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A Case Study on a Fire Disaster using Fire Dynamics Simulation (FDS) and Experimental Techniques to Reconstruct a Textile Factory Fire Scene

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1. Introduction

The fire investigation result provides the recommendations to adjust and make the policies associated with fire safety, and responses to the significant developments to the judicial administrations to practice to identify the responsibility of criminal and civil. The fire science progress has been approved in the courts to use scientific methods to show the fire scene accidents. Accordingly, fire simulation has been a major tool to analyze fire investigation[1].

National Fire Protection Association (NFPA) 921 [2] explains the reconstruction fire scene as:

> The fire reconstruction process is one of the fires that ignite the fire scene to go out, can explain the smoke development and fire spectacle, non-fire distribution situation, and the impacts of automatic suppressor manual equipment, ventilation effects, the building designing itself, human life safety devices casualties, etc.

These involved the fire damage projections, the behavior of human aspects, adopted appropriate scientific methods and material evidence, fire engineering, and science, etc. These calculations result (for example, flame height, spreading and smoke layer, temperature, burning time, etc.) compared with the actual condition can lead the investigation direction in the fire

scene. It is important in analyzing the chain of flammable burning materials, quickly assists in detecting the flaming to narrow the fire origin area, and then rational identifies fire cause[3].

Fires incidents have indirect and direct causes and illustrate some problems concerned with the firework control of the associated organization. In this perspective, positive significance to determine the fire cause through fire investigation, and the following aspects are basically embodied: 1). It can collect data on fire safety policies from both directions, identify the actual problems, recognize the objectives to accomplish the initiative, and support specific operations to promote fire safety. 2). It can provide experience and materials for enhancing firefighting service from the perspectives of adjusting firefighting plans, exploring new strategies, adding modern equipment, etc. 3). It can provide basic fact-finding where the legal obligation to educate the public and enhance awareness about their safety by punishing the concerned persons. 4). It can introduce research fields to fire and departments of scientific research and contribute accurate fire and timely information for fire organizations[4].

Presently, fire investigation methods mainly consist of survey inquiring, investigation events, scene experiments, technical appraisal, the final of which is an example of a fire investigation. In this context, fire investigation with modern techniques has become the most important preference for fire accident investigation [5]. Around the world, people are facing critical fire challenges which cause property damage and life losses. The post-disaster investigations integrate laborious tasks, For example, full-scale fire simulation tests. Despite the fact, that such tests achieve precise simulation results[6], they need monetary investment and considerable time. Over the last ten years, several schools and governmental organizations worldwide have persevered in simulating and examining the factors, methods, and fire disaster results[7][8]. An investigation relating to building evacuation has spread wide-ranging. The research results illustrated that waiting time, walking time and escapee response time are the three major contributing factors and have an impact of entire evacuation time. Outbreak duration, fire-generated smoke decreases the visibility of the environment evacuation and enhances waiting time and walking time, and resulting in simulation problems [9,10]. In spite of the fact that full-scale simulations are more accurate than software simulation, but software simulation results are still acceptable [11,12].

Currently, many researchers have used the simulation of fire to investigate the fire occurrence process and advancement in various cases, and mostly work has been completed to

increase the accuracy of fire numerical simulation, e.g.,[5,13] illustrated about the Fire-Structure Interface (FSI) developed a “Dual-layer” model which distributed in two layers (cold and hot layer). [14] developed methodology for probabilistic risk assessment (PRA).The Fire Simulation Model (FSM)contains art-of-the-state fire initiation models, post-fire failure damage propagation, fire development, damage scenario-based, and fire service response by using a fire dynamic simulator and CFD code in this simulation.[15] Carried out some workplace experiments and computational simulations. The comparative study demonstrated that the geometry and fire diameter of the enclosure consequence the grid size. The dependable of fire dynamic simulator for far-field temperature advance declarations when grid sizes of adequate were used to half the fire diameter.

