 1000 people were inside the building while the capacity was 690. The numbers differ but all of the sources indicate that the nightclub had exceeded maximum occupancy.

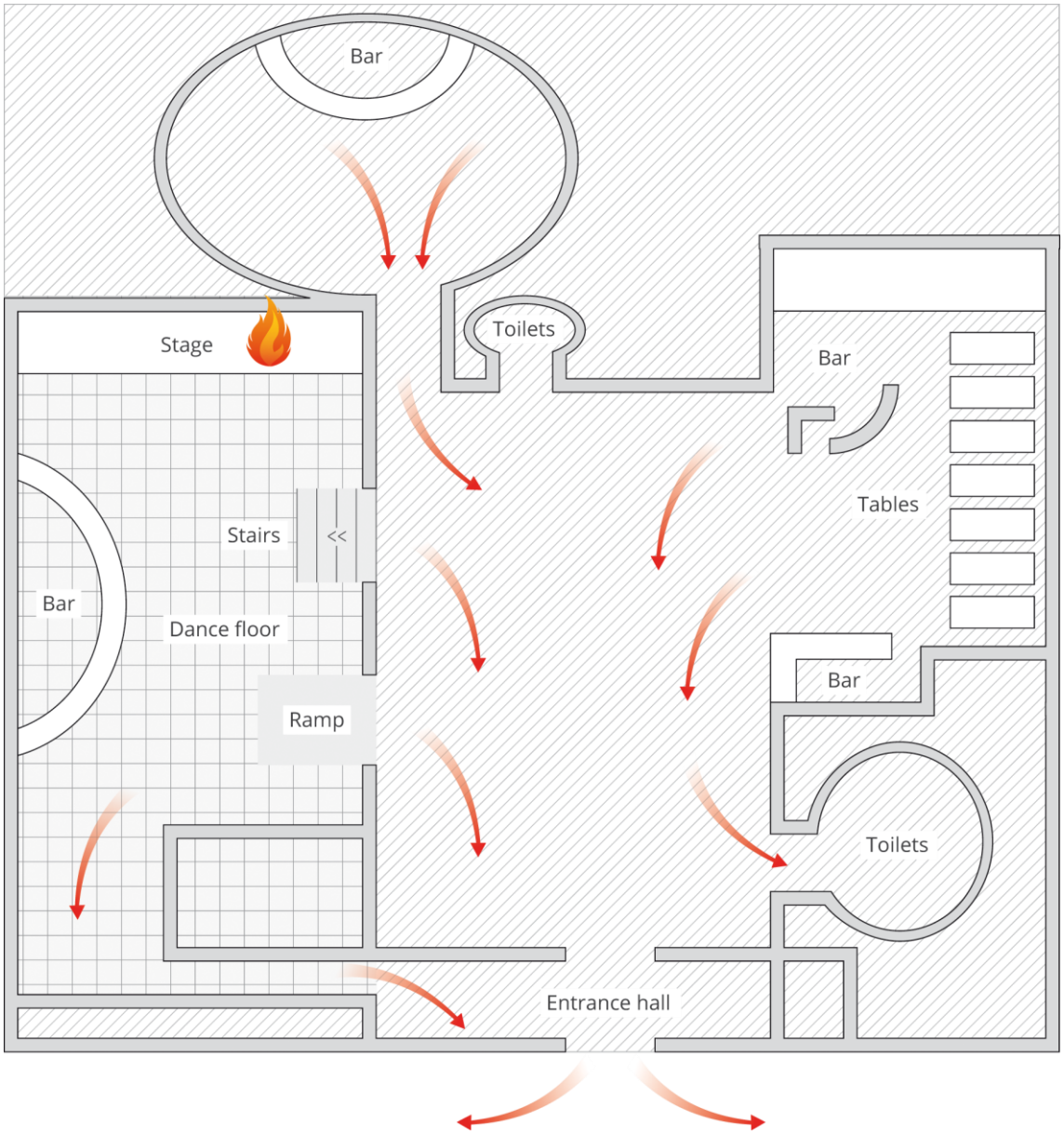

Figure 3: Layout of the Kiss nightclub; The flame indicates the origin of the fire; The arrows indicate the movement of people; Figure is based on [45]

In the aftermath it was found that the nightclub's public-health license and fire-safety plan had expired in August and that the fire brigade had not done checks for several months [47],

[49]. The owner applied for an extension and the club was allowed to continue operating. The Brazilian regulations require a minimum number of two exits for a nightclub [51]. Questions arose about how a club without basic safety precautions could have obtained a license in the first place [50]. It should be mentioned that, in Brazil, it is common practice that patrons have to tab their expenses and pay when exiting. This was also the case for the Kiss nightclub [44].

Description of the Incident and Human Behaviour

The fire started at about 2.15 a.m. when a member of the band lit a pyrotechnic flare and ignited the soundproofing non-fire-retardant polyurethane-foam at the ceiling. From there the fire and smoke rapidly spread throughout the building. In one article it is mentioned that the fire cut off the power supply which left the venue in darkness [50]. The band was handed a fire extinguisher but it did not work. In [49] it is mentioned that parts of the roof collapsed and trapped several occupants inside.

Some witnesses stated that the guards at the door refused to let people leave without paying, but as soon as they realized the seriousness of the situation they actively helped people to get out of the building. Other witnesses said that the guards did not stop people from exiting. One witness said that some people knocked over the security guard and opened the door [46]. The metal barriers in front of the entrance slowed down the evacuation even further. As a result of everybody trying to exit through the main entrance, there was a crowd crush. Firefighters had to break through the wall to enter the venue [50]. Witnesses stated that, during the evacuation, people mistook doors leading to dead-ends for emergency exits. At least 50 bodies were found in the bathrooms [45], [46]. In [52] it is mentioned that over 180 people were found in the bathrooms. Several people tried to find refuge in refrigerators [47]. According to a medical professor at least 90% of the deaths were caused by smoke inhalation [46].

Image 1: The inside of the Kiss nightclub after the fire; Large amounts of debris can be seen in the back of the image; Image taken from [53]

Shortly after the incident several nightclubs in Brazil have been checked. Random checks in 29 nightclubs in Sao Paulo revealed that 9 were running without a license while 8 were not even registered [50]. Owners are often discouraged from obtaining a license as the application process can take years. Additionally, a registered nightclub needs to pay taxes.

Identified Critical Factors

Even though the Kiss nightclub was allowed to continue operating after applying for an extension of its license, it violated the law by only having one exit, instead of the mandatory two. The fire and smoke could spread so rapidly due to the fact that non-flame-retardant PU-foam was used and was ignited by a pyrotechnic flare. There was no evidence of a detection and alarm system, an automatic suppression system or a smoke and heat control system. The attempts to extinguish the fire failed because the fire extinguisher did not work. The nightclub was overcrowded. The nightclub had a dead-end configuration. There were metal barriers in front of the entrance slowing down the evacuation. The power supply was cut by the advancing fire and the lights went out.

The entrance area that was supposed to be used by the large number of occupants can be seen in the following images.

Image 2: Entrance area of the Kiss nightclub from the outside after the incident; Image taken from [54]

Image 3: Entrance area of the Kiss nightclub from the inside after the incident; Image taken from [55]

3.2 Lame Horse Club, Russia, 2009

In the early hours of December 5th, 2009 a fire broke out in the "Lame Horse Club" in the city of Perm in Russia. On this particular night the 8th anniversary of the nightclub was being celebrated. The fire started due to a pyrotechnic display that was lit on stage which ignited the ceiling. A total of 156 people died and 100 were injured [56]. The sources used for this analysis are mainly newspaper articles but also different video footages from the night itself and the news. These videos show the venue both before and during the initial phase of the fire [57].

Description of the Building and the Situation Prior to the Fire

The nightclub was located in a one storey building and had a surface area of 500 m² [58]. The nightclub had two exits, the main entrance and a rear exit. At the main entrance there were two double swing doors placed behind each other. On the evening of the fire only one leaf of each double swing door was open. The rear exit was not signed as an emergency exit while the main entrance was [59]. In [60] windows are mentioned. It is unknown if those could be used for an evacuation or not. The videos show many tables and chairs at the venue [57], [61].

In the video that was shot during the incident it is not possible to hear a fire alarm [57]. The building had no automatic suppression system [62]. Fire extinguishers or a smoke control system are not mentioned in any of the reports or videos. The building's interior finishing consisted mainly of wood; the ceiling was decorated with twigs [59], [63].

The nightclub had a capacity of 450 people. In total 282 people were invited to the party. The exact number of occupants is unknown [60]. According to [62] there were more than 200 people within the venue. In no article it is reported that the venue was overcrowded. The pyrotechnical devices used for this party were not certified for indoor use, only for outdoor use [62]. The nightclub had already received two fines after failing fire safety inspections one year earlier [60]. People living close to the building accused the fire brigade of corruption and of approving the safety standards of the venue for the past 8 years [62]. The nightclub expected a fire safety inspection in the following week [59].

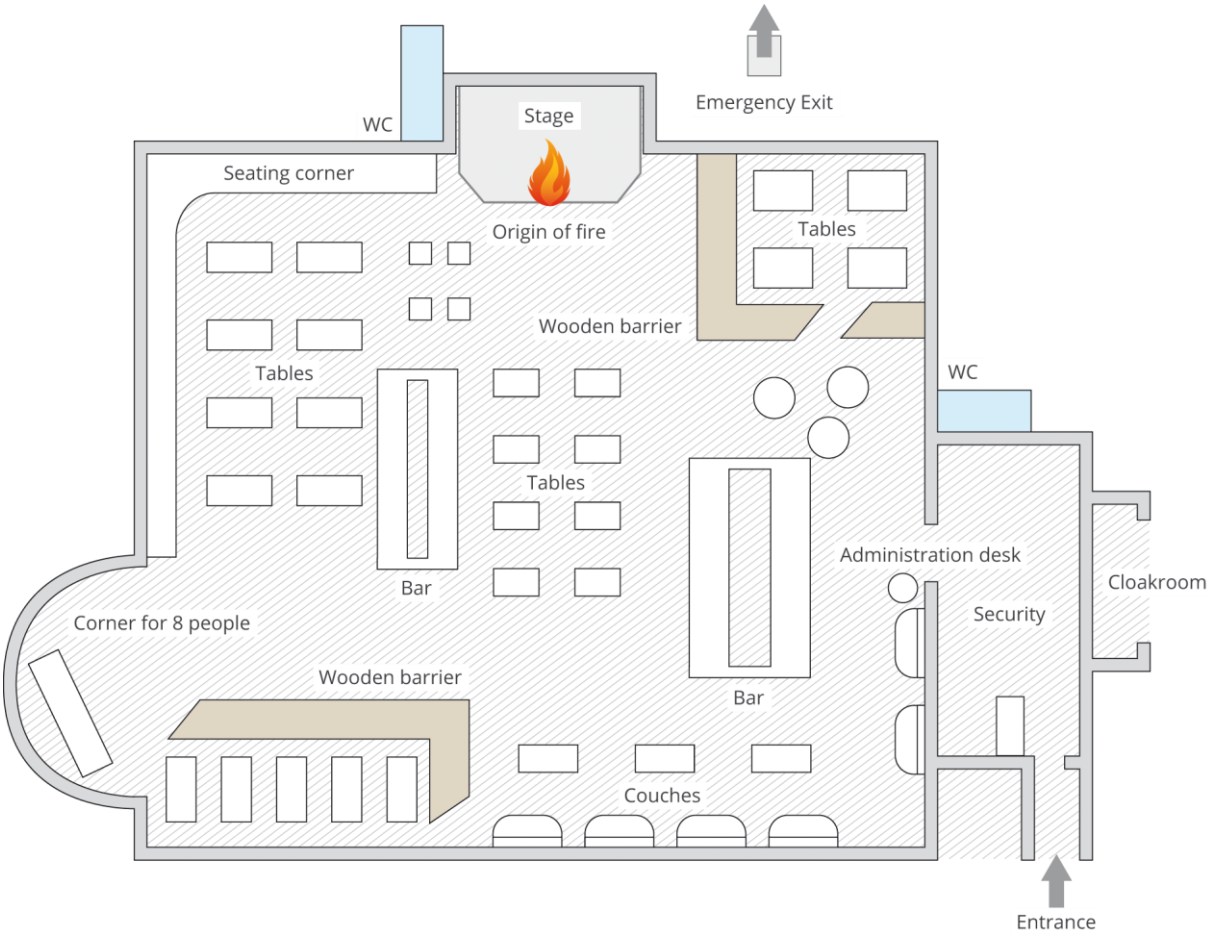

Figure 4: Layout of the Lame Horse Club; The exact location of the rear emergency exit is unknown; The flame indicates the origin of the fire; Figure based on [61]

Description of the Incident and Human Behaviour

The fire was started by a pyrotechnic display which ignited the wooden brushwork on the ceiling when *"[...] a performance artist juggled so called cold-flame pyrotechnical maces"* [57], [63]. The pyrotechnic display was not certified for indoor use [62]. Due to the choice of materials the fire and smoke spread quickly throughout the nightclub [59].

