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POST-INCIDENT EGRESS ANALYSIS OF THE KISS NIGHTCLUB FIRE USING NETWORK MODELING

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Abstract. *A network model has been used to study the Kiss nightclub fire evacuation. Total evacuation times and cumulative number of evacuating agents are the results obtained from information recompiled from NFPA journal investigation report, the police report and other sources. An analysis of various evacuation scenarios that examine and analyze diverse evacuation time variables within the fire incident were examined to assess the network model performance.*

1. INTRODUCTION

Nightclub fires remain a critical concern at present, considering that 60 % of the deadliest nightclub fires have occurred during the last two decades. As with other assembly occupancy fires, have resulted in a considerably high number of casualties and long-term physical and emotional trauma to the survivors. The Kiss nightclub fire is considered to be the deadliest fire in a nightclub in Latin America. The variables that restricted occupants' egress were: overcrowding, exit availability, security personnel delay to open exits, lack of fire detection and alarm system, lack of emergency lighting and deficient emergency management planning.

Many questions about the tragedy have not yet been answered and pose an interesting challenge for this egress analysis study. Would it have been possible for the occupants of the building to evacuate safely if the nominal venues' capacity had been respected? How did the limitation of one exit affect the overall egress? And what if the security personnel delay had been avoided? In this article, EvacuatioNZ (network model) is used to model evacuation scenarios that relate to the Kiss nightclub fire using information obtained from NFPA Journal investigation report, the police report and other technical sources in order to reconstruct the incident as closely as possible and use the model to examine different plausible scenarios. Also, EvacuatioNZ's capabilities and limitations are examined to evaluate its performance against an actual event and assist in the continuous improvement of the model.

Previous work has proved EvacuatioNZ's model components performance [1], compared evacuation times with trial evacuations, applied the model to examine theatre-type buildings [2] and another case study building [3]. Also, EvacuatioNZ has been used to study the Station Nightclub fire evacuation [4] and benchmark against other similar modeling work, and used to investigate sensitivity of occupant evacuation variables such as: age, gender and physical conditions [5].

2. BACKGROUND

Incident description

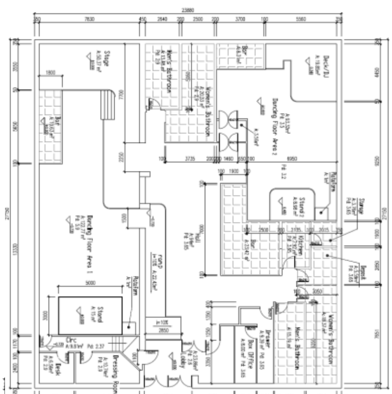
The Kiss nightclub was a single-story building in Santa María, Río Grande do Sul, Brazil. The fire occurred in January 2013 as a result of pyrotechnics igniting polyurethane foam installed in the stage's ceiling and dancing floor area at the start of a country music presentation. The fire killed 242 people, of whom 235 died inside the building, and injured 123 of whom 75 were in critical condition. Although, the fire caused considerable damage to the building, the building did not collapse. The fire can be considered as a combustible (fuel) rich-fire.

A more detailed description of the events leading to the fire and evacuation can be found in the NFPA Journal investigation report [6] and in the Santa María final police report [7]. Information contained in the NFPA report describes the preliminary findings after the fire had occurred, a comparison between this fire and the Station nightclub fire and a regulatory comparative analysis between Brazilian prescriptive code and NFPA; while the Santa María police report details the legal proceedings, post-incident investigations, witness testimonies and overall litigation process after the fire. Also, video documentary resources regarding reconstruction of the events that occurred during the fire and survivors testimonies can be viewed in the Discovery Channel film documentary, A Tragedy in Santa María [8], and Brazilian Globo Television Network Journal, Reconstruction of the Santa María fire incident [9] .

2.2. Description and geometry of the building

The Kiss nightclub was a small venue surrounded on three sides by other buildings with a façade facing the Rua dos Andradas street. The exterior dimensions were of approx. 81 ft. by 76 ft. In the middle of the façade, two sets of two doors with a total width of 142 in were the only evacuation means. The structure had external clay brick walls, the roof had a gabled metallic structure with a false plasterboard ceiling and interior masonry walls were covered by wooden panels and a ceramic floor.

The Kiss nightclub underwent continuous interior modifications in the time leading up to the fire, many of these were not properly documented and thus generated ambiguity regarding specific measurements and configuration of the venue. Preliminary investigation information presented in [6] refers to the plans of the building submitted to the city council some time before the fire as seen in Figure 1. Additional information regarding the physical layout of the building is presented and discussed in the Globo Television documentary where a replica of the building was built based on witness testimonies. An approximated building plan is presented in Figure 2 sketched and adapted from [7-10].