Despite that, fire numerical simulation adopted in fire incident investigations. The National Institute of Standards and Technology, US illustrated the example related FDS in supporting the investigation on some severe fire cases. For example, single-story nightclub Rhode Island-based on timber-structure simulated the fire occurrence in February 2003, showing the uniformity between the Fire Dynamics Simulator (FDS) results in numerical simulation and the full-scale fire experiment consequences and demonstrating the crucial role of firefighting proficiency in handle and control fire below similar terms. Furthermore, [16] mentioned experiment in a Ten-Storey building apartment, Taiwan in 2008, which purpose to make computer fire simulation to reconstruct the fire process. Because of the stack impact, the first source of fire that happened on the third floor spread rapidly through the flat porch. The upper floor caused the death of three families on the tenth floor.

[6] Performed numerical simulation experiments in the warehouse fire models to reproduce the fire process, containing combustion characteristics, development and ignition of the fire. It was observed that when seal or order sheet on the carton fired through a burning cigarette, ultimately carton would be illuminated; the fire spread and development in numerical simulations strongly according to the experiment process.

In 11thSeptember 2012, a horrible textile fire disaster occurred in a garment factory, namely Ali Enterprises. The investigation authorities referred to the detrimental fire in the history of Karachi. The research purpose has been considered in order to realize the potential losses of different types of incidents, and the general errors and causes which have to lead to

increased disasters. The researcher expects to obtain more awareness of fire accidents to identify fire behavior through different modern techniques.

2. Tangible textile fires in Karachi Pakistan

During the 8 years from 2014 to 2021, there were 19 cases of tangible textile factory fires affecting textile societies in Karachi. This shows an average almost three fire accident at an industrial site per year in the past 8 years. Furthermore, fire accidents occur as a result of destruction of textile sector as shown in Table 1.

Cause	Name of Industry	Location & City	Accident occurred Year	Manufactured Product
careless	KBI industry	A- 32 Manghopir Rd, Industrial Trading Estate, Karachi	2014	Textile raw material
yet to be ascertained	Abdullah Garment	Valika Chowrangi, SITE, Karachi	2015	Garments
Short circuit	Harmain Textile	Sector 6-B, New Karachi, Karachi	2015	Weaving, stitching, and warehouse
careless	Old garments warehouse	Gulbai, Karachi	2015	Garments Warehouse
Electric fault	Nazeer Dying & Stitching	Hanifa compound, Azizabad, Karachi	2015	Dying and stitching
Electric short	Towel factory	Cattle Colony, Karachi	2016	Towel manufacturing
careless	Old cloth warehouse	Spencer Kanta, Karachi	2016	Cloth warehouse
Intentional	Mundia Textile	Hawkesbuy Road, Karachi	2016	Non-woven and woven manufacturing
careless	Essa Tex (Pvt) Ltd	Plot No: G-13, SITE, Karachi	2016	Home Textile Products
careless	Ideal Textile Mill	Plot No: B-13/ SITE, Karachi	2016	Manufacturer textile

Intentional	M/S Rajwani denim	Zafar town, Landhi, Karachi	2017	Garments
Short circuit	Mundia textile Mill	SITE, Karachi	2017	Spinning
careless	Dying Hosiery Garments	Sec 12-A Plot No-6, Karachi	2017	Bath towel institutional item and kitchen item
careless	Sajid Textile	Plot No: SA-88, Scheme 33, Ahsanabad, Karachi	2018	Bath towel and kitchen item
ascertained yet	Lucky One textile Mill	Block-22, F.B. Area, Karachi	2018	Weaving and processing unit
Short circuit	Star Textile Mill	Nera Site Police No. D-137/E, Zia Morr, SITE	2019	Cotton and polyester yarn
Intentional	Garment Factory	Plot No. 20, Sec:12-D, Gabol Town, North Karachi	2019	Garments
electrical short circuit	Al-Awal garment factory	47-1,Sector 12-D North Karachi Industrial Area Karachi's New Industrial Zone	2021	Garments
Electric short circuit	BLI factory	Korangi karachi	2021	Manufacturing textile products

Table 1: list of Major fires accidents in textile processing industries in the Karachi (2015-2021 November)[1]

3. Case studies

A "case study" most clarified form includes research and investigation of "real-life scenarios of a limited number of conditions or events through detailed analysis context and their associations" [17]**.** The "case" may emphasize an organization, industries, project, individual, phenomenon, or event, rooted in a particular place and time. Majority of cases based on real cases [18].Case studies present constructive means to improve our knowledge and information base using

[12]*Source : Karachi Municipal corporation (KMC) Fire department*

accidents experienced by others. The interesting puzzle contributes to understanding and knowledge of fire behavior [19].