When the situation became apparent to the guards they tried to open the second leaves of the double swing doors at the main entrance to improve the egress. Some of the staff members exited through the backdoor. It was not known to ordinary guests. Officials stated that most of the victims died of smoke inhalation [64].

Image 4: Burning ceiling in the Lame Horse Club; Image taken from [57]

Identified Critical Factors

The nightclub did not fulfil the required safety standards and therefore operated illegally. The pyrotechnic display that was used was certified only for outdoor use. The choice of materials led to an easy ignition and a rapid spread of fire and smoke. There was no evidence of a detection and alarm system, an automatic suppression system, a smoke and heat control system or fire extinguishers. The rear emergency exit was not signed and ordinary occupants did not know about it. The full width of the main entrance was not available as the second leaves of the door were initially sealed.

3.3 Santika, Thailand, 2009

During a New Year's Party on the night from December 31st to January 1, 2009 a fire occurred in the very popular nightclub "Santika" in Bangkok, Thailand. The fire began due to the use of pyrotechnic igniting combustible material at the stage. The fire killed 66 people and injured 236 [65]. Sources for this incident include an investigation report carried out by the Center of Education and Research on Advanced Fire Safety Science and Technology in East Asia, journal and newspaper articles and video footage.

Description of the Building and the Situation Prior to the Fire

The nightclub was a free standing steel-framed building with two stories above and one storey below the ground [65]. The inside of the club was divided into three main areas. The separated VIP area consisted of two stories and a staircase in the area itself. The entrance to the VIP area was at the back of the south side terrace. Another main area was the mezzanine level above the seating area. From the U-shaped mezzanine level people could look onto the stage and the seating area. The third area was the actual ground floor [65]. The floor level on the ground floor was uneven. At the centre of the guest area there was a circular shaped area which was lowered by 40 centimetres. The terrace on the east side was raised by 30 centimetres. The whole guest area was 90 centimetres lower than the entrance hall. In order to connect the different levels there were stairs with two to five steps depending on the difference in height.

The building had three major evacuation routes, the main entrance and two 70 cm wide doors leading to the east side terrace [65]. There were corridors behind the stage that could have been used for evacuation purposes but since the fire originated in between the crowd and the alternative ways of evacuation it would have been very difficult to exit there without a member of the staff who was familiar with the building. On the east side there were six tall and 70 cm wide windows. The height is not specified. Two of these windows served as doors and were part of the major evacuation route. The investigation report is not clear on the condition of the other eastern windows. In the text it says that they did not have a handle to open, but that the glass was broken and the windows used to escape. The layout presented in the report indicates that they were iron barred. There was a lobby leading to the southern terrace. On the south side there were four windows that were secured with iron bars and could not be used for evacuation. There were several windows on the east and south side on the mezzanine level but they were secured with iron bars as well and could not be used for evacuation either.

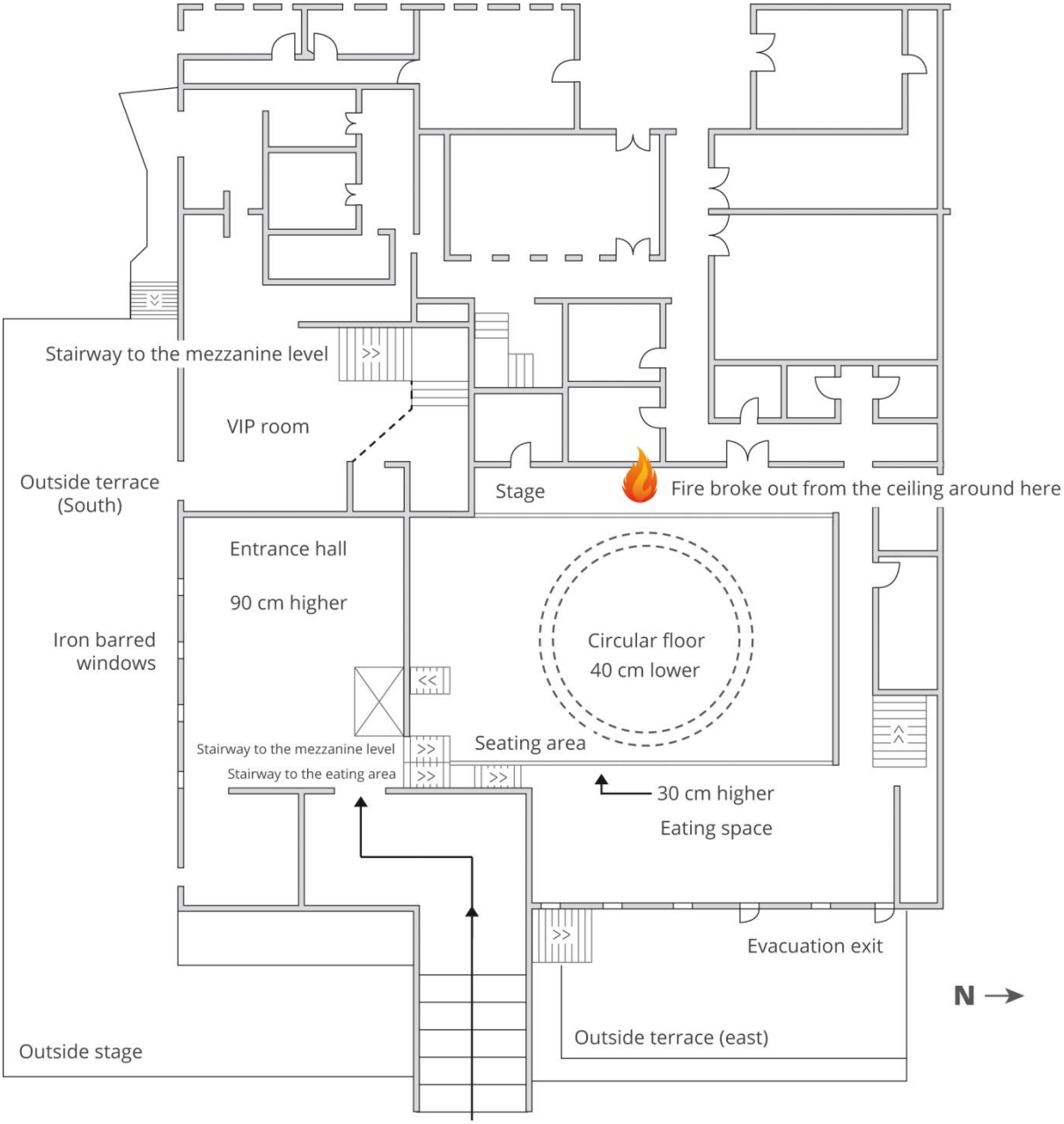

Figure 5: Floor plan of the main floor of the Santika nightclub; The flame indicates the origin of the fire; Figure based on [65]

There were several tables placed in a semi-circular way around the lowered centre of the guest area [65]. Small counters for drinks were placed close to each other. The connection from the seating area to the main entrance was narrow, enough for normal use, but not wide enough for an evacuation.

The following image gives an impression of what the nightclub looked like. It should be mentioned that the picture was most certainly not taken on the night of the incident. In the video of the night no tables in front of the stage can be seen [66].

Image 5: An impression of the area around the stage of the Santika nightclub; Image taken from [67]

The nightclub had only a few lighted exit signs and no emergency lighting. The building was not equipped with a detection and alarm system, an automatic suppression system or a smoke and heat control system. The building was equipped with several fire extinguishers.

It was estimated that 1000-1200 people were in main area of the club [65], [68]. According to [68] the maximum number of occupants based on the NFPA 101 Life Safety Code would have been 898. Reports describing the area as "densely packed" testify to the fact that the venue was overcrowded. At the time Thailand's regulations did not specify occupancy limits [68].

During an investigation carried out by the Ministry of Justice it was found that the building was licensed as a residence and not as nightclub [68], [69]. For residential buildings, fire safety inspections were not required at the time. The club therefore operated illegally. In 2004 the owners of the nightclub *"[...] had applied for a license to operate as an entertainment venue [...]",* but were refused by the police. From June 2004 until 17th September 2006 the police filed 47 charges against the nightclub. After this date there were no further charges. Since then one of the shareholders of the company was a senior police officer. There is no evidence of bribes being paid or that the senior police officer used his position to hinder police action against the Santika.

Description of the Incident and Human Behaviour

The fire started minutes after midnight due to a pyrotechnic display on stage which ignited the combustible materials near the ceiling [65]. There were no attempts to fight the initial fire or give guidance for the evacuation. The fire and smoke spread rapidly to the sides of the venue. People became aware of the severity as they felt the radiant heat and saw a cloud of black smoke. Soon after the fire broke out there was a power failure and the lights in the nightclub went out. Since the venue had no emergency lighting and there were only a few emergency exit signs, people had difficulty finding the exits. In the first seconds of the fire people believed that it was part of the show. A few people however, including the performers started to evacuate immediately. A while later *"[...] a chandelier with a diameter of nearly 10 meters fell down [...]"* from the ceiling and crushed a considerable number of people in front of the stage to death [65]. The exact number is unknown. The chandelier can be seen intact in Image 5 and as debris in Image 7.

The VIP room was located close to the stage and burned down very quickly [65]. The evacuation route from the VIP room was obvious, directly leading to the terrace and not many victims were found here. Since the windows on the mezzanine level were secured with iron bars the occupants had to use the staircase leading to the entrance hall. There, the flow of people merged together with those coming from the area in front of the stage. The evacuation was slowed down by the complex geometry of the venue as well as by the furniture obstructing the escape. An unknown number of people locked themselves into different rooms on the ground floor and tried to prevent the intrusion of smoke into their shelter. This worked and they were saved by the rescue service.

The staircase leading to the entrance hall where several egressing flows merged resulted in a bottleneck [65]. Thirty-two fatalities were found around the main entrance [68]. In total 55 out of 66 people died in the building while the other 11 died at a later stage.

The fire was reported to a police station at 00:20 a.m. while the first rescue service received calls at 00:40 [68]. Due to heavy traffic they did not arrive before 00:48 a.m. When the fire fighters arrived, they were unable to access the site immediately, as numerous taxis and patrons in their cars blocked the entrance.

Image 6: The staircase leading to the entrance hall of the Santika nightclub; Image taken from [65]

Image 7: The area around the stage of the Santika nightclub after the fire; Image taken from [70]

Identified Critical Factors

The nightclub was licensed as a residence; therefore operated illegally and did not fulfil the fire safety requirements. The fire started due to the pyrotechnic display and was able to spread so rapidly because of the materials used at the ceiling. There was no fire alarm, automatic

suppression system or smoke and heat control system. The main area of the nightclub was overcrowded. The means of escape were not sufficient for the number of people. This is especially true for the main entrance. Additionally, tables and drinking counters obstructed the evacuation. Shortly after the fire started the lights went out. Since the nightclub did not have emergency lighting and only few lighted exit signs, the occupants had difficulty finding the exit. The evacuation itself was complicated by the complex and uneven design of the building. A huge chandelier fell from the ceiling and killed an unknown number of people. Furthermore, the fire and rescue work was delayed. The fire department was alerted 20 minutes after an emergency call had reached the local police station.

3.4 Luna, Scotland, 2009

On January 1st 2009, during a New Year's party, an incident happened in the "Luna" nightclub in Edinburgh, Scotland. Nobody died and only three people were mildly injured by falling melted plastics. There was no need to take them to the hospital. Since no major damage occurred there are not many sources for this incident. It is still interesting to do a short analysis because of the human behaviour that was captured on a video [71]. Due to the limited information, the structure for this analysis is different.

The nightclub was equipped with a fire alarm, but besides that one can only speculate about fire safety precautions. On the particular night there were 400 occupants in the venue [72]. No overcrowding was mentioned.

According to the newspaper, indoor pyrotechnics set fire to the plastic netting on the ceiling shortly after midnight. The plastic melted and dropped to the floor. The occupants did not seem to be impressed by the events and continued dancing. People were singing the anthem "the roof is on fire" [71]. Some were walking right through the falling debris. The fire alarm sounded 1 minute and 11 seconds after the video started. It is unknown how long the fire burned before the video was recorded. Most people kept a minimum distance to the falling debris, also as the fire spread and the debris covered more and more of the floor area. After 2 minutes and 30 seconds, two people, presumably staff, instructed the occupants to leave. People seem to follow these instructions. Apparently the configuration of the nightclub, especially concerning materials, prevented the fire from spreading rapidly. The fire growth

rate seems to be slow compared to some of the other, more catastrophic fires that have been presented.