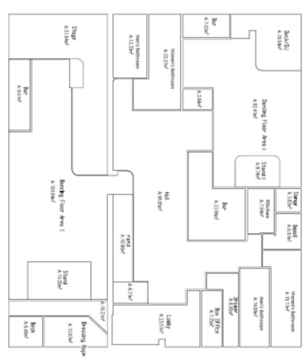
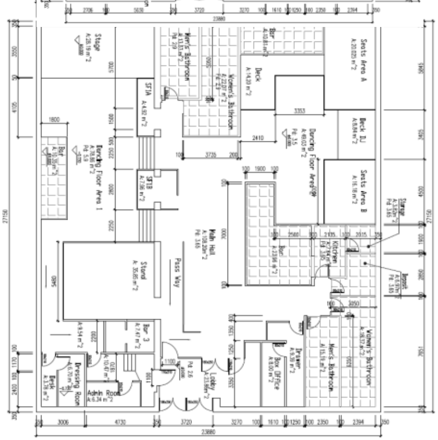


Figure 1: Kiss nightclub NFPA Journal Investigation plans
- Diagrams sketched and adapted from [6].



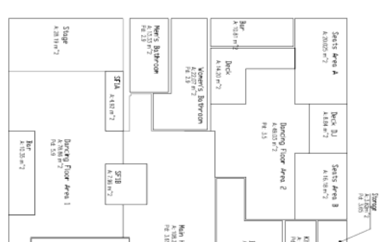


Figure 2: Kiss nightclub Globo Television Network plans - Diagrams sketched and adapted from [7-10].

Whereas to assess the configuration uncertainty both Figure 1 and 2 plans were modeled, examined and compared using EvacuatioNZ considering the practicality of the coarse network model approach of the software.

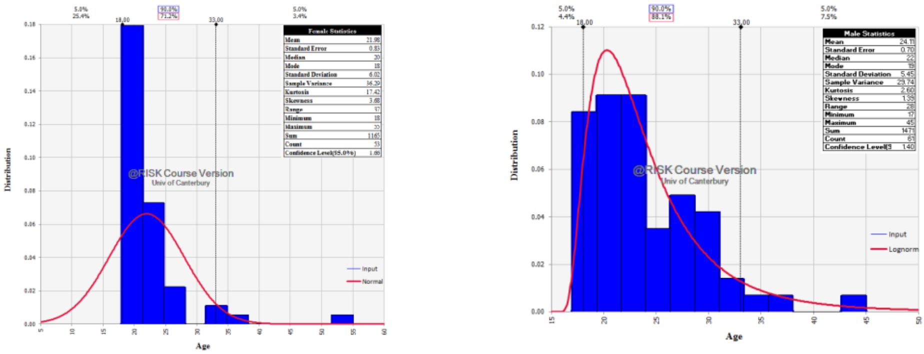
2.3. Occupant numbers

There is no clear information on the number of occupants who were in and around the Kiss nightclub building during the fire. Evidence included in the final police report presented by the Santa Maria Police Department [7] collected testimonies from 142 survivors. 125 of them claimed more than 1,000 occupants and the remaining 17 estimated between 1,000 and 2,000 occupants. Other sources such as [8] and [10] mention figures near 1,000 and 1,061, whereas the maximum allowed occupants for the venue would have been 740 occupants, according to Brazilian code NBR 9077/2001. Also, a total of 29 staff and support members are noted as part of the nominal operation of the venue [7]. A photograph taken before the fire depicts the venue's overcrowding and the dispersed distribution of the occupants within the dancing floor of one of its environments. Whereas using image measuring tools a range from 1.82 to 2.33 occupants/m^2 can be estimated as exemplified in Figure 3 for this particular dancing floor environment.

Figure 3 Photography taken before the fire, adapted from [11]

2.4. Occupant characterization

There is no mention of age and gender of interviewed survivors included in police enquires and interviews. In order to characterize the plausible occupant's age and gender, available information from the victims of the fire was used to estimate statistics and data fit using @Risk software from [12]. Gender distribution was found of 46 % female and 54 % male. Figure 4 show age statistic data fitting using @Risk software. The statistical fitting is adapted to assess uncertainty using EvacuatioNZ agent-type capability. Although EvacuatioNZ has the capability of including body mass index (BMI) to profile population 'fitness' as considered in [5], this information is not examined in the present study.



(a) (b)

Figure 4: Statistics fitting for age data using @Risk software (a) Female (b) Male

2.5. Pre-evacuation time

It is important to acknowledge that given the different locations of the occupants within the venue, not everybody was aware of the fire initial cues registered considering the nightclub was configured to uphold different environments within its venue as mentioned in the various descriptions of the incident. The nightclub lacked of fire detection and alarm system, that could have alerted occupants to start evacuation maneuvers in a specific time. Also, it was clear that in the early stage of the fire occupants did not realize the degree of the threat as the fire spread rapidly within the polyurethane foam and the perceived physical cues were relevant until physical properties of fire intensified dramatically. Other factors that affected the recognition of these fire cues were: artificial smoke, laser lighting, loud noises and music, this factors represent a limitation within the modeling process and are not assessed in the study.