4. Failure of Corporate Social Auditing

4.1 SA8000 Certification: the Role of RINA SAAS and SAI

An Italian company RINA Services, Headquartered, Genoa issued an SA8000 certificate to the Ali Enterprises factory in August 2012. RINA provides assessment, certification and inspection services in compliance with international and national standards[2]. RINA has authorized to accomplish SA8000 certification by Social Accountability Accreditation Services (SAAS), which is the certification agency of Social Accountability International (SAI), the SA8000 standard established by the US-based organization as shown in *Fig. 3*. According to RINA, RI& CA mentioned in the audit report about the textile factory that

> "*The sufficient quantity of fire safety buckets and fire extinguisher were available; "fire extinguishers were accessible and visible to all workers; access to passage and fire extinguishers leading to exits was saved free from any kind of hindrance and obstacle; emergency exits and primary exits are kept in closed and opened while workers are inside facility; procedures of emergency exist, containing records of fire-fighting training and regular emergency drills".*

The above statement shows that the factory was more secure for the working environment. This certificate issued ten days before the massive fire accident by RINA. In spite of the fact, researcher contradicted the above statement when questionnaire data were analyzed; workers categorical denied the above statement that they were not getting any kind of fire safety measures. It demonstrates magnitude about the authenticity and credibility monitoring system alleged companies of an international audit[3].

[2] RINA Services, "Overview", undated, available at: https://www.rina.org/en

[3] Source: National Trade Union Federation Pakistan (NTUF) - https://www.medico.de/fileadmin/_migrated_/document_media/1/summary-of-research-on-baldia-factory-fire-tra.pdf

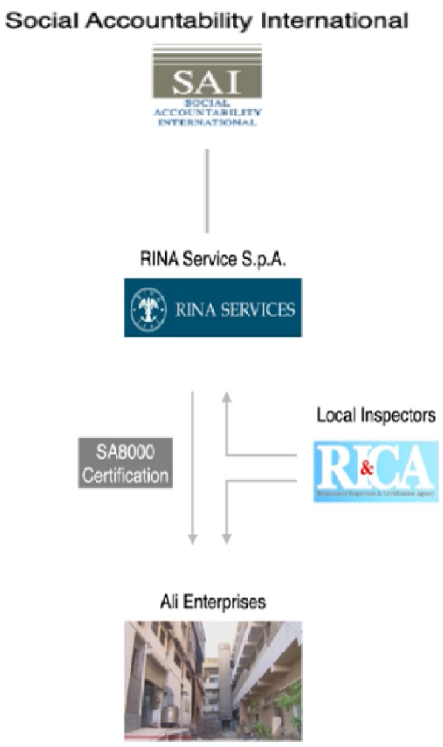


Fig. 3. The role of RINA SAAS and SAI

4.1. Basic factory fire accident information fire in Karachi

Over the past decades, Pakistan has become one of the most devastated countries and exposes destructive consequences on environmental, economic and social progress, and develops substantial disastrous events to property and life in the regions. The Nation (2012) reported that annually 16,500 peoples killed, 164,000 injured, and 400 billion (PKR) direct economic and property damages in the Pakistan. Yearly, statistical values of total fire accidents in the Karachi as shown in *Fig. 1*. Furthermore, some serious incidents in the manufacturing industries occurred during 2015-2020 as mentioned in ***Table 1***.