Identified Critical Factors

The fire began when the ceiling materials were ignited by a pyrotechnical device. The choice of materials however did not allow a rapid spread of fire and smoke. The instructions of the staff helped to get every occupant out.

Image 8: Burning debris in the Luna nightclub; Image taken from [71]

3.5 República Cromañón, Argentina, 2004

In the late evening of the 30th of December 2004 a fire broke out in the nightclub República Cromañón in Buenos Aires, Argentina. The nightclub was hosting a popular rock band. The fire broke out due to a flare that was lit by somebody within the crowd of fans. In total 193 people died. The exact number of injuries is unknown and reports vary widely. In the newest

newspaper article 1400 injured people are mentioned [73]. This chapter is mainly based on newspaper articles as well as the official judgment by the jurisdiction of Buenos Aires.

Description of the Building and the Situation Prior to the Fire

The nightclub was located in a two-storey building. The main entrance was located on the lower floor and led to the outside. Right behind the main entrance there were six doors leading to the main area of the nightclub. Four of them were locked. A connection to a nearby hotel was on the same level. The emergency exit on the lower floor was locked with a padlock [74]. This exit was marked with an illuminated exit sign. Another exit was located next to the stage but was not used by many. A fence in front of the stage was blocking the way to this exit.

There are no reports of a detection and alarm system, emergency lighting, an automatic suppression system or a smoke and heat control system. Ten out of the fifteen fire extinguishers that were in the venue were depressurized and could therefore not function. Out of the remaining five, three were sealed and one had expired. The nightclub had a ventilation system that consisted of four fans above the stage designed to exchange air. Two of the fans were sealed by masonry [74].

The club’s interior finishings consisted of polyurethane foam, some highly combustible materials and cotton wool. The walls were insulated with a layer of polyurethane foam on top of a layer of highly combustible cotton wool [74]. It is not reported whether the polyurethane foam was flame retardant or not.

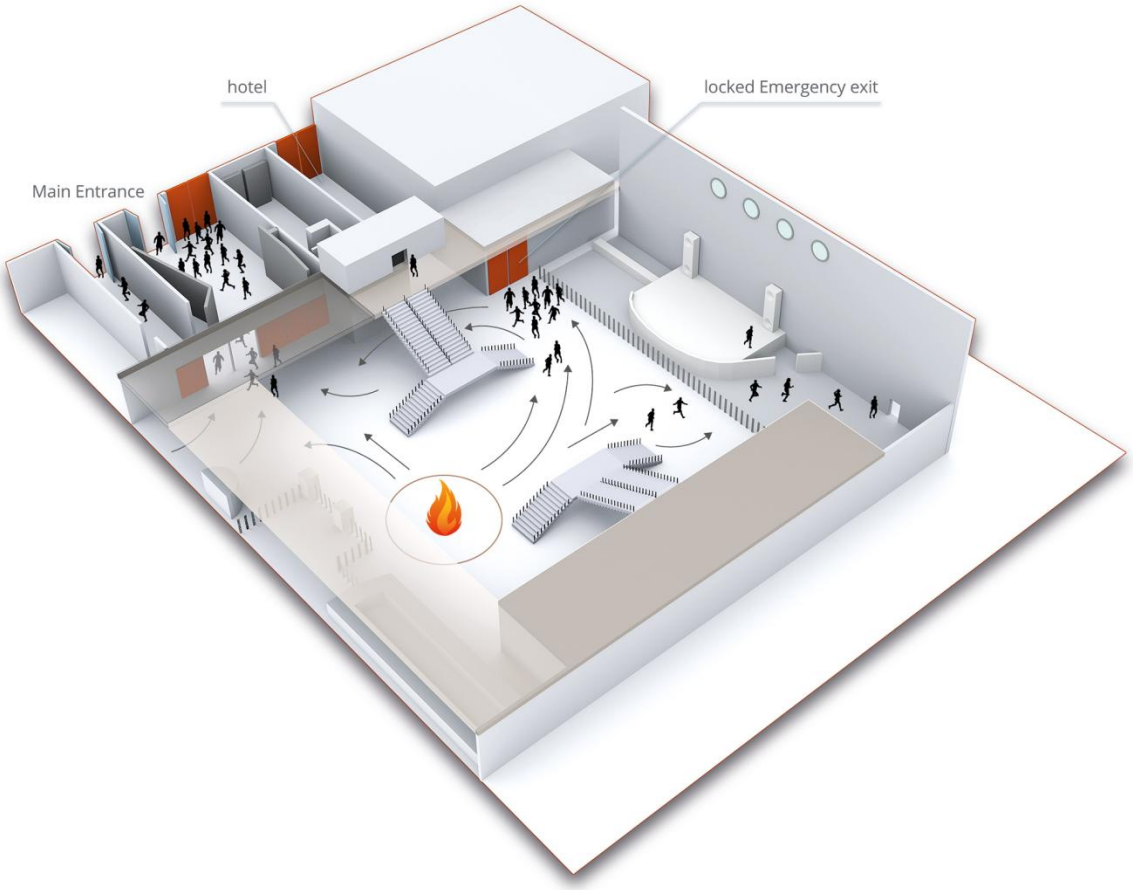

Figure 6: Layout of the República Cromañón nightclub; The flame indicate the origin of the fire; Figure based on [75]

On the particular night there were approximately 3000 people in the venue while the nightclub was allowed to host a maximum of 1031. The minimum number of occupants within the venue was found to be 2811 [76]. Other sources indicate an allowed number of 1300 but also indicate more occupants [77]. In [74] it is stated that three times as many people as allowed entered the venue. Witnesses stated that it was very crowded and that moving was partly not possible. Also minors were granted permission to enter the nightclub by the guards even though the nightclub sold alcoholic drinks and was therefore not allowed to let minors enter [76]. The nightclub's fire safety license had run out in November and needed to be renewed by the fire department. This did not happen.

Description of the Incident and Human Behaviour

Somebody within the crowd lit a flare which ignited the ceiling. When the combustible materials caught fire, toxic gases were produced and quickly spread through the venue. The

technical institution INTI calculated the level of toxicity based on the materials and volume of the building [74]. They found a level of 225 ppm of cyanide in the air. A lethal dose for lab rats lies in between 150 ppm and 220ppm. The light went out shortly after the fire started. It is unknown whether this happened due to the fire or if someone switched them off purposefully [74].

Witnesses reported that people were jumping over each other and that some occupants fell on the ground and were trampled. Those who managed to exit the venue tried to help the fire fighters and paramedics [77]. Many people were attracted by the emergency exit sign light above the locked door. According to survivors, the firefighters opened this door 40 minutes after the fire began, however, the firefighters state it was less. Most of the victims were found around that area [74]. A lot of people were under the influence of alcohol [78]. Many people ran towards the toilets on the upper floor instead of trying to make their way towards the exits. Most of the fatalities were due to smoke inhalation [77].

Identified Critical Factors

The nightclub did not have an approved fire safety concept. The fire was started by a pyrotechnical device. The choice of materials led to an easy ignition as well as to a fast spread of fire and smoke. There was no evidence of a detection and alarm system, an automatic suppression system or a smoke and heat control system. The fire extinguishers, except for 1 out of 15, were not functioning. The nightclub was overcrowded. The emergency exit on the lower level was locked. Of the 6 doors leading to the main entrance four were locked which hindered the evacuation even further. The exit at the stage was blocked by a fence. Shortly after the fire started the lights went out making orientation and evacuation more difficult.

It is mentioned that a lot of people were under the influence of alcohol. It is not known if this had a negative effect on the evacuation or not.

3.6 The Station, U.S.A, 2003

On the 20th February 2003, a fire broke out in The Station nightclub in West Warwick in Rhode Island in the U.S.A. The Station was hosting several bands. The fire broke during the main act of the night. The band started their performance with a pyrotechnic display which

ignited the soundproofing foam of the stage. From there the fire and smoke spread rapidly throughout the whole club resulting in 100 fatalities and over 200 injuries. A detailed investigation report is available [79]. In the aftermath of the fire, 355 witnesses were interviewed [80]. In the night of the fire a video was shot by WPRI-TV [81].

Description of the Building and the Situation Prior to the Fire

The Station nightclub was a freestanding single storey wooden framed building constructed in 1946 [79]. Since then, the owner and function changed numerous times. Throughout its history it was a restaurant, a pub and a nightclub. It is worthy to note that it was first built as a nightclub. It had an area of 412 m².

The building had four exits - the main entrance and three alternative exits [79]. The main entrance was located on the northern side; two emergency exits were located at the eastern side and another one close to the platform at the western side of the building. A ramp and stairs were installed at the main entrance. The side exits led to stairs as well. In front of the main entrance there was a railing that people faced when exiting. They could either go left and use the stairs or go right and use the ramp. The width of the double-door main entrance and the corridor were the same. About halfway down the corridor a single door led to a small ticket area. Just before the ticket area the corridor was connected to the main bar area. Behind the ticket area the corridor led to the concert area.

The windows of the buildings were mainly on the north side, on the left, and the right side of the main entrance. The windows left of the entrance were double-hung while those on the right side of the entrance were sunroom-type windows. At the southern side of the building, small windows were installed in both the restrooms and offices, but they were secured with bars. Behind the main entrance a short corridor was located.

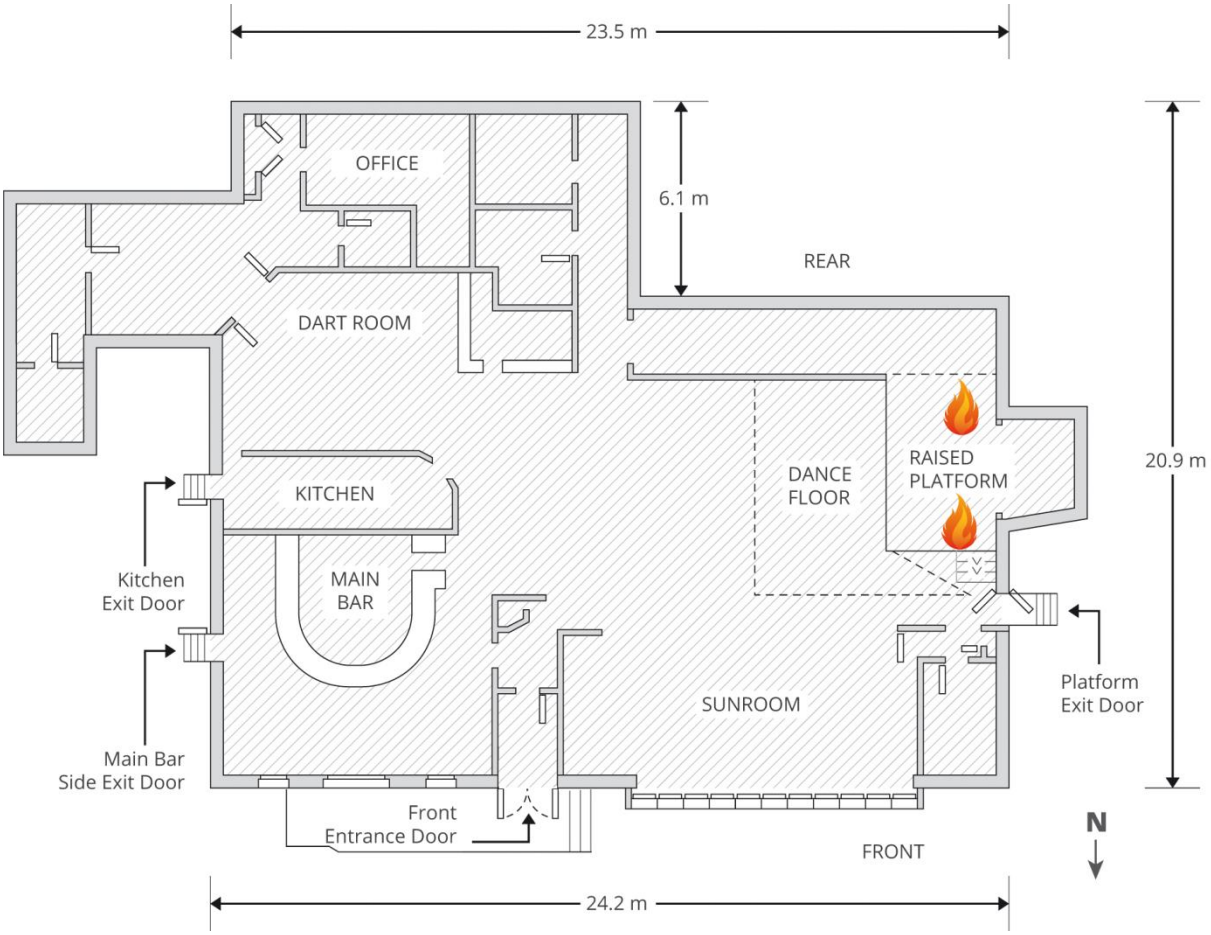

Figure 7: Layout of The Station nightclub; The flames indicate the origin of the fire; Figure based on [79]

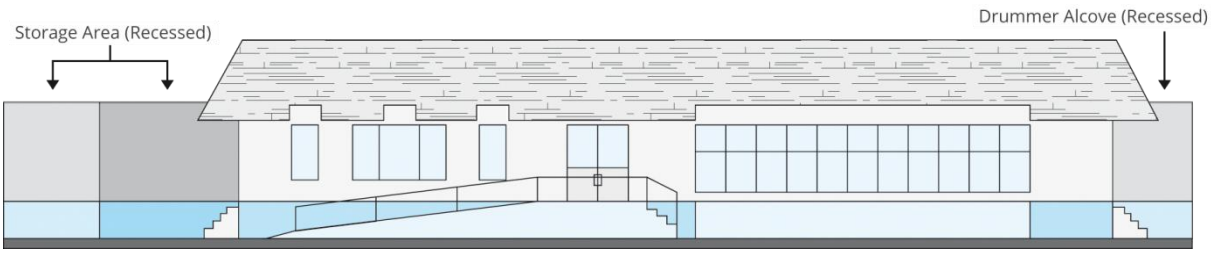

Figure 8: The north side of The Station nightclub; Figure based on [79]

The building was equipped with heat detectors, manual fire alarm boxes and horn and strobe notification units. Although they functioned properly during the fire, they were not linked to the local fire brigade [3]. There was no automatic suppression system or smoke and heat control system. At the time an automatic suppression system was required only for newly built nightclubs, but not for existing buildings, such as The Station. Moreover the building

was equipped with several portable fire extinguishers. The staff did not receive any training on how to act during a fire emergency [80].