Five different occupant groups were examined to assess pre-evacuation times within the building geometries, each group was considered in relation to its location and where the fire started, this arrangement is shown in Table 1. Each occupant group was fitted with a pre-evacuation time distribution and values were assessed considering information from survivor's testimonies presented in [6-10] and actual video footage recorded inside the venue disclosed in the final police report [1]. Albeit attempts to track occupants through the video footage was attempted it was not possible to accomplish given the video footage is not stabilized passed an estimated 80 s since the fire started. The video footage proves conducive while assessing group 1 and 2 pre-evacuation times and providing a base timeline to compare with eyewitness statements. Timeline mentioned by the final police report remarks that after 40 s within the video footage the occupant that was filming realized the risk and started to evacuate, as he was one of the last occupants to evacuate this 40 s timeline was included as a maximum limit for the first group. Pre-evacuation time distributions are included in Table 2. Using EvacuatioNZ distribution and truncation capability a triangular distribution was devised to fit the data similarly to information examined in other actual fires.

Table 1: Group distribution within nodes in the evacuation model.

Area / Nodes	Agent Type
Dancing floor area 1/ stage front areas	Group 1
Stand area 1	Group 2
Main Hall (and pass way areas)/ lower walk-way areas	Group 3
Dancing floor area 2 / Hall extension / lobby and entrance areas	Group 4
Bathroom areas	Group 5

Table 2: Pre-evacuation time (s) distributions for agent-type groups.

Group	Distribution Type	Most Likely (s)	Min (s)	Max (s)	Fire Cue
Group 1	Triangular	25	15	40	Live music band presentation has stopped. Rapid fire spread over polyurethane foam. Security employee was unable to extinguish flames and rapidly uses stage microphone to notify occupants located in dancing floor area 1 and surrounding stage front area to evacuate.
Group 2	Triangular	35	25	55	Flame appearance and occupants from adjacent dancing floor area 1 have initiated to evacuate towards exits. Many occupants evacuate pushing occupants towards exits.
Group 3	Triangular	50	45	75	Lights went out inside dancing floor area 1, substantial groups of occupants were evacuating, shouts and brawl in the exit doors. Physical variables intensify (smoke spread velocity).
Group 4	Triangular	75	60	85	Physical variables intensify (smoke has spread heavily), electric power and lighting failure, groups of occupants are already evacuating.
Group 5	Triangular	95	85	105	Physical variables intensify (smoke has spread heavily and is dispersed all over the building), electric power and lighting failure, occupants trying to find other exit areas given high density bottlenecks.

It is important to understand that although the information regarding pre-evacuation time is scarce, and occupants within the venue could have undertaken other actions after processing the first cues of the fire; eyewitnesses and survivors' testimonies depict an overall egress of the occupants in the areas near the fire origin were triggered by actions of other occupants meanwhile further located occupants egress was triggered mainly by change in environmental conditions inside the building.

2.6. Occupant Egress

It is important to note that the venue's only exit mean was the main entrance conformed by two exit doors next to each other. One of the two double doors available to exit was blocked by a metal barrier (guard rail) which objective was to enable patrons to go temporarily outside to smoke but avoid they could leave the venue without paying [6]. These barriers were a common set-up within the venue, the rate of egress from the main hall and pass way towards the lobby area was also limited by guard rails; this constriction and the additional security personnel delay led to a bottleneck in the main entrance during the fire, whereas occupants started to evacuate through the main entrance and were detained by security officers that avoided patrons to exit considering they were not aware of the developing fire in the venue and the normal operation of the nightclub required patrons to pay before they could leave the building.

Information obtained from the final police report mention different delay times; one survivor mentions that the doors remained closed for nearly 10 s, other three survivors stated that security personnel had held the door closed for over 1 min, two survivors mentioned a time of 2 mins, other two survivors stated nearly 3 mins and a survivor mentioned a 10 mins delay time, which was not considered in this study considering the overall duration of the fire. Also information presented in the police reports state that a taxi vehicle was located in front of the main entrance of the venue, this is a limitation for the current study given the scarce information provided by the investigation documents reviewed.

At this stage the baseline model includes occupant characterization and pre-evacuation times further information will examine egress modelling.

3. POST-INCIDENT EGRESS MODELLING

3.1. Model description

EvacuatioNZ is a fire egress model that uses a coarse network model approach to simulate expected evacuee behavior and evacuation times to exit. Building spaces are represented as network nodes using a graphical interface called yEd, whereas the nodes are connected by arcs with defined distances and constrictions (doors, stairs, leaves and openings). Information specified by the user can be inputted deterministically or in a probabilistic distribution, the model incorporates the Monte Carlo method with unlimited simulations to assess uncertainty and output can be obtained quantitatively through data reports, two dimensional graph output and three dimensional animated output using Smokeview.