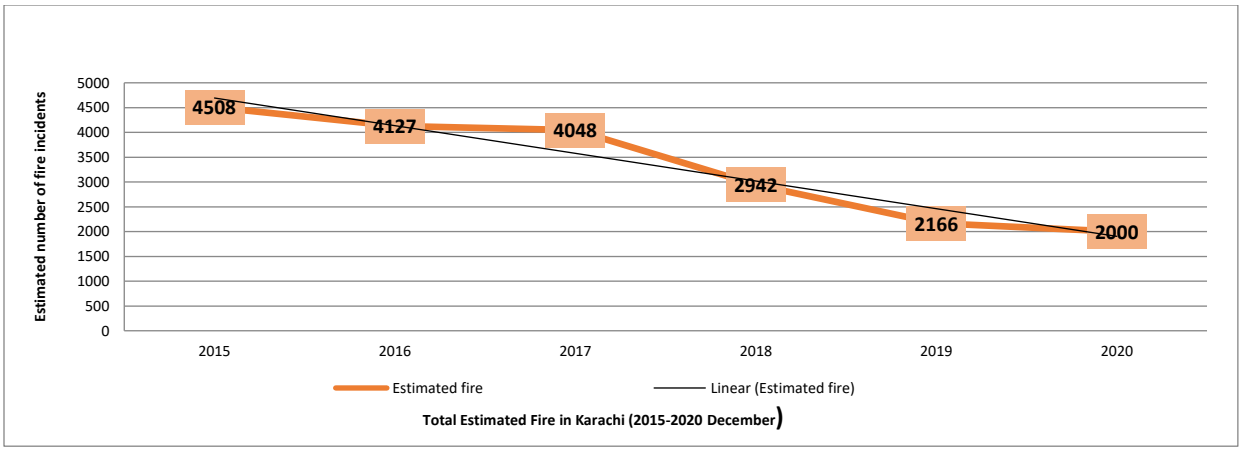
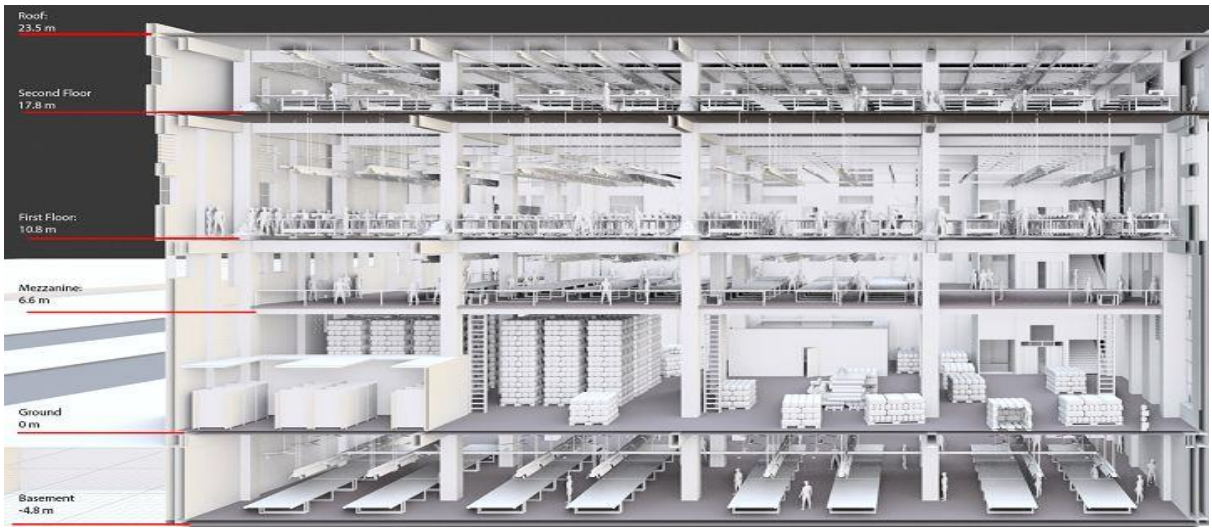


Fig. 1. Fire Accidents in the Karachi (2015-2020 December)[4]

On September 12, 2012, a three-story textile garment factory in Karachi, Pakistan (SITE) fire occurred at -6:00 PM, total killing 262 workers and seriously injured 55 (Clean Cloth Campaign, 2012)[5] shown in *Fig. 2*. The three-story building was based on the Basement floor, Ground floor, Mezzanine floor, 1st first floor, and 2nd floor. The building is approximately 23.5m high from Ground Floor to Roof. The relative heights of the floors are as follows: Basement = -4.8 m, Ground floor = 0 m, Mezzanine floor = 6.6 m, First Floor = 10.8 m, Second Floor = 17.8 m, Roof = 23.5 m as mentioned in **Table. 2**. The total factory area covered 0.96 acre.