The interior finishing most certainly consisted of painted surfaces, wooden panelling, and expanded foam plastic insulation. *"The wood structure and panelling in the nightclub were estimated to contain over 95 per cent of the fuel load [...]"* [79]. Soundproofing polyurethane foam was installed on the interior walls and around the platform.

The maximum number of allowed occupants for the venue was 404, if all tables and chairs were put aside. This was done on the particular night [3]. The minimum number of occupants was 455 considering the 355 witness statements that were collected and the 100 fatalities [79]. This leads to the conclusion that the club was overcrowded. This was confirmed by a number of witnesses describing The Station as *"[...] uncomfortably crowded [...]"*. Other witnesses reported that the nightclub was crowded, but not uncomfortable; some stated that only the area close to the stage was crowded. Only three out of 355 witnesses stated that the nightclub was not crowded [80].

After interviewing the witnesses it became apparent that not all exits were easy to see. The exit in the kitchen was only visible to those in the kitchen or to those looking through the food-pass window behind the front entry way. The exit close to the stage was at least partly blocked by a large speaker. The only visible exits were the main entrance and the emergency exit in the main bar. Above each exit illuminated signs were installed. In the video it appears that the sign above the exit next to the stage was not lit [81], [80].

Description of the Incident and Human Behaviour

At about 23:07 the band started their performance by setting off a pyrotechnic display. The sparks ignited the soundproofing foam in the alcove where the drummer was located. From there the fire and smoke spread rapidly. In the first seconds the fire was misinterpreted as being part of the show. This was stated by 80 survivors [80]. As seen in the video the first reactions to the fire occurred at around 10-20 seconds after ignition [81]. After 25 seconds, the flames reached the ceiling and the occupants started to evacuate. The band became aware of the danger and stopped playing 30 seconds after the fire had started. The alarm went off and the emergency strobe lights began to flash 41 seconds after ignition. The fire department received calls reporting a fire in less than a minute.

After approximately 90 seconds, the smoke layer descended to ca. 0.3 m above of the floor. It was found afterwards that conditions in the middle of the area in front of the stage were lethal by that time. Patrons and the staff were breaking the windows in both the main bar and the sunroom in order to evacuate. Around 100 seconds after ignition, the main entrance became jammed with occupants. Those who escaped tried to help those who were trapped in the crowd crush [79]. In less than six minutes after ignition, flames were seen at the front door and the windows.

In total, eight people tried to fight the fire with both water and fire extinguishers, but their attempts were ineffective [80]. Some employees tried to get fire extinguishers from different locations within the building, but the fire developed too rapidly for an efficient use when they returned.

The bouncer of the band tried to block the exit close to the stage for evacuation [80]. Under normal circumstances it was reserved for the band. Some people went through it regardless. Others turned around and went to the main entrance.

In total, 169 witnesses reported that they faced obstructions during the evacuation [80]. For most of them the crowdedness, as well as the crowd crush at the main entrance, were the main issues. Out of the survivors, 74 mentioned that they were on the ground at one point during the evacuation. They had fallen, were knocked down or dropped down in order to breathe more easily.

For 347 out of the 355 witnesses, the exit choice could be identified [80]. Out of these 347 witnesses, 127 exited through the main entrance. Some of the survivors stated that they used this exit because it was the only way that they knew. Sixty-two others attempted to use the main entrance to evacuate but in the end they exited through windows or the bar exit. They later stated that it was too crowded around the main entrance.

The majority of fatalities were found around the main entrance. At least 50% of the survivors exited through the main entrance or tried to do so [80]. A problem was the single door and the ticket desk within the corridor reducing the effective width available for evacuation [79]. Twenty-six fatalities were found in the southern part of the nightclub which was a dead-end configuration.

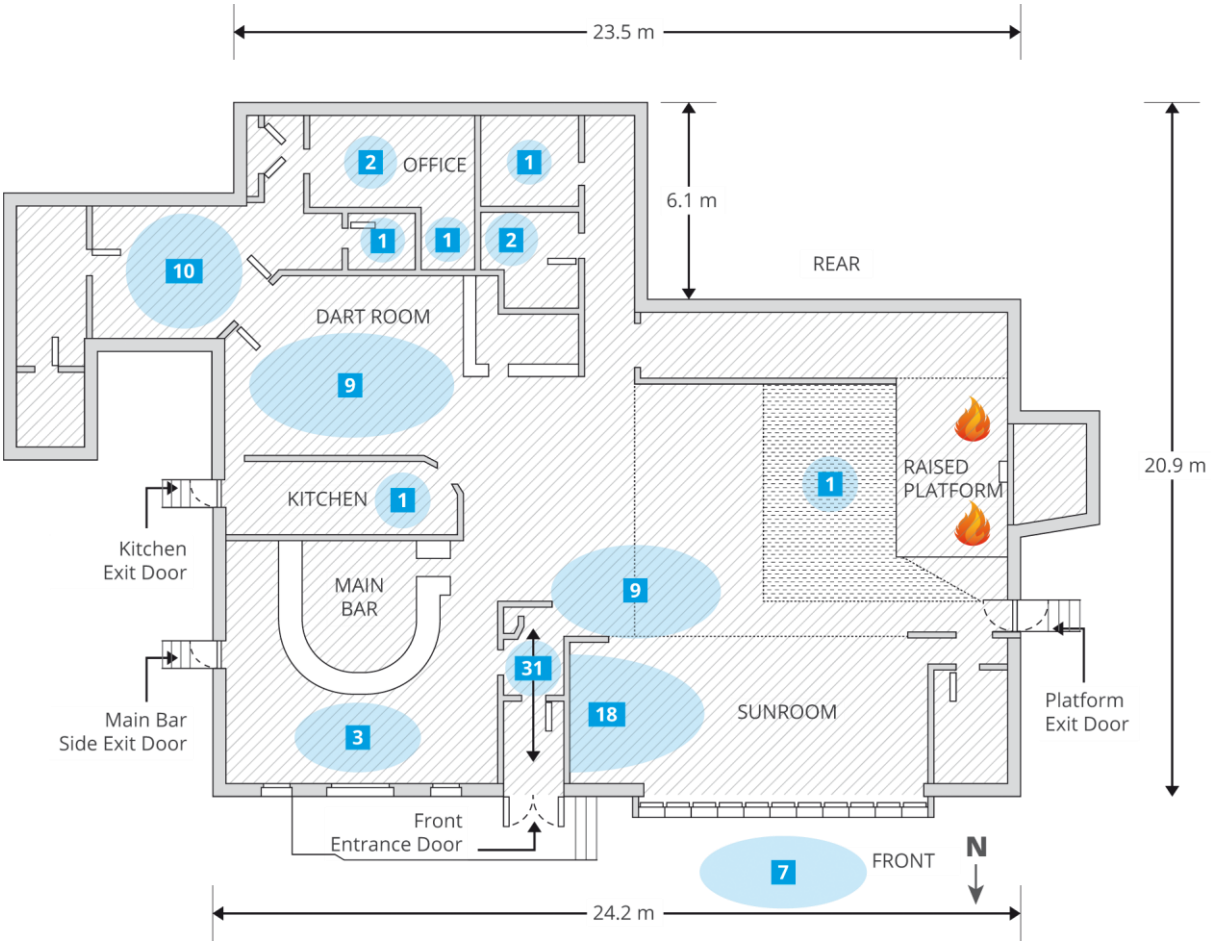

Figure 9: Location of fatalities in The Station nightclub; The flames indicate the origin of the fire; Figure based on [79]

Image 9: Crowd crush in the main entrance of The Station nightclub; Image taken from [82]

Image 10: The pyrotechnic display igniting the soundproofing foam at The Station nightclub; Photo Credit: Daniel Davidson (Copyright holder); Image taken from [82]

Image 11: Initial fire at The Station nightclub; Photo Credit: Daniel Davidson (Copyright holder); Image taken from [83]

Identified Critical Factors

The rapid spread of fire and smoke was due to the materials in the building that were easily ignited by a pyrotechnical display. There was no automatic suppression system or smoke and heat control system. There was no fire extinguisher close enough to the stage to allow a suppression of the fire. The nightclub was overcrowded. The main entrance had a too low capacity. The emergency exits were partially not visible and not well signed. A door in the corridor and a ticket desk reduced the useable width of the corridor leading to the main entrance even more. Instead of running to the exits, some people ran into the southern part of the club, which was a dead-end.

3.7 The Fine Line Music Cafe, U.S.A., 2003

On February 17th 2003, a fire occurred in the Fine Line Music Cafe in Minneapolis in the U.S.A. The fire started because the combustible ceiling of the venue got ignited by a pyrotechnic display used by a rock band [84]. This sounds all too familiar but there is one major difference when comparing this fire with others. In this fire not a single person died or got injured. Under normal circumstances little would have been heard about this incident. What made it interesting for the media and investigators is the fact that The Station nightclub fire happened only three days later and people wanted to know what made the difference. Due to the limited information, the structure for this fire is different from the other analyses.

The Fine Line Music Cafe was equipped with an automatic suppression system even though the regulations did not demand it [84]. The staff had trained regularly for evacuating the building. In fact they had a fire safety training earlier on the same day. In total there were 120 guests in the venue. The premise has not been reported overcrowded.

As part of the show, a band member shot a pyrotechnic display which ignited the ceiling and rapidly went from the smouldering stage to engulfing the ceiling in flames [84]. The staff reacted quickly and managed to guide everybody out safely in less than two minutes. Additionally sprinklers controlled the fire. The occupants were very calm. Debris started falling down shortly after people left the mezzanine level. The manager stated he did not know that the band wanted to use pyrotechnics.

Identified Critical Factors

The fire started because a pyrotechnical device ignited combustible materials at the ceiling. The main factors that led to a successful evacuation were the employees who were trained for this situation and managed to guide everybody out quickly and the sprinklers that controlled the fire.

3.8 La Goajira, Venezuela, 2002

On the 30th of November 2002 a fire broke out in the La Goajira nightclub in Caracas, Venezuela. In total, 47 people died and 12 were injured. Newspaper articles and a newscast are the only sources for the analysis of this incident [85], [86].

Description of the Building and the Situation Prior to the Fire

The nightclub was located in the basement of a hotel. The venue was divided into two rooms. It did not have any emergency exits; the main entrance was the only exit. There were no windows that could have served as additional exits. The nightclub was equipped with some fire extinguishers, but reports indicate that they were defective [85]. There are no reports of a detection and alarm system, an automatic suppression system or a smoke and heat control system. An unlicensed kitchen with improvised wiring was located close to the main entrance [87]. The materials used in the venue are not specified, but it can be said that the materials in the kitchen were of such a nature that a large amount of smoke was produced.

There were 400 occupants in the venue. The exact capacity of the nightclub is unknown but it was overcrowded according to the investigators [87]. Nightclubs in that area seldom comply with regulations and also this nightclub did not fulfil the safety standards [85].