Population configuration requires to specify the number of occupants and their distribution throughout the building (starting position), occupant properties (age, gender, body mass index, height, familiarity and consciousness), movement data (speed model), agent interaction (groups, following leaders), pre-evacuation delays and exit behavior. The model enables multiple occupant characterization providing detailed log reports of each occupant. Exit behavior specifies how an occupant would travel towards an exit node and is incorporated to the occupant's properties. Exit signage, preferred and mixed routes of evacuation can be specified by the user using colored paths and arrows in the graphical interface where exit routes are colored green, preferred paths are blue and mixed paths are purple. Behavior subtypes, probabilistic selection and occupants' own selection can be customized into the model.

EvacuatioNZ incorporates the effect of smoke and reduced lighting into occupant uncongested walking speed. Movement in smoke is estimated through a reduction factor based on work developed by [13] whereas Jin's curves have been assumed normalized and extended to the point where speed becomes zero for both irritant and non-irritant smoke. Extinction coefficients exceeding the limit of the curve are assumed to give a walking speed of 0 m/s and thus representing occupant immobilization. Movement in reduced lighting can be incorporated using Proulx's model that uses worked developed by [14] for three lighting types and alternatively a reduction factor.

Detailed information regarding EvacuatioNZ model can be reviewed in [2, 4] and additional considerations to set-up egress modelling can be examined in [15].

3.2. General set-up

Geometrical dimensions of both venue configurations discussed previously are fixed as rectangular areas within a network representation as shown in Figure 11 and 12. Doors, openings and constrictions are established according to the lay out measurements. Steps within the nightclub are considered as they proved to have affected occupant's evacuation process as mentioned in [9]. Although ramps may have decreased occupant's velocity, there is no evidence stated in the police reports or other sources that could have had a representative effect on the evacuation process. An exit route was defined towards the front entrance, considering this was the only exit in the venue. Guard rails played a significant role in restricting egress flow towards the exit, although occupants could have pass beneath or above them; they are fixed as wall restrictions within the model. Occupants are considered to be randomly distributed within the venue; to assess occupants starting position EvacuatioNZ disperse capability was used to distribute occupants within the populated nodes for all the scenarios.

In order to compare the different scenarios examined in this study and the actual event it is necessary to contemplate a range of casualties considering that during the fire many evacuees returned inside the building to rescue occupants. Although the total amount of victims in the venue during the fire was of 235. According to information included in witness statements [7] fire-fighter response was overwhelmed in numbers and in tasks during the emergency response. Initially emergency personnel dissuaded evacuees from returning to the building but many of them did not accept considering they had friends and family inside. According to statements provided by responding fire-fighters they acknowledge that if civilians would have been prevented to aid the number of casualties would had increased significantly [7]. There is no specific information of the number of occupants rescued, but some figures are mentioned in the police report. One survivor mentioned he was able to assist in rescuing 3 occupants, other survivor stated that was able to retrieve 6 occupants, a former employee mentioned that he had manage to retrieve 10 occupants (4 of them deceased), other survivor mentioned he was able to retrieve 15 occupants, another survivor stated he was able to retrieve 30 occupants some of them already deceased. Albeit as a result of these actions at least 5 evacuees died while attempting to rescue others [7]. Considering this information, it can be approximated that the number of expected casualties could have been between 235 and 260.

3.3. Baseline Modelling

The first step to examine both geometries and evaluate the evacuation variables involved in the modelling of the fire is to deterministically examine the occupant evacuation times without the selection of a preferred egress route, allowing agents to select the minimum travel distance to the exit node, using an unimpeded travel speed of 1.20 m/s. Also, as a first step for the modelling both exits are assumed to be available for the evacuation, security personnel delay is ignored and also the effect of smoke and lack of lightning is disregarded. And as a simple approach the pre-evacuation time was assumed to be zero.

In order to examine different number of occupants within the venue, occupant densities were fixed between a range of 1.51 agents/m^2 to 3.50 agents/m^2 using EvacuatioNZ maximum node density capability, to assess 740 (scenario A- nominal capacity comparison), 1000 (scenario B), 1100 (scenario C), 1200 (scenario D) and 1500 occupants (scenario E) within the geometries; whereas the 29 staff and support members are embedded within the model in fixed starting positions according to sources. Although, a density of 3.50 agents/m^2 would appear unpractical from a design perspective it is examined to evaluate statements exposed by witnesses.

3.3.1. Geometries comparison

Deterministic evacuation times for different number of occupants of both geometries were obtained using EvacuatioNZ and are presented in Figure 5. It is noticeable that the Globo Television Network layout while evaluating different number of occupants has consistently minor evacuation times, this is a reasonable result considering the NFPA journal layout presents an additional constriction with two additional entrance doors in the second dancing area and presents fewer connecting doors in comparison with the Globo Network layout.