[42]*Source : Karachi Municipal corporation (KMC) Fire department*

[5] *Source: Clean Clothes Campaign (CCC)* - file:///C:/Users/Administrator/Desktop/clean%20cloth.pdf*

Fig 1. The building dimensions

Fig. 2. Textile Factory Fire Scene

Floor	(Unit: m^2)	Dimensions (unit: m)	Approved Intended Use
Basement floor	42210	210(L)*201(W)*-4.8(H)	Cutting and washing department
Ground floor	42210	210(L)*201(W)*0 (H)	Warehouse, Combustible material, clothing bails
Mezzanine Floor	42210	210(L)*201(W)*6.6 (H)	Pressing and quality department
First floor	42210	210(L)*201(W)*10.8 (H)	Stitching unit
Second floor	42210	210(L)*201(W)*17.8 (H)	Stitching unit

Table 2. The building dimensions

Table 2

Background details for the building	**(Unit: m^2)**
Space dimension	42210
Height of the floor	42210
Area	42210
Ceiling height	42210
Initial temp	42210
Rooms in floor	42210
Wall material	42210
ventilation	42210

4.2 Methodology approached in Fire accident investigation process

The National Fire Protection Association (NFPA 921) standard became applicable for properly fire investigation in 2000. Fire scientists understand fire behavior through experiments and scientific research. Here, the Traditional fire investigation process adopted which relates to the new approach.

Accordingly, fire investigation methods mostly comprises fire investigation scene, preliminary conclusion of fire accident investigation, interview with successful evacuees and workers, fire accident simulation, experiment scene, reconstruction scene of fire scene, and the last submit the fire investigation report which composes the preferred approaches of fire investigation in this research as shown in Fig. 4.

In the present study, an accident investigation method was based on an interview with industry workers and successful evacuees. The data collected through questionnaires. Firstly, the questionnaire draft form was the design and a significant literature review studied. The *Statistical social package of social science (SPSS, 23)* software used to determine the statistical analyzes after obtaining the data from filled questionnaires. The program reliability based on the worker's level, demographics information, and testimony and causes fire accidents and their information level and knowledge. In order to determine the data frequency distribution, described by the frequency table. The Likert scale having range 1-5 were used in the questionnaire paper, including 5 = strongly agree, 4= agree, 3=Not Sure, 2=disagree, 1=strongly disagree.

After that, two more methods of investigation accidents based on Fire Dynamic Simulator (FDS) and multiple crowd simulations (MCS). This approach efficiently alliances computer simulation and investigation fire accidents and can offer influence in determining the fire cause, contributing cases for buildings fire prevention, measuring the damage caused by it, and getting where accountability lies in accordance with legislation.

Against the background of our analysis, we formed a film and 3D model that simulates and illustrates the route of fire and investigation of the building's defect and uncertainty to it. We also investigated with the objective to stimulate the propagation of smoke and the routes that the peoples fled the building.

We used smoke simulations and crowd to rebuild the real situations of the fire, and how to test other, in the factory architecture legally flexible variations would have taken to various consequences during evacuation.

5. Results and discussion

The demographic features like Gender, Age, Marital status, and Educational level participating in the survey shown in the Table 1. Therefore, 103 (85.8%) workers were male, while 17 (14.2%) were female. Correspondingly, 3.3% of the workers are below age 19, 46.7% are 20-29, 27.5% are 30-39, 15.8% are 40-49 and 6.7% are 50-59. Accordingly, 40.8% of the workers are single, whereas 59.2% are married. Furthermore, 38.3% of the workers are Illiterate, 18.3% Middle education, 19.2% Secondary school certificate, 16.7% Higher secondary school certificate, and 7.5% completed an Undergraduate degree certificate.