Image 12: The main entrance of the La Goajira nightclub; Image taken from [88]

Description of the Incident and Human Behaviour

At about 01:00 a.m. a fire in the kitchen started due to faulty wiring [86]. The kitchen was located close to the main entrance. According to witnesses, there were attempts to extinguish the fire but the fire extinguishers malfunctioned. The people rushed to the only exit. Witnesses reported trampling [87]. However, the exit was quickly blocked by the rapidly developing fire, which trapped the occupants inside. The fire fighters were able to save some occupants with the help of oxygen tanks [87]. Most of the fatalities were due to smoke inhalation [85].

Identified Critical Factors

The nightclub did not follow the regulations and did not fulfil the safety standards. The faulty wiring in the unlicensed kitchen led to the ignition. Whether a simple detector in the kitchen would have improved the situation is subject to speculation. The only exit was located close to the fire origin and got quickly blocked by smoke. There was no evidence of a detection and alarm system, an automatic suppression system and a smoke and heat control system. The fire

extinguishers were malfunctioning. The venue was overcrowded. Having only one exit, the venue was a dead-end configuration.

3.9 Gothenburg Dancehall, Sweden, 1998

On October 28th 1998 a fire incident during a Halloween party in a dancehall in Gothenburg occurred. The dancehall was located on the 2nd floor. The fire originated in one of the two staircases leading to the dancehall, where furniture was stored. In this incident, 63 people died and 180 were injured. Official investigation reports by the Swedish government as well as the NFPA are the main sources for the analysis [89], [90].

Description of the Building and the Situation Prior to the Fire

The free standing building was built in the 1930's and had several different types of occupancy in its lifetime, but also when the fire occurred [90]. The part in which the party was held had two storeys, while the other part of the building had only one. In the 1990s the second floor was converted into a dancehall. It was not a regular nightclub. The building had two exits which had illuminated signs above the door. Apart from the exits there were eight unobstructed windows on the northeast side of the building which were 2.2 m above the floor. The windows had dimensions of 1.8 by 0.8 m. Three of these windows had a vertical drop of 6 m to the ground level; the other five were above an adjacent roof. There were five windows on the opposite side, but they were secured with bars.

In the building there was one main staircase directly leading to the outside and one rear exit leading to a corridor in the single storey part of the building [89]. Right in front of the main staircase on the second floor there was a ticket desk as well as two other tables in the corridor. A stage was located at the rear exit. The DJ booth was located on the stage.

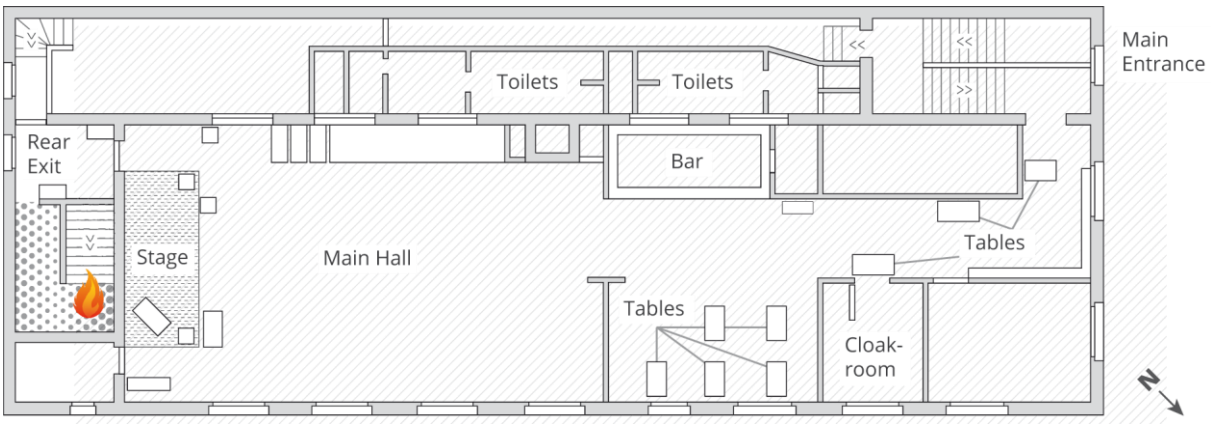

Figure 10: Layout of the dancehall in Gothenburg; The flame indicates the origin of the fire; Figure based on [89]

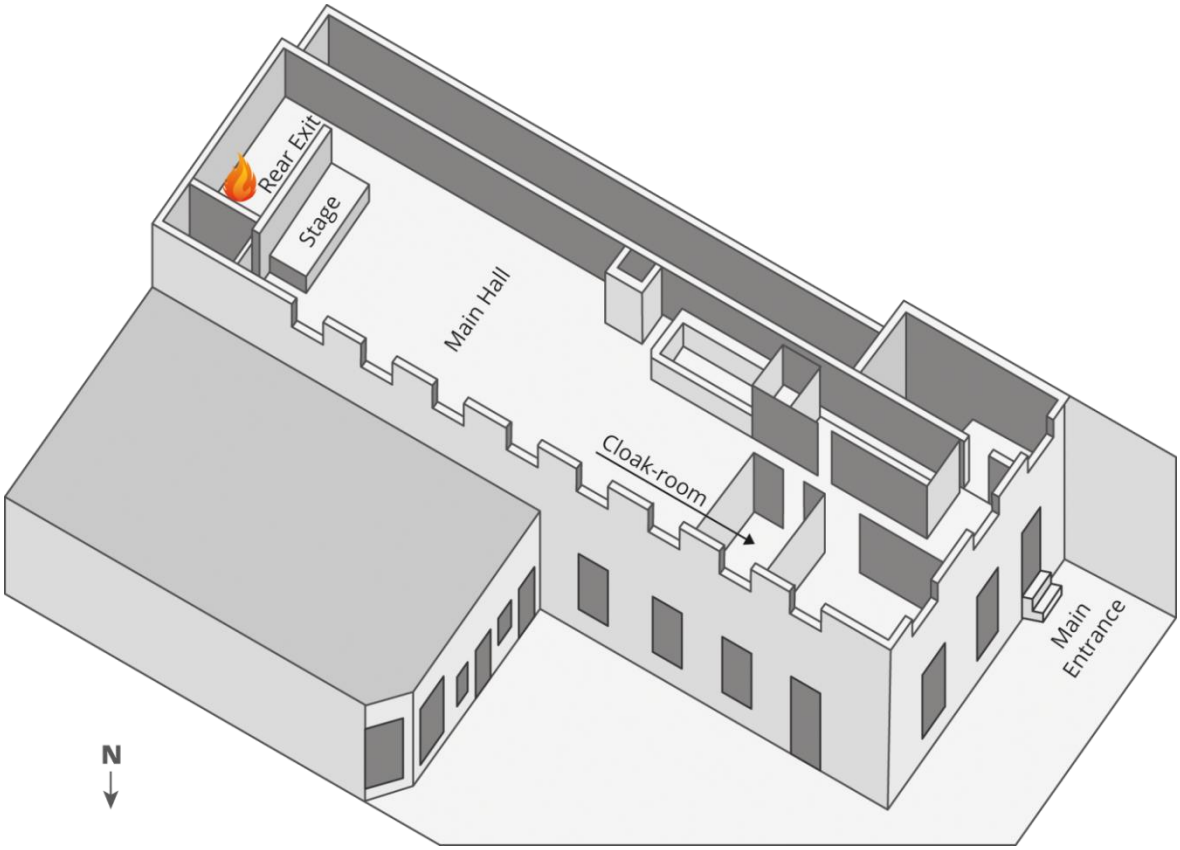

Figure 11: 3D layout of the dancehall in Gothenburg; The flame indicates the origin of the fire; Figure based on [90]

The building did not have any detection and alarm system or automatic suppression system. Fire extinguishers are not mentioned in the reports. The ventilation of the room was controlled by an exhaust fan with a capacity of 3800m³/h. It is unknown whether the ventilation was on or off on this particular night. Additionally, two fans were located in the kitchen [89].

The building was mainly built out of concrete and masonry block. Suspended acoustic tiles were used for the ceiling. Flags and other decoration were reported to have been in the main

hall. *"The interior wall finish was non-combustible plaster finish and possibly combustible wood panelling"* [90]. Several chairs and tables, which were partly made of combustible material, were located in the main hall. Many tables, chairs etc. were moved from the main hall to the rear staircase to make more space for the party. The main fire load was located in the rear staircase. The fire load within the dancehall was relatively small [89].

The estimated minimum number of occupants was 398 [89]. In the aftermath of the fire the local fire department stated that they would have allowed only 150 people into the party in order to ensure a safe evacuation. Witnesses stated that the party was overcrowded. There are reports of people stating that it was not possible to dance and that people were standing shoulder to shoulder [90].

In 1998 in Sweden it was necessary to get a permit for a party where admission is charged. The fire service then would have estimated the maximum number of allowed occupants. In the case of this party, no permit was obtained. Tickets were sold. The party therefore happened illegally [89], [90].

Description of the Incident and Human Behaviour

In the aftermath it became apparent that the fire was arson committed by four teenagers who were denied to enter the party [91]. The fire originated in the rear stairwell. Combustible materials, mainly wooden furniture, were stored in the rear stairwell to make more room for the party. From there the fire spread into the main hall and ignited the furnishings and decorations [90].

The fire was manually detected by one of the two DJs who opened the door to the rear staircase and saw the fire. It is not certain whether he was the first to detect the fire or not. It is unknown whether he closed the door after his discovery or left it open. The fire brigade was alarmed at around 23:42. Two instructions were made by the DJs. One was: *"Fire, Run, Out"* while the second one was *"Fire, don't panic, take it easy, but everybody should go"*. Some people followed that advice while most remained dancing [89]. The DJs started disconnecting their stereo equipment. After one of the DJs realized he would not be able to make it through the dense crowd in time, he broke a nearby window and jumped on the roof of the adjacent building [90]. The music kept playing. The announcement of the fire was commented on as being "cool" by an unknown person via microphone. Somebody started rapping a popular

song. People continued dancing afterwards. The DJ gave out another warning. He seemed to be stressed.

Some witnesses mentioned popping light bulbs and seeing smoke as first cues to the presence of a fire [90]. Others mentioned smelling the smoke and being irritated by it, as first cues. Some mistook it for a smoke machine. One patron wanted to investigate the ambiguous cues further and checked whether the fire was a real threat or not. He burned himself at the doorknob and left the door partially open. When black smoke entered the room everybody rushed to the exit [89].

Out of the survivors that were interviewed after the incident, 62 occupants took the first warning serious while 159 did not. For 88 people data is missing. Survivors stated that especially the ticket desk at the main staircase had caused problems and slowed down the evacuation for about a minute. The high pressure on the main entrance resulted in a crowd crush [89].

When the fire fighters arrived at around 23:49 p.m. a large number of people were outside of the building blocking access to the scene. The officer had to walk in front of the fire truck and instruct people to clear the way [90]. The crowd was actively hindering the work of the fire fighters. There are reports of fire fighters being assaulted. *"Police officers were required to restrain and control the crowd to allow fire personnel to operate"* [90].

Several people jumped out of the windows in the second floor that had a 6 m vertical drop. After jumping or being pushed by those behind them they lay injured on the ground, which made it impossible for the fire fighters to place ladders and operate quickly. Twenty-three were found dead in a room that served as the cloakroom close to the staircase. Some entered voluntarily while others were pushed inside because the pressure on the main escape route was immense [89]. Most of the fatalities were due to inhaling smoke [90].

The investigation board of the incident found that if there would have been a detection system in the staircase the disaster would have been most likely avoided [89].

Identified Critical Factors

The organizers failed to get permission for the party and operated illegally. The arsonists were able to start this fire because there was enough fuel stored in the rear exit. There was no

evidence of a detection and alarm system, an automatic suppression system, a smoke and heat control system and fire extinguishers. The dancehall was overcrowded. Only the main entrance and several windows were available for the evacuation. The ticket desk in the corridor leading to the main entrance slowed down the evacuation for about a minute. The majority of the occupants did not take the warnings announced by the DJs seriously. When the fire fighters arrived they were hindered in their work by the conditions on-site.

3.10 Critical Factors

Nine different nightclub fires have been analysed and the critical factors that influenced the cause of events identified. Even though each case had a unique configuration, several factors remain similar. In all cases, it has never been just a single factor leading to the disaster or a positive outcome but always a combination of different factors.