3.3.2. Occupant's evacuating speed within geometries

In order to reconstruct as close as possible the evacuation process during the fire agents are assigned ages and sexes using the characterization discussed previously in section 1.4, this information is used to estimate occupant's unimpeded evacuation speed using Ando et al.'s (as cited by Smith) correlation included in the EvacuatioNZ advanced agent type capability. Normal and log-normal distributions obtained in Figure 4 were fitted for statistical data with truncated limits. Results obtained are presented in Figure 6.

To assess probabilistic distribution information within the model, EvacuatioNZ incorporates the Monte Carlo algorithm and in order to use it efficiently is necessary to know its rate of convergence, previous work developed by [2] stated that in between 100 to 500 simulations will give representative results. Also reported by [3] a number of 500 simulations gave convergence on the final mean evacuation time. The scenario modelling case was fixed to run 300 simulations given equipment memory availability.

3.3.3. Pre-evacuation times distribution within the geometries

Pre-evacuation times are fixed within the occupants as discussed in section 1.5. Occupants are organized within five groups and pre-evacuation times distributions were fixed into the model, results are included in Figure 7.

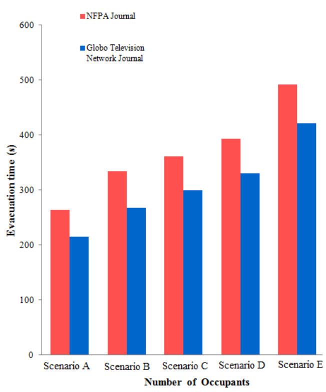


Figure 5: Geometries comparison.

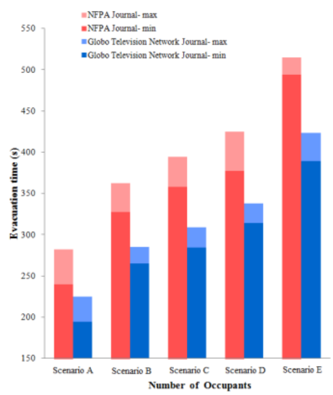


Figure 6: Evacuation time (s) comparison incorporating occupant characterization.

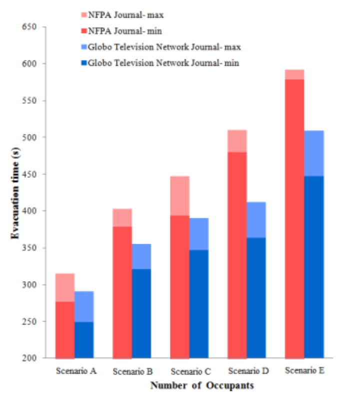


Figure 7: Evacuation time (s) comparison incorporating pre-evacuation times.

At this stage evacuation times comparison within both geometries including occupant characterization and pre-evacuation time information have proven consistency within its results.

3.3.4. Exit availability

Evidence included in [6] suggests that exit availability played a critical role hampering overall exit, as explained in section 1.6. To examine the effect of one exit availability within the discussed geometries, one of the main lobby exits was modelled as unavailable, and evacuation times re-assessed. Figure 8 shows comparison results between evacuation times for the NFPA layout while considering one exit. Results show in both geometries that in average evacuation times will increase from 34 up to 46 % while modelling the use of one exit door instead of the two available in this specific set-up.

3.4. Environmental conditions within the models

3.4.1. Smoke

Smoke spread velocity and temperature within the smoke layer were critical conditions that triggered evacuation in the building considering that the ignited polyurethane foam had been installed in the stage and dance floor area 1 ceiling. Also, according to witness description included in [9], the AC system worsened the smoke spread in the areas next to the stage front where the fire started.

There is research available that discuss the effect of smoke in occupants while evacuating during similar fire conditions included in [4] [16] [17] and information regarding post-incident medical cyanide poisoning assessment of injured survivors of the Kiss nightclub can be review in [18]. Although, there is information available that could be used to simulate the fire and smoke spread, this process would require more time. To include the effects of smoke within the model, EvacuatioNZ smoke capability was used considering a general approximation of the extinction coefficient in the model nodes, this feature is based on work developed by [13]; whereas does not consider the effects of products of combustion on occupants such as CO, CO_2, HCN, etc.

Tenability threshold was fixed when reaching a total of 240 s (4 mins after fire ignition - approx 03:19 am), as stated in survivors' testimonies. This limit in the model represents total incapacitation of the occupant to continue its evacuation and it is quantified as a casualty within the scenario modelling. The starting time of the smoke is fixed at 60 s (1 min after fire ignition -approx. 03:16 am) were an extinction coefficient of 0.20 m^{-1} is assumed. Considering this upper and lower limit and time frame, an exponential relationship was correlated; and the smoke extinction values included in the model as shown in Figure 9.