Table 1

Distribution of Gender, Age, Marital status and Level of education respondents

Distribution of Gender	**Frequency, f**	**Percentage, %**
Male	103	85.8
Female	17	14.2
Total	**120**	**100**
Distribution of Age (years)	Frequency, f	Percentage, %
below 19	04	3.3
20-29	56	46.7
30-39	33	27.5
40-49	19	15.8
50-59	08	6.7
Total	**120**	**100**
Marital status	Frequency, f	Percentage, %
Single	49	40.8
Married	71	59.2
Total	**120**	**100**
The Education level	Frequency, f	Percentage, %
Illiterate	46	38.3
Middle education	22	18.3
Secondary school certificate	23	19.2
Higher Secondary school certificate	20	16.7
Undergraduate degree	9	7.5
Total	**120**	**100**

5.1 Fire safety measures (FSMs) in a textile factory

The data collected was examined and Standard deviation (SD) and Mean ($\bar{x}$) were computed, and results are mentioned in Table 2.

The statistical values for Iron burglar windows were ($\bar{X}$) = 4.60, SD = 0.61 and Exit door locked ($\bar{X}$) = 4.54, SD = 0.98 as shown in Table 2. Here ($\bar{X}$) is near to 5, hence it is measured as 5. The result indicates that workers strongly agreed that windows were covered with iron burglar grills and exit doors permanently locked. The projected photo of the Federal Investigation Agency (FIA) verified the above results as shown in *Fig. 5 and Fig. 2.* The Joint Investigation Team (JIT) and Federal Investigation Report mentioned in the report that factory have five doors for escaping. Unfortunately, three doors were locked permanently remaining two doors were locked due to heat expansion. During the fire accident all these doors were unable to open.

Furthermore, (National Fire Protection Association (NFPA), 2015) discussed about the hazardous risk raised by illegal bars, classifying that a mean of escape or window should be usable from the internal side. The exit door must be unlocked. The workers must be the ability to unlock an exit door without any tools, keys or expert knowledge (Occupational Safety and Health Standards, 2014). According to Law (The factory act, 1934) "exit door shall not be locked".

Table 2
Fire Safety measures

Variables parameters	Mean	SD
Iron burglar Windows	4.60	0.61
Exit door locked	4.54	0.98
Timber floor structure	4.34	1.13
Fire alarm system	3.77	1.46
Availability Hazardous material	3.71	1.33
Emergency lighting	1.98	1.34
Fire safety equipment	1.85	1.26
Emergency exit sign	1.83	1.21
Fire extinguisher	1.75	1.26
Fire hose reel	1.27	0.56
Accident prevention measures	1.23	0.83
Protective clothing	1.15	0.52
Fire sprinkles	1.13	0.59
External staircase	1.12	0.41

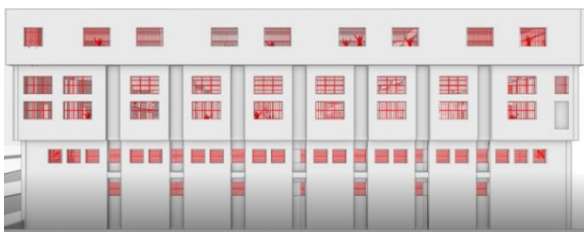


Fig.4. Iron burglar windows

Fig.5. Doors permanently locked

Statistical value for the timber structure floor was ($\bar{x}$) = 4.34 and SD = 1.13 as given in Table 2, which indicates that workers agreed to the presence of timber structure on the mezzanine floor. In violation of this law, the projected photo of the Federal Investigation Agency (FIA) proved that timber structure was completely destroyed-visible amongst too wretched a twisted steel beams which supported to timber floor of the mezzanine as shown in *Fig. 5*. Karachi Building Regulation () stated that all steel and other metal structural member shall be protected with non- combustible materials to provide the required fire resistance. This law also stated that concrete fire protection on steel columns shall be reinforced and enclosed by wire mesh, metal clips or specially wound wire of not less than 12 gauge size with a pitch not more than 4 inch (10 cm). The approved construction drawing of the building mezzanine floor should construct with roller compact concrete.