Table 1: Overview of the identified critical factors

Nightclub	Identified Critical Factors	Fatalities	Injuries

Kiss	• Nightclub operated illegally
	• The use of pyrotechnics
	• The choice of materials
	  • Rapid spread of fire and smoke
	• Manual & automatic fire protection systems
	  • Lack of a properly functioning detection and alarm system, automatic suppression system and smoke & heat control system
	  • Only 1 out of 15 fire extinguishers functioned
	• Occupant load
	  • Overcrowding
	• Means of egress
	  • Only one exit
	  • Dead-end configuration
		241	> 600

	• Metal barriers in front of the exit • Lights went out (No emergency lighting)		

Lame Horse Club	• Nightclub operated illegally
	• The use of pyrotechnics
	• The choice of materials
	  • Rapid spread of fire and smoke
	• Manual & automatic fire protection systems
	  • Lack of a properly functioning detection and alarm system, automatic suppression system, smoke & heat control system and fire extinguishers
	• Means of egress
	  • Emergency exit not signed and only known to staff
	  • Main entrance's width reduced by initially sealed 2nd leafs of the main doors
		156	100

Santika	• Nightclub operated illegally
	• The use of pyrotechnics
	• The choice of materials
	  • Rapid spread of fire and smoke
	• Manual & automatic fire protection systems
	  • Lack of a properly functioning detection and alarm system, automatic suppression system and smoke & heat control system
	• Occupant load
	  • Overcrowding
	• Means of egress
	  • Too low main entrance capacity
		66	236

	• Bad signage of emergency exits • Tables and drinking counters obstructed the evacuation • Complex geometry • Lights went out (No emergency lighting) • Falling chandelier • Delayed firefighting and rescue operations		
Luna	• The use of pyrotechnics • The choice of materials • Slow fire spread • Instructions by staff	0	3
República Cromañón	• Nightclub operated illegally • The use of pyrotechnics • The choice of materials • Rapid spread of fire and smoke • Manual & automatic fire protection systems • Lack of a properly functioning detection and alarm system, automatic suppression system and smoke & heat control system • Fire extinguishers malfunctioning • Occupant load • Overcrowding • Means of egress • Emergency exit locked • Four out of six doors leading to the main entrance locked • Stage exit not available • Lights went out (No emergency lighting)	193	1400
The Station	• The use of pyrotechnics • The choice of materials	100	>200

	• Rapid spread of fire and smoke
	• Manual & automatic fire protection systems
	  • Fire extinguishers not close enough to the fire origin
	  • No automatic suppression system
	  • No smoke & heat control system
	• Occupant load
	  • Overcrowding
	• Means of egress
	  • Too low main entrance capacity
	  • Kitchen and stage exit partially not visible
	  • Bad signage of emergency exits
	  • Door and ticket desk in main corridor
	  • Dead-end configuration		

The Fine Line	• The use of pyrotechnics • Training of staff • Manual & automatic protection systems • Automatic suppression system	0	0

La Goajira	• Nightclub operated illegally
	• Faulty wiring in kitchen caused fire close to the entrance
	• The choice of materials
	  • Rapid spread of fire and smoke
	• Manual & automatic fire protection systems
	  • Lack of a properly functioning detection and alarm system, automatic suppression system, smoke & heat control system and fire extinguishers
		47	12

	• Occupant load
	  • Overcrowding
	• Means of egress
	  • Only one exit
	  • Dead-end configuration		

Gothenburg Dancehall	• Party happened illegally
	• Arson
	• Manual & automatic fire protection systems
	  • Lack of a properly functioning detection and alarm system, automatic suppression system, smoke & heat control system and fire extinguishers
	• Occupant load
	  • Overcrowding
	• Means of egress
	  • Only main entrance and several windows available for egress
	  • Desks in the evacuation route
	• Warnings not taken seriously
	• Delayed firefighting and rescue operations
		63	180

The table shows that out of the 9 analysed fires 7 were started by a pyrotechnical device. Two of these fires had no fatalities. Therefore, 5 out of 7 fires that led to fatalities were started by a pyrotechnical device. Those were the 5 deadliest fires of those presented. In these cases the nightclubs' interior finishing consisted of combustible material which enhanced the rapid spread of fire and smoke. Within 90 seconds the conditions in the middle of the area in front of the stage of The Station nightclub were untenable. While numbers are not present for the other incidents, the newspaper articles and reports indicate a rapid spread as well.

In case of the fires with fatalities, 6 out of 7 times the nightclub operated illegally. In most of the cases, not even basic fire precautions were present. The Santika nightclub was not even registered as a nightclub, but as a residence. In several cases the nightclubs had to pay fines but were allowed to continue operating. In 6 out of 7 cases with fatalities, the venue was overcrowded.

For all cases with fatalities, the manual and automatic protective systems were insufficient. For most venues no detection or alarm system, automatic sprinkler system or smoke & heat control system has been reported. It is not known whether or not these systems were present, but if they were they were not functioning properly. In several cases there were attempts to extinguish the initial fire; these were ineffective mainly due to malfunctioning fire extinguishers. It should be noted that while in some cases the attempts to extinguish failed in other cases there were no extinguishers at all. Naturally it will be more difficult to protect a club from arson but if the organization in the nightclub in Gothenburg would have been such that the staircase hasn't been used as storage for combustible materials the likelihood of such a disastrous outcome would have been lower.

Many of the identified critical factors are connected to the means of egress. In the Kiss and La Goajira nightclub, only one exit was available. In other cases more exits existed, but they were not fully available. In the Lame Horse Club, the 2nd leafs of both doors at the main entrance were initially sealed. In the República Cromañón fire, the emergency exit and 4 out of 6 doors leading to the main entrance were locked. The stage exit was not accessible. In the Lame Horse Club, the Santika and The Station nightclub, the emergency exits were badly or not signed. Two of the exits of The Station were only partially or not at all visible. In the Gothenburg Dancehall fire, the rear exit was unavailable because it was the fire origin. For The Station as well as the Santika nightclub, especially the main entrance capacity was too low. In a few cases there were obstructions in the escape route. Metal barriers outside of the main entrance of the Kiss nightclub slowed down the evacuation. During the evacuation of the Santika nightclub tables and drinking counters were obstructing the evacuation routes. In The Station nightclub, there was a ticket desk in the main corridor which additionally got narrowed down by a door. A railing outside of the main entrance further obstructed the evacuation. In the Gothenburg dancehall fire, tables were located in the evacuation route leading to the main entrance. An issue connected to too few emergency exits or a not very well implemented fire safety concept can be the problem of a dead-end configuration. This was the case for all the clubs with only one available exit as well as for The Station nightclub.

A complex geometry as in the Santika nightclub can slow down an evacuation. During the Kiss, Santika and República Cromañón fires the lights went out making orientation even more difficult. These nightclubs were not equipped with emergency lighting. It is unknown whether the other nightclubs had emergency lighting or not.

The factors leading to the positive outcomes of the Luna and The Fine Line Music Cafe fires were the use of non-combustible materials and instructions given by the staff, in case of the Luna club, and an automatic suppression system and trained staff in case if The Fine Line Music Cafe.

As most dominant critical factors the illegal operations of nightclubs; the use of pyrotechnics; the choice of materials; manual & automatic fire protection systems; the occupant load and the means of egress were identified. In all fires with fatalities, the manual and automatic protection systems as well as the means of egress were insufficient. The training of staff was another factor that was found to greatly improve evacuations, but was not listed as its absence can have negative consequences.

In a lot of cases, the different human behaviour models & theories can be linked to what happened. For the Luna and The Fine Line Music Cafe fire the occupants left the building following the instructions of the staff. A role rule model applied. For The Station nightclub fire, it was verified that most people tried to exit through the main entrance which links to the Affiliation Model. Similar observations were made for the Santika fire. The Theory of Affordances applies for all cases where the emergency escape routes were badly signed or not functional. It is obvious that in all cases with fatalities the ASET was smaller than the RSET.

4. Evaluation of Evacuation Experiments

In this section three different evacuation experiments from Lund University and the University of Ulster are evaluated. The chosen evacuation experiments are presented because they are set in nightclub environments and therefore suited to develop further understanding of an evacuation in a nightclub environment.

4.1 Lund University

In 2011, two evacuation experiments in a nightclub environment were carried out by Nasr and Wall [14]. The experiments took place in two different nightclubs in Lund, Sweden. Club A is a one storey building. Club B, additionally to a floor on the street level, has a basement which directly leads outside as well. Even though the nightclubs are similar, the experiments had one major difference. In Club A, the guards and staff were instructed to actively improve the evacuation, by instructing and pushing the occupants while in Club B the guards and staff were told not to do so. Cameras were installed prior to the experiments. There were two observers in each premise to observe the evacuation. In Club A, a voice alarm system was installed with flashing lights next to it whereas in Club B an ordinary fire alarm was installed. Outside of the club a survey was carried out and the BAC was measured. This happened voluntarily. Blankets were provided for the occupants to cope with the weather conditions.

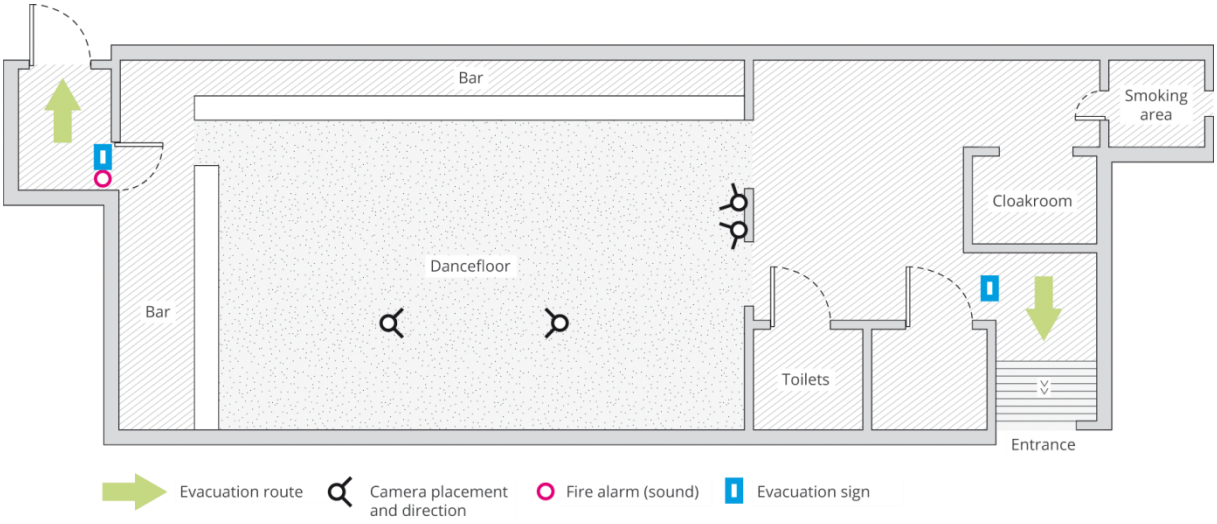

Figure 12: Layout of Club A from the evacuation experiment carried out by Lund University; Figure based on [14]

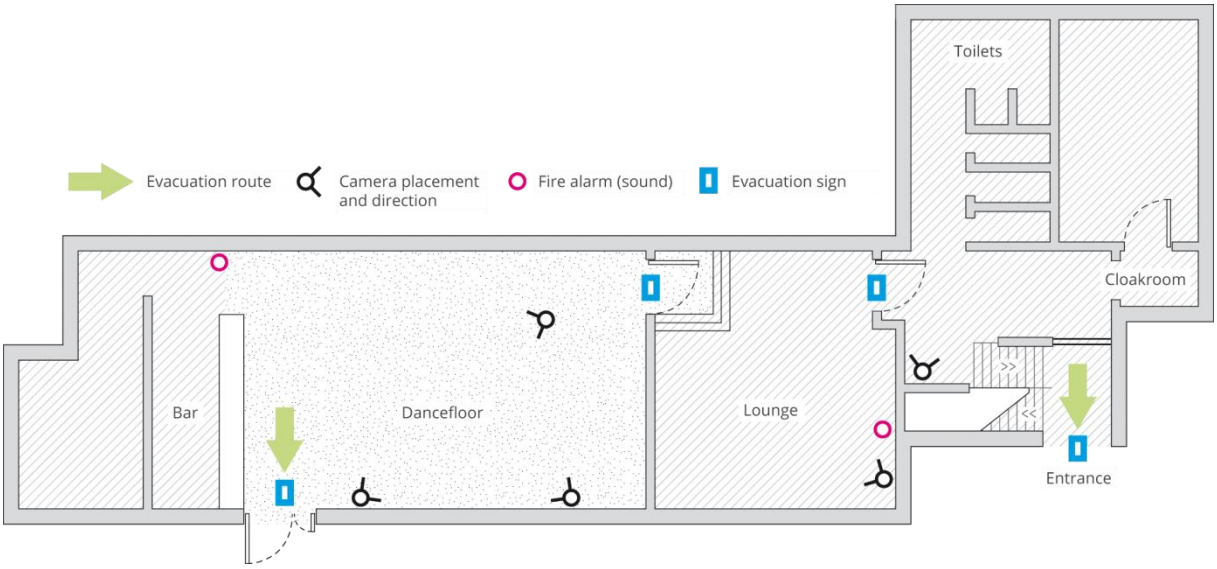

Figure 13: Layout of Club B from the evacuation experiment carried out by Lund University; Figure based on [14]

The Evacuation in Club A

The estimated number of occupants for Club A was 100-150. As soon as the voice alarm sounded the light was turned on and shortly after that the music was turned off. On the dance floor the alarm was not heard by any of the observers before and after the music was turned off. The voice alarm got lost in the high level of noises of the occupants. The flashing lights that were placed next to the fire alarm were not perceived by any of the observers. People did not seem to understand an evacuation was ongoing. Many occupants were standing on the dance floor and waited until the guards verbally instructed people to leave or actively pushed them out. The people in the smoking area refused to leave until a guard actively pushed them out. The people at the bars were not motivated to evacuate. Many were waiting for their drinks. The main entrance got jammed for a short period because people stopped to get their jackets from the closet. The guards pushed the occupants out efficiently. Only six people used the rear exit.