3.4.2. Interior lighting

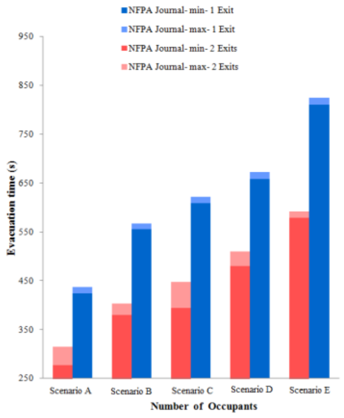


Figure 8: Evacuation time (s) comparison.

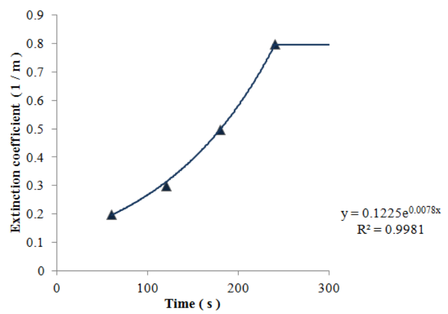


Figure 9: Extinction coefficient included in the model.

Information included in [7] describes that inside the building fragments of 14 emergency lights were found but it was not possible to determine whether the devices were in operation during the fire due to the state of degradation as a result of exposure to heat and flame. Statements provided by survivors agree that none of the emergency lights worked during the fire and acknowledged that there were other sources of lights that provoked disorientation during the evacuation process. Through the analysis of the evidence presented in the mobile device video footage recovered by police it is noticeable that after approximately 80 s the dancing floor area 1 lost electric power and that lighting in the back appear to still be working.

There are some survivor statements regarding the time on which the electric power was lost inside the venue: one survivor mentions that after two minutes the entire nightclub lost electric power, another mentions three minutes and other survivor states that electric power was lost when exit doors were opened by the security personnel. To assess the effect of lighting within the model, EvacuatioNZ lighting capability was used considering a general approximation of the reduction factor based on work developed by [14], whereas a reduction factor from 1.0 to 0.1 is fixed within the nodes at a maximum limit of 180 s.

Environmental conditions inputted into the model define the tenability limits inside the building as described in section 3.1 and as they gradually progress they limit occupant's evacuation process by reducing occupant's unimpeded walking speed until this value is 0 m/s and the occupant cannot move anymore whereas the immobilisation of the evacuee is considered as a casualty. The expected number of casualties in the model is given by the difference between the total number of occupants and the cumulative number of occupants that exit safely the building. This information is obtained from EvacuatioNZ node report. Figure 10 shows results for scenario A, B, C, D & E considering the discussed settings in section 3.4.

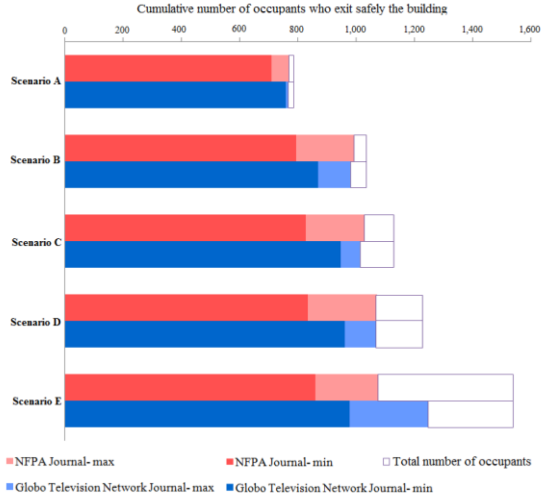


Figure 10: Cumulative number of occupants who exited safely the building comparison.

As shown in Figure 10 results from the NFPA Journal layout exceed the range estimated in section 3.2 whereas at this point this geometry approximation is discarded from further analysis. Also it is possible to discard scenario E as the number of expected casualties would have been considerably higher than the assessed range. At this point given the results compared the study focuses on analyzing the Globo Television Network geometry for scenarios B, C and D where other evacuation variables and information is examined.

3.5. Exit behaviour and egress considerations

It is impossible to recreate each individual's exit behaviour given the high degree of uncertainty and information availability for this present study, although a general approximation can be examined. As an overall egress consideration it could be assumed that the occupant groups that would have the higher number of casualties where located in the furthest area of the venue this considering pre-evacuation times were higher and the fire cues were not clearly evident au contraire groups located near the ignition source would had higher probabilities to evacuate safely considering the clustered environments within the venue. This consideration can be supported by information presented in [7], which evidence that the members of the performing music band located at the ignition point of the fire (furthest distance from the exit) managed to evacuate through the congested venue whereas one of the members died while returning to the nightclub to retrieve property as reported by [19]. Also a survivor's testimony included in [8] described that her partner was located in one the bathroom areas before the fire and was not able to escape.