Fig 6. Timber structure with twisted steel beam

Statistical value for the fire alarm system ($\bar{X}$) = 3.77 with SD = 1.46 proved that workers agreed about the availability of one alarm system which was inaudible and ineffective. The above result violates the Pakistan factory Act which mentions that every factory must have clearly audible and effective alarm system to provide escape warning in case of an emergency situation (The Factories Act, 1934)[6]. The alarm system had also failed during another fire, which took place 7/8 months previously. Despite the incident, the alarm had no repaired in this factory as shown in *Fig. 5*.

Fig.8. Fire alarm system

Statistical value for the availability hazardous material was ($\bar{x}$) = 3.71 and SD = 1.46 as given in Table 2, which indicates that workers agreed to have hazardous material available on the floor. Despite the fact, that clothing bails wrapped in polyethylene plastic which is predominant fuel for the fire as shown in *Fig.4*.

According to SA 8000 guidelines flammable and hazardous materials should properly stocked and kept away from ignition sources.

The Pakistan law stated that a free passageway gives access of escape in case of fire. In violation of this law, witnessed and FIA report stated that clothing bails stored on the main floor which frequently blocked on escape route.

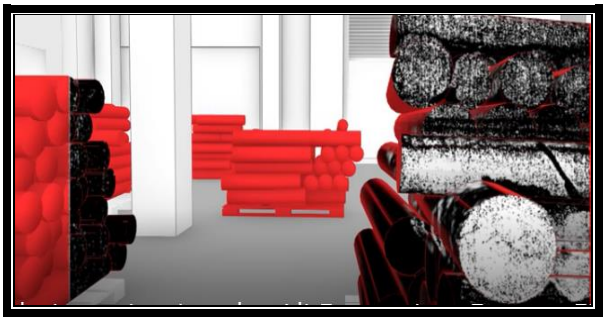


Fig.7. Hazardous materials

Statistical value for emergency lighting was ($\bar{X}$) =1.98 and SD = 1.34, fire safety equipment ($\bar{X}$) =1.85 and SD = 1.26, emergency exit sign ($\bar{X}$) =1.83 and SD = 1.21 and fire

[6]*Source: The Factory acts, Pakistan (1934) –* https://www.ilo.org/dyn/natlex/docs/WEBTEXT/35384/64903/E97PAK01.htm

extinguisher ($\overline{X}$) =1.75 and SD = 1.26; mean value of these variable near to 2, which indicates that workers disagreed about the practices of these measures in the factory.
The artificial or natural, suitable and sufficient emergency lighting must be implemented on special points where emergency light functions automatically in case of emergency or electricity breakdown in the passages or workroom (Pakistan, The Factories Act, 1934)[7].The lack of fire safety equipment has an adverse impact on the entire business, i.e. human capital assets and development infrastructure [24]. The mean value signified that workers disagreed for the existence of emergency exit sign facilities in the workplace. In case of fire, an emergency exit sign fixed on every door, window, and wall.(Pakistan, The Factories Act, 1934)[8] mentioned that clear understood sign an adequate size red letters must be pasted in understanding language.

Fire extinguisher

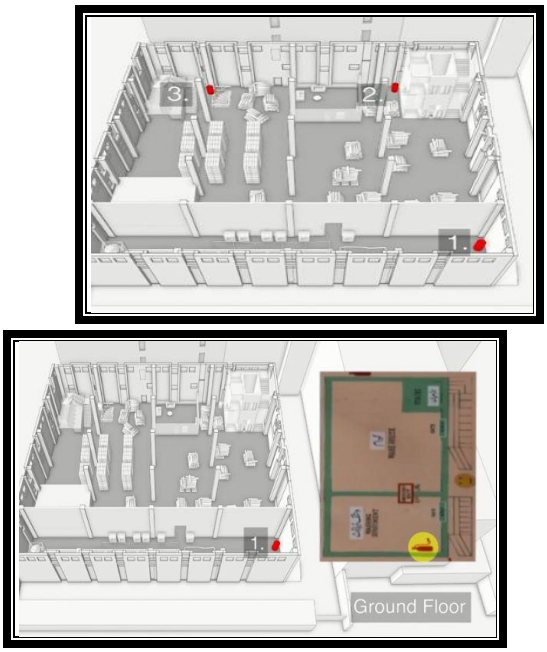
Statistical value for fire extinguisher was ($\overline{X}$) =1.75 and SD = 1.26, mean variable near to 2, which indicates that fire extinguisher were not present in the factory.
A fire extinguisher is a wheeled or moveable equipment for reduced the tendency of primarily fire or small fire by discharging extinguishing chemicals[25].
The Pakistan law stated that there should one fire extinguisher for space up to 557 Sq-meter or 6000 Sq-feet and subsequently addition for each additional 557 Sq-meter or 6000 Sq-feet at the space.