The Evacuation in Club B

The estimated number of occupants for Club B was 150-200. The evacuation started with the fire alarm being triggered. Shortly after that the lights went on. The alarm was heard clearly first in the lounge, whereas on the dance floor only after the music was shut off. At first, the occupants did not know how to behave and looked around waiting for other people to react.

Several people in the lounge remained seated on the couch and used their mobiles; they did not seem to have any desire to evacuate. A lot of people queued in front of the closet to retrieve their jackets. Even after 10 minutes into the evacuation there was still a long queue. In the first three minutes only 20-30 people managed to get out of the nightclub. In total 16 people used the rear exit. The rear exit was better known to people than in Club A since it led to the smoking area.

Results of the Study

In both clubs the evacuation was very calm and peaceful. The occupants moved in groups. Single actions out of a group were very rare. The only stressed movement was when a single person ran out of sight of the camera. It is unclear whether that person ran outside or somewhere else. People who were at the bar were less motivated to evacuate. Only a few people asked for more information about what was going on.

When comparing the two experiments it can be seen that if the staff and guards are well instructed, an evacuation can be greatly improved. On the other hand if no guards or staff aid the occupants a very slow evacuation is possible. The fact that people tried to retrieve their jackets was most certainly related to the weather conditions.

The survey after the evacuation shows that everybody in Club B heard the alarm, whereas only half of the occupants did so in Club A. Nobody perceived the voice alarm as an actual alarm. The survey shows that in both clubs the majority of people have not seen an exit sign, despite the fact that there were exit signs.

Nasr and Wall used three different methods to rate the alcohol consumption of the occupants. Firstly, their BAC was measured. Secondly, the occupants were asked how many drinks they had consumed. Thirdly, their state of drunkenness was subjectively rated by the person conducting the interview. The average BAC during the interviews was 1.09% and 0.72% for Club A and Club B, respectively. They were then asked if they heard an alarm and saw the exit signs. The results show, that percentage wise, most people that have been rated as sober heard the alarm. The more drunk people were categorized, the less they heard the alarm. The same can be said for the ability to see exit signs. These findings are not supported by the measured BAC or the number of drinks consumed. Nasr and Wall found that, even though the subjective rating shows a clear trend, all methods are not very reliable. The BAC seems to be

the most scientific method but it does not take into account the drinking habits. People used to drinking might be less affected by the same BAC as a person not used to drinking.

The authors of the thesis gave several recommendations based on their experiments. Guards should be instructed on how to facilitate an evacuation and should point out alternative exits in order to prevent congestion at the main entrance. It was found that a voice alarm is unsuitable for a noisy environment such as a nightclub. A normal fire alarm yielded better responses. Additionally, they suggested that the fire alarm should be connected to the DJ booth, directly shutting off the music when the alarm goes off. The cloakroom and bar should be closed and not serve occupants anymore as soon as an alarm goes off. Relatively few people saw an emergency exit sign. The authors therefore suggest more emergency exit signs.

Additional Remarks to the Original Analysis

The original video footage that was used for the above described experiments was analysed another time with focus on the critical factors identified in chapter 2 [92]. There are several factors that led to tragedies that do not apply in this case. The nightclubs were operating legally. The nightclubs had several exits. They did not seem overcrowded. There was no pyrotechnical show. In several nightclub fires that have been evaluated in chapter 2, it was found that the emergency exits were poorly signed. According to the surveys that were carried out this was the case in this set of experiments as well. In a real fire smoke can block the visibility of the signs even more.

In the evacuation experiments, people queued up for retrieving their jackets which slowed down the evacuation. In the Lame Horse Club and the Gothenburg dancehall, the cloakroom was located in the corridor leading to the main entrance, but there are no reports of people slowing down the evacuation by queuing for their jackets. The cues of being in a dangerous situation were much stronger in the fire incidents than in the experiments.

The main point that was found during a second analysis is, that the behaviour of the staff was of great influence on the behaviour of the occupants. In both sets of experiment the staffs were not participating in the evacuation. In the videos it can be seen that waiters/waitresses clean the counters or collect bottles while the evacuation was ongoing. In Club A people were actively approached by the security guards and instructed to leave the building while in Club B they were not. The behaviour of the staff in both clubs, apart from the guards instructing the

occupants in Club A, was a contradictory cue to being in a dangerous situation, as indicated by the fire alarm. Even though it was a non-dangerous situation it clearly shows how influential the behaviour of employees can be. This is being supported by a set of evacuation experiments in different retail stores in the UK and by the outcome of the Beverly Hills Supper Club and The Fine Line Music Cafe [15], [84], [93].

4.2 University of Ulster

In 1997, an evacuation experiment was carried out in a pub called Dick's Cabin in Ireland [94]. This particular pub was chosen because, at the time, it was very popular among the local teenagers. The aim of the experiment was to provide data on characteristics and movement as well as the behaviour of people during an evacuation from a licenced pub or club. For the analysis, video cameras were installed prior to the evacuation. No interviews with the occupants were performed.

The premise has a floor area of approximately 250 m² with three main areas as well as interconnecting areas [94]. The Lounge and the Public Bar are located in the front of the club and can be accessed via the front entrance leading into the Lounge. The front entrance has a width of 1 m. A function room is located in the back of the club. From there an exit with a width of 1.2 m leads via a concrete stair to a yard from which another street can be reached.

In the nightclub's license, the maximum number of allowed occupants per room is described [94]. Even though the whole premise was licensed to hold more occupants, the function room was overcrowded. In a comment by the management it became clear that the amount of people on that night was low compared to other nights.

Table 2: Occupancies for Dick's Cabin; Based on [94]

Location	**Allowed number of Occupants**	**Number of Occupants on the night**	**Evacuation Time [s]**
Lounge Bar	125	76	180
Public Bar	60	15	120
Function Room	120	150	400
Total	305	241	400

The fire brigade and police were informed and kept updated throughout the evacuation [94]. Within the premise, only the bar manager, the owner and the research author had knowledge of the ongoing events. The employees were not informed about the evacuation. The doormen were generally instructed to assist the occupants in the event of an evacuation and open all exits.

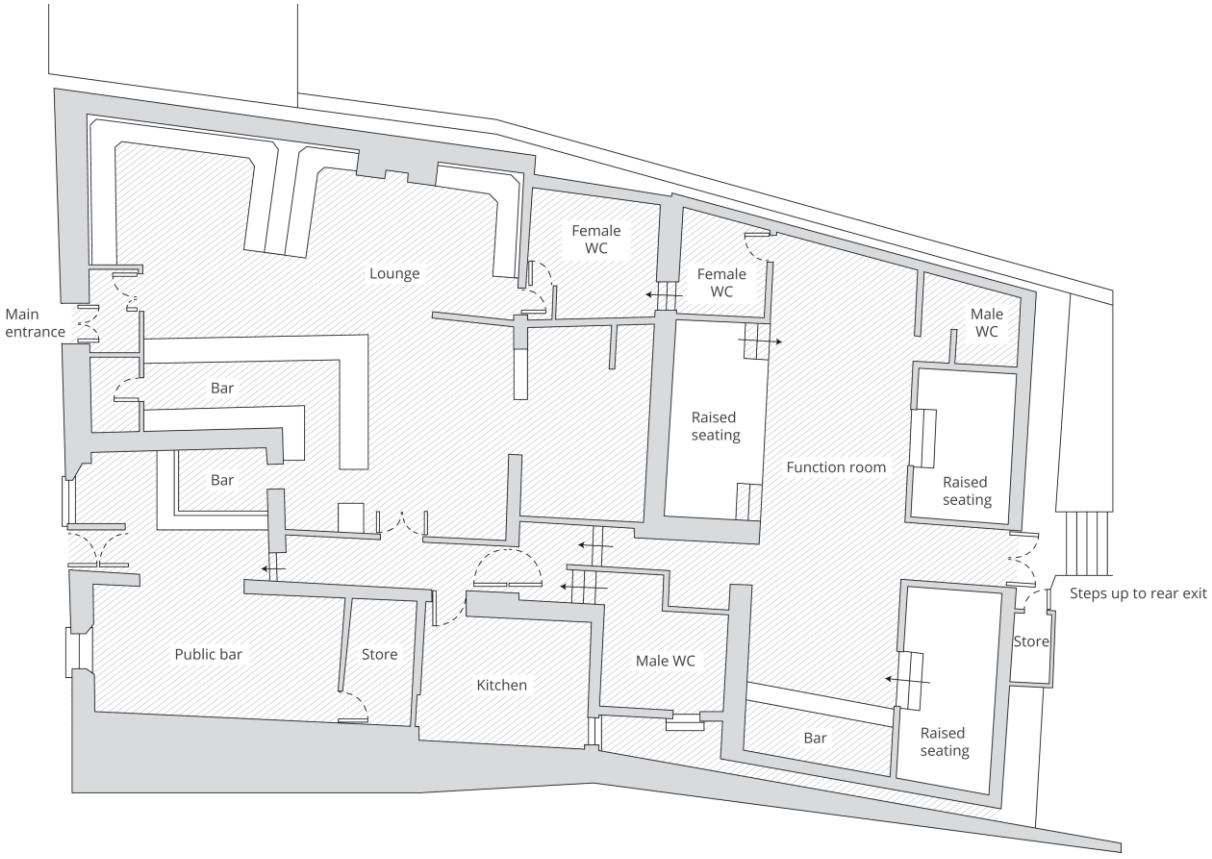

Figure 14: Layout of Dick's Cabin; Figure based on [94]

The Evacuation

The alarm started at 0:25 [94]. Along with the alarm, the music stopped and the flood lights were switched on. The light in the function room operated with 16 seconds delay. Those sitting started the evacuation at 60 seconds and those standing at 45 seconds after the alarm went off. Following the alarm, the staff forced the patrons to leave the premise by the closest exit. The staff was blocking the linked corridor leading to the front exit and forced the patrons to use the rear exit. This happened despite the fact that some patrons made verbally clear that they wished to use the other main entrance because the rear exit was unfamiliar and seemed unfriendly to them. There was congestion at the rear exit.

In total, 16 announcements were made during the evacuation. Most information was given to the occupants in the function room using a P.A. system. The people in the front of the building received only two announcements. In several cases, occupants were going to the toilet while the evacuation was ongoing. In the worst case, a female went to the toilet 130 seconds into the alarm and exited 50 seconds later. In another case a male re-entered the premise at 220 seconds when the doorman was distracted.

Additional Remarks to the Original Analysis

One critical factor that was identified in chapter 2 was overcrowding. In most analysed nightclub fires one maximum number of occupants is mentioned. This experiment shows that single rooms can be overcrowded without the maximum capacity of the venue being reached. Further on, it is questioned by the author of the original report whether the codes are conservative enough in their allowed number of occupants. BS5588:6 allowed even more occupants than there already were in the function room on that night, 177 in total, as stated in [94]. It should be kept in mind that it already took the existing number of 150 occupants, 400 seconds to evacuate and that congestion occurred [94]. BS5588:6 was replaced by BS9999:2008 where areas that are designed for dancing/clubs/assembly have an assigned floor area of 0.5 m²/person; a bar area 0.3, loose seating of 0.75 and loose tables of 1.0 as stated in BS9999:2008 [95]. In [94] it is mentioned that the function room has a total area of 75 m². The exact configuration and what really is included in the 75m² is unknown. From the layout it is assumed that both the bar area and the raised seating areas are included. It is estimated that the allowed number of occupants for the function room using the current regulation is 125, which is just slightly bigger than the number being mentioned in the license, but much less than estimated by the author using the old regulation BS5588:6.

Alcohol did not seem to have an effect on the movement of people. However, people were instructed to use a certain exit. In a real situation this is not necessarily the case. Alcohol can then affect the exit choice [94]. The familiarity with the main entrance, as well as the negative perception of the rear exit, lead to the conclusion that more people would have used the front exit if they had not been prevented from doing so. Apart from the venue being partly overcrowded and that exit choice was limited by the instructions of the guards, none of the factors identified in chapter 2 applied for this evacuation.