Also, according to witnesses statements included in [8, 9] during the evacuation process lighting failed in all of the building except in the bathroom areas where a green source of light emitted misleading evacuees to this area. Evidence suggests that between 100 to 180 casualties were located in the bathroom area. Considering the range of casualties located in the bathroom areas, EvacuatioNZ exit/preferred route capability is used to incorporate group egress towards the bathroom area for agent-type groups 4 and 5 (see Table 2). The exit behaviour is arranged using EvacuatioNZ subtype behaviour capability whereas an average probability of 55 % of the exit behaviour is set-up to exit towards the main entrance and 45 % of the group towards the bathroom areas for the discussed groups. These percentages are estimated considering the balance of population distribution within the scenarios examined, considering a value of 180 evacuees orientated towards the bathroom areas. Using yEd graphical interface the preferred and exit routes are incorporated in the model as shown in Figure 11 and 12.

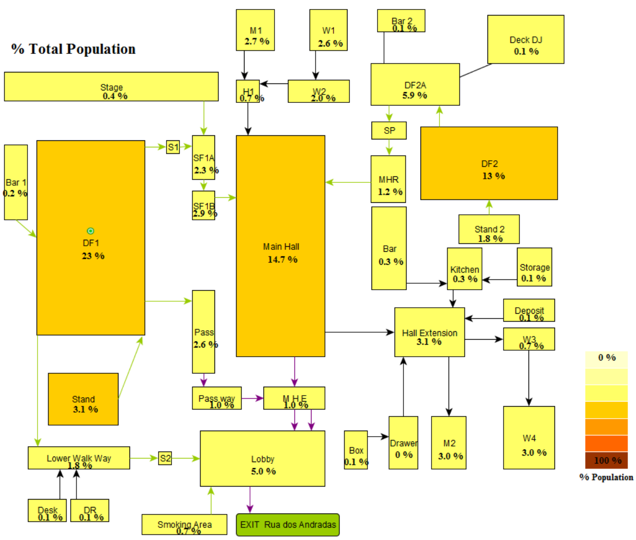


Figure 11. NFPA Journal model set-up in yEd graph interface.

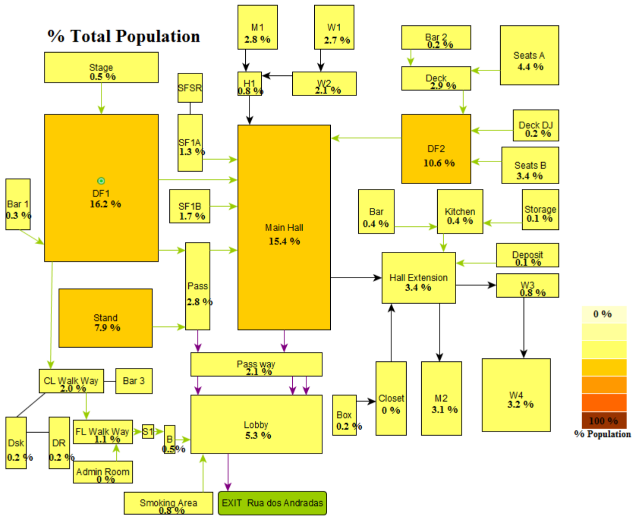


Figure 12: Proposed layout model set-up in yEd graph interface.

Results for scenarios B, C and D are presented in Figure 13. While comparing average results, scenario C and scenario D prove to exceed the expected casualties range discussed in section 3.1, whereas scenario B has an average expected number of casualties of 248 that is between the considered ranges and matches density range discussed in section 2.3.

3.5.1. Exit delay

According to the incident reports, during the evacuation of the building the security officers delay caused a bottleneck in the exit areas in the first stages of the evacuation process, as discussed in section 1.6. Delay times of 10 s, 30 s, 1 min, 2 mins and 3 mins are examined in the exiting nodes towards the lobby area for scenario B using EvacuatioNZ delay capability. A sensitivity analysis is shown in Figure 14. While comparing the information analysed for scenario B and the range of casualties considered in section 3.2 it is noticeable that a delay time of 180 s would have been unfeasible and delay times of 10 s and 30 s would become not significant while comparing the minimum cumulative number of occupants who exited safely. A delay time of approximately 60 s can be considered plausible for the actual event considering that would represent a reasonable time that matches between examined results and survivors' statements.

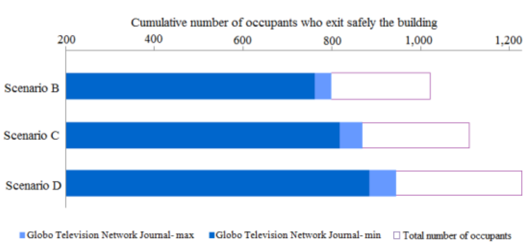


Figure 13: Scenarios comparison.

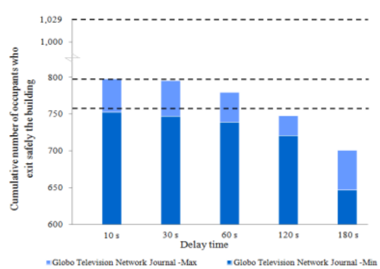


Figure 14: Sensitivity analysis.