5. Current State of the Art of the Regulatory Basis

In this section, it is analysed how the regulations in the U.S.A. and the UK address the critical factors that have been identified as most dominant.

Illegal operations of nightclubs

It lies within the scope of the enforcing authorities to control illegal operations of nightclubs. The NFPA, 101 Life Safety Code states that code is be enforced by the authority having jurisdiction [96]. The enforcing authorities for fire safety in the U.S.A. are the fire departments. In the UK the authorities for the enforcement of fire safety are the fire and rescue service [97], [98].

The use of pyrotechnics

In the U.S.A. the use of fireworks in a nightclub environment is regulated by NFPA 1126 [99]. In this standard, the circumstances under which indoor pyrotechnics are allowed are defined. The facilities in which fireworks are being used need to be in compliance with the NFPA 101, Life Safety Code. The use of indoor pyrotechnic is to be individually approved by the authority having jurisdiction. Furthermore, the number and placement of fire extinguishers and other minor safety precautions are regulated. In the UK the use of fireworks is regulated by a number of different regulations, such as BS 7114, The Fireworks Regulation 2004 and others [100], [101], [102]. In these regulations fireworks that are typically displayed on a stage are not defined.

The rapid spread of fire and smoke due to the choice of materials

In the U.S.A., guidance on resistance of the structure and use of materials is given in the local building codes and NFPA 5000 [103]. The interior finishing is regulated in the NFPA, 101 Life Safety Code [96]. In the UK this general guidance on the required fire resistance of the materials can be found in the Approved Document B as well as BS 9999:2008 [95], [104]. The required resistances can be lowered when using an automatic sprinkler system.

Insufficient manual & automatic fire protection systems

If the occupant load exceeds 300, the nightclub needs to be equipped with an approved alarm system. Following The Station nightclub fire, all newly built nightclubs in the U.S.A. are required to install an automatic sprinkler system [96]. For an occupant load over 100, an automatic sprinkler system is also required for existing buildings. A smoke controlling system is required if a stage is installed that exceeds 93 m². Portable fire extinguishers are not required, also not for existing buildings that do not require a sprinkler system. In the UK, a manual fire alarm system is mandatory, not an automatic one [105]. Sprinklers are not required, but can lead to a relaxation of other requirements [95], [104]. Provisions for smoke and heat control are mentioned but only to protect the fire-fighting and rescue operations. Fire extinguishers are specifically recommended for so called "first-aid fire-fighting", but are not required.

Overcrowding

The problem rather than the determination of the allowed maximum number occupants is to make sure that not more occupants than allowed are within the venue and single rooms. This point needs to be regulated by the authorities. The occupant load for the U.S.A. is determined using the so called *occupant load factor*, which depends on the exact usage of a certain area within the venue, i.e. dance area or sitting area [96]. The surface areas of the individual areas are then divided by the according occupant load factor and summed up in order to get the allowed number of occupants. The allowed number of occupants for each room needs to be posted near the main exit of this room. In the UK, the so called *floor space factor* is used in a similar way [95], [104].

Insufficient means of egress

In the U.S.A., a minimum number of two escape routes from *"[…] any mezzanine, story, or portion thereof […]"* is required [96]. The exit width depends on the type and number of occupants. Following The Station nightclub fire, where most people tried to exit through the main entrance, the main entrance/exit width of a newly built nightclub must now have a capacity of 2/3 of the maximum occupant load. For already existing nightclubs, the main entrance must have a width that can cope with one half of the maximum occupants [96].

Dead-end corridors are restricted to a length of 6.1 m [96]. In the UK, the design of the means of egress is regulated in [95] and [104]. A minimum number of two escape routes for every storey must be provided. The exit width depends on the risk profile of the type of building and the number of occupants. When calculating the exit width, the maximum number of occupants needs to be accommodated by n-1 available exits, in case one of the exits is unavailable. In the U.S.A. and the UK the exit width must not be less than the width of the corridor leading to it [95], [96]. Emergency lighting in the U.S.A is regulated by [96] whereas in the UK three different codes regulate this [106], [107], [108].

The training of staff

In both the NFPA 101, Life Safety Code as well as BS 9999, training of the employee and fire drills are required [95], [96]. In BS 9999, it is mentioned that fire drills should be done when most people are inside and should be as realistic as possible. This can, for example, be achieved via smoke penetration.

6. Discussion

An analysis of different incidents and experiments was performed and critical factors influencing a fire emergency in a nightclub were identified. In the field of fire safety, most is learned from past incidents; therefore the analysis of recent nightclub fires is a good basis for finding critical factors. As most dominant critical factors, the illegal operations of nightclubs, the use of pyrotechnics, the choice of materials, manual and automatic fire protection systems, the occupant load and the means of egress were identified. Additionally the training of staff was found to be very helpful. It should be mentioned, however, that it was always a combination of factors that influenced the events of each fire.

Two evacuation experiments were analysed to gain further insight into an evacuation in a nightclub environment. Most of the critical factors could not be verified since they did not apply in these evacuations. For the evacuation experiment carried out by Lund University, it was found that staff can play an important role in an evacuation. Additionally, a voice alarm system was found to be unsuitable for a nightclub environment. In the evacuation experiment carried out by the University of Ulster, it was found that single rooms can be overcrowded without the maximum allowed number of occupants for the whole venue being reached.

6.1 Recommendations for Safety Measures

The majority of the presented nightclub fires occurred in developing countries. This is also true for the majority of recent nightclub fires in general [109], [110]. For Brazil and Pakistan, it was found that the regulations of developing countries are not as evolved as those of developed countries [111], [112]. This is assumed to be true for the majority of developing countries. It is recommended that countries with less developed regulations adapt their regulations to more developed ones such as from the NFPA or completely adopt them. This is exactly the recommendation given in a study concerned with fire safety in Pakistan [112]. The NFPA is promoting this and several countries already use the NFPA’s expertise or their complete codes [113]. In response to the Santika fire, Thailand decided to proceed with this step [68]. The NFPA Life Safety Code has already been translated into 5 more languages other than English.

Having a high developed regulatory basis is important, but it will yield no improvement of the situation if not aggressively enforced. In a study concerned with the current state of the art in Brazil, it was found that apart from the regulatory basis and enforcement especially the fire safety culture needs to be improved [111]. It is important that the building owners are made aware of the dangers and do follow the regulations also in between inspections. Several of the nightclubs presented continued to operate despite expired licenses, filed fines, and official knowledge of inadequate fire safety conditions. Additionally, it was found that corruption is a problem in developing countries [114]. It is recommended, that the governments implement aggressive enforcement, fight corruption and start campaigns to improve the safety culture. Also, for the developed countries, it is important that enforcement and fire safety culture are constantly improved and/or kept at a high level.

Additionally, it is recommended that future research continues to develop further understanding of the problems connected to a fire scenario in a nightclub environment and their solutions. Suggestions for research topics are given in chapter 7.

6.2 Limitations of the Study

Specific recommendations for safety measures, concerning the improvement of regulations, are not given, since most of the nightclub fires with fatalities that are presented here occurred in illegally operating nightclubs. It is therefore impossible to say whether the regulations in those countries sufficiently address the issues or not, since they were not followed.

It could be argued that the critical factors identified by analysing specific nightclub fires are only valid for specific cases with a similar configuration and not representative of nightclub fires in general. However, a wide range of nightclub fires was studied. The venues range from rural to inner city clubs and represent different populations with different cultural backgrounds and countries from all around the world with a different regulatory basis.

Official investigation reports have only been used for the analysis of the Santika, The Station nightclub and the Gothenburg dancehall fire. All the other analyses are based on newspaper articles. It is not certain that the articles correctly describe what happened. It needs to be said that even though the referenced newspaper articles often differ in details, the main description of the events are the same. Information about nightclub fires without fatalities is very little. Two cases were briefly presented, but there might have been more factors to identify if more

information was available. The nightclub fires with fatalities that were presented are all very extreme cases. The critical factors that were identified led to catastrophic conditions. In less catastrophic scenarios, other factors might lead to less severe but still dangerous situations.

In chapter 3.1, it was found that occupants queuing to retrieve their jackets from the cloakroom during an experiment slowed down the evacuation immensely. This was not found to be a critical factor in the Lame Horse Club or the Gothenburg dancehall fire where the cloakroom was situated in the evacuation route to the main entrance. While the conditions in both fires were very severe, in less severe scenarios, this factor may expose patrons to considerable, unnecessary risk. The cues in the experiment were not as strong. It is not verified whether this might be a problem in less extreme situations.

It could be argued, that it is unknown to what extent detection and alarm systems, automatic suppression systems or smoke and heat control systems would have improved the situation. For most presented nightclub fires, a rapid fire and smoke spread has been reported. During The Fine Line Music Cafe fire, an automatic sprinkler system controlled the fire and the trained staff was able to guide everybody to safety. Sprinklers as well as the use of fire extinguishers also controlled the fire in the Neighbours nightclub fire. It should be said that safety cannot be created by simply installing an automatic sprinkler system. The safety concept needs to be overall functional. In the fires where pyrotechnics were the ignition source, the fire was visible and its severity became apparent in a matter of seconds. The occupants started evacuating quickly. For the people who were around the area where the fire started, a detection and alarm system would most certainly not have improved the situation. During The Station nightclub fire, people started evacuating before the fire alarm went off. It needs to be said, that for people in different areas of the venues, such as toilets or rooms other than the room of the fire origin, an alarm would have maybe improved the situation.

7. Future Research

A study should be carried out verifying whether or not the addressed measures in the presented regulations are sufficient or not. Verification of the sufficiency of measures is very difficult since experiments only to some extent represent a realistic scenario. Sadly, most is learned from real incidents. Therefore the next nightclub fire that happens hopefully verifies that the current regulatory basis, if followed, is sufficient.

In most of the nightclub fires, a rapid fire spread was enabled by the materials used in the building. The time to safely evacuate was short. More research on how to reduce the pre-movement should be done.

People need to be guided effectively and fast towards the closest exits. Guidance by signs, alarms etc. should be such that people intuitively do the right thing without having to think. Research on what is the optimal design for these instalments needs to continue. The experiments presented in chapter 3.1 have already verified that a voice alarm system is unsuitable for a nightclub environment. Further research on optimal design should consider the human behaviour theories such as the affiliation to the main entrance, the findings of the nightclub fire analyses, as well as the effects of alcohol and other drugs. To gain as much transferable knowledge as possible, the experiments should be carried out as realistically as possible.

Apart from not following regulations, nightclubs are sometimes not even registered. This was the case for the Santika nightclub. Additionally, this is supported by the governmental checks in Brazil in the aftermath of the Kiss nightclub fire. For obvious reasons it is easier to control nightclubs that are registered. A study should be carried out quantifying the number of unregistered nightclubs as well as trying to give an answer to the following question: How can it be guaranteed that nightclubs are registered?

It would be interesting to study the effectiveness of fire safety enforcement, especially in developing countries and to then use the input for improvement towards or maintenance of high enforcement standards. Furthermore, it is questioned how the following of regulations can be guaranteed in between inspections if the owners are unwilling to follow those, and how it is possible to sensitize the owners of nightclubs to the subject of fire safety and improve the current fire safety culture in general.

Initially, a survey concerning night club safety was planned to be in this thesis. Due the lack of time, it was disregarded. The idea remains. The purpose of this survey is to estimate the current level of safety in nightclubs all around the world. If clear results are shown, it could be used to increase the awareness of the topic. Simple but fruitful questions, based on the identified critical factors, should be developed. Those questions should be designed so that the answer can be given with either a yes or no or in numbers with the lowest number being a complete disagreement (no) and the highest number being a complete agreement (yes). In order to reach a representative amount of people, the idea is to program a webpage in such a way that it can be viewed on a smartphone without having to zoom in or out or making adjustments to be able to answer it. The idea is that people can answer the survey while being in a nightclub. In order to make this survey accessible to a lot of people, it should be translated into the most spoken languages. To get a lot of answers from people, it is vital that the survey is easy to understand and handle as run for a long time.

8. Conclusion

The aim of this study is to develop safety measures for nightclubs on the basis of critical factors. The most dominant critical factors are listed below.

- Illegal operations of nightclubs
- The use of pyrotechnics
- The choice of materials
- Manual & automatic fire protection systems
- Overcrowding
- Means of egress

Additionally, the training of staff was found to greatly improve an evacuation. In order to create a safer nightclub environment the following measures are recommended:

- Countries with less developed regulations should adapt their regulations according to those highly developed such as those put forth by the NFPA or BSI or completely adopt them.
- Developing countries should improve the enforcement of regulations and their fire safety culture as well as increase the effort of fighting corruption. Those goals are similarly valid for developed countries.
- Research to develop further understanding of the problems a nightclub faces, in a fire scenario, should continue.

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