4. MODELLING EGRESS OF THE KISS NIGHTCLUB

The analysis of the scenarios related to the Kiss nightclub evacuation have been developed varying known evacuation parameters (baseline modelling) towards gradually examine variables with higher degree of uncertainty. In the current study, modelling the Kiss nightclub fire uses the occupant load consistent with scenario B (1,000 patrons and 29 staff members) and pre-evacuation time distribution discussed in Table 2. Agents are characterized using information regarding ages and sexes from Figure 4, whereas EvacuatioNZ Ando's occupant speed capability is used to estimate unimpeded walking speed. Exit availability is restricted to one exit and environmental conditions are included using EvacuatioNZ smoke and lighting capability. Exit behaviour is arranged to probabilistically direct 45% occupants of groups 4 and 5 towards in an around bathroom areas while considering a delay of 60 s in the exit doors to simulate the security personnel intervention. Results included in Figure 15 show an average of 776 occupants exit safely the building, this meaning an expected average of 253 casualties which is within the range discussed in section 3.1.

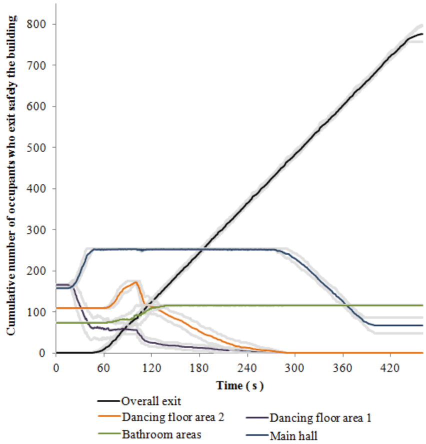


Figure 15: Average cumulative number of occupants that have exited the building for the EvacuatioNZ modelling of the Kiss nightclub fire with a total of 1,029 occupants.

The egress behaviour of both dancing floor areas, main hall and bathroom areas are included in Figure 15. It is noticeable that through user intervention EvacuatioNZ was able to recreate egress towards the bathroom area and surroundings as discussed in section 3.5; whereas the total occupants located in and around the bathrooms was of 171 in comparison with the 180 mentioned in the reports. Also from Figure 15, it is noticeable that in some areas the number of occupants' increase over certain periods of time, this is due to the surrounding areas which in order to evacuate transit through the analysed areas.

Considering the existent capability of the software to recreate the Kiss nightclub fire there are some scenarios that can be simulated for the actual event. Modelling the fire scenario with the same occupant load but considering exit is set-up completely available, security personnel delay avoided and pre-evacuation time fixed to 25 s in order to simulate a fire detection and alarm system. Results show an average of 1,007 occupants exit safely the building and 22 expected casualties. Reducing the occupant load to the venue's nominal capacity and considering the same scenario, all the occupants of the venue manage to evacuate safely in an average of 252 s.

There are various limitations that have to be considered to understand the results presented in this study, first there is no clear information regarding the physical barriers within the venue which imposes a high level of uncertainty to examine presumed constrictions that could had altered the rate of egress of occupants towards the main exit such as metal guards. Another limitation is the information availability of the physical condition of the occupants. The final police report does not include any statement that could clarify if there was a reduction of evacuation capability as a result of physical or medical conditions (wheelchairs and mobility impaired occupants) within the occupant groups. This consideration as reported by [20, 21] cited by [22]could have resulted in extending evacuation times of fire-induced evacuation affecting other evacuees. Another limitation of the study relates to the effect of alcohol consumption within occupants. An important limitation that will have to be assessed in future research relates to developing a smoke spread model that could be incorporated to EvacuatioNZ capabilities.

EvacuatioNZ performance has proven consistency within the different scenarios evaluated. EvacuatioNZ offers a wide variety of capabilities that this study was not able to explore given the limited amount of technical information available from the fire reports.

5. CONCLUSIONS

- ✓ By modelling and matching the number of casualties with the proposed model, it is estimated that a total of 1,000 patrons were in an around the venue and their egress was delayed in approximately 60 s by security personnel inside the venue.
- ✓ The most realistic scenario for the Kiss discotheque fire is consistent with geometry presented in Figure 2, Globo Television Network Journal.
- ✓ Given the proposed model’s capabilities to recreate the Kiss nightclub fire, it is estimated that if the nominal capacity of the venue would have been respected, exits completely available and security personnel delay avoided, all the occupants of the building would had escaped safely in an average time of 252 s.
- ✓ Through user intervention EvacuatioNZ was able to recreate egress towards the bathroom areas and surroundings as detailed in the police report and other sources.
- ✓ In this particular incident it was noticed that the geometry configuration had quite an impact and in particular analysing pre-evacuation times in clustered areas.
- ✓ EvacuatioNZ network model proves consistent while analysing egress variables within the scenarios considered for the Kiss nightclub fire.
- ✓ In order to have a more accurate reconstruction of the actual event it is necessary to develop a smoke spread model that could be incorporated to EvacuatioNZ smoke capabilities.

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