The ground floor blocks possess an area 1600m2, which means there should have a maximum of three fires extinguish on the ground floor as shown in Fig 6 (a)

According to the emergency evacuation plan on the building was showing only one extinguisher inside the building as shown in Fig 6 (b).

Furthermore, witness mentioned that there fire extinguisher cylinder were empty and no worker was trained how to operate them, also stated that during my time of employment nobody ever came for their maintenance (Shezad Ali).
This means that even if the fire extinguisher has been functional. The national provision was below the legal requirement. Furthermore, factory workers also responded that the fire extinguisher in the block was empty and the workers did not know to operate"(Sindh Factories Rules, 1975)[9].

[7]*Source: The Factory acts, Pakistan (1934) –* https://www.ilo.org/dyn/natlex/docs/WEBTEXT/35384/64903/E97PAK01.htm
[8]*Source: The Factory acts, Pakistan (1934) –* https://www.ilo.org/dyn/natlex/docs/WEBTEXT/35384/64903/E97PAK01.htm
[9]Source: Sindh factories rule , 1975 https://www.ilo.org/dyn/natlex/natlex4.detail?p_lang=en&p_isn=50088&p_country=PAK&p_count=447&p_classification=13&p_classcount=12



Statistical variable for fire hose reel ($\overline{X}$) = 1.27 and SD = 0.56, accident prevention measures ($\overline{X}$) =1.23 and SD = 0.83, Protective clothing ($\overline{X}$) = 1.15 and SD = 0.52, fire sprinkles ($\overline{X}$) = 1.13 and SD = 0.59, an external staircase ($\overline{X}$) = 1.12 and SD = 0.41. The mean value near to 1, which illustrates that workers strongly disagreed availability of these parameters in the industry premises. The fire hose reel is fire safety equipment and most significant for any fire incidents. It is a pivotally mounted and the vertical axis on a base, easily rotate at 360° and unwind any desired position in terms of fire [27].

Statistical value for accident prevention measures is also provided in Table 1. Therefore, accident prevention measures reduce the accident phenomenon rate, therefore enhances the productivity and performance of the industry. [28] have illustrated that accidents can be prevented through the actions, policies and practices which will be effective to both workers and industry.[29] Have mentioned that fire accidents have a negative impact on the performances of the industries.

Protective clothing secures workers from extreme environments, hazardous materials (i.e. coldness or hotness) and physical cuts, which conclusively damage workers' performance. Worker's encouragement started when the workplace possess hazardous materials which directly leads to the injury [30,31].

The installation of automatic sprinkler systems should be compulsory within a building to support extinguishing fires immediately [32].

The external staircase solutions for fire escape and secure emergency evacuations. The engineering variables and building evacuations involved typically estimated for the occupant population to arrive safely in such a massive fire accident. For that purpose, The National Institute of Standards and Technology (NIST) predicts the achievement of exit systems for event reconstruction, building design and emergency planning [33].

Fig.10. External staircase

6. Fire simulation-using FDS

6.1. FDS model description

Fire dynamics simulator (FDS) is a computational fluid dynamics (CFD) model that illustrates the smoke flow and hot gases from a fire. The Navier-Stokes equations solved numerically suitable for low-speed, thermal conduction on the transport of heat and smoke from fires. The purpose of the FDS to solve the practical problem of fire in fire safety engineers, at the same time when providing a tool to examine combustion and fundamental fire dynamics. There is a distinctive characteristic, the turbulence modeling **(k-ε),** used in FDS. It can distinguish fires in complicated geometries, and involving a broad-spectrum of physical phenomenon. To describe the unresolved flow of energy and momentum on a large eddy transport coefficients. Recently, the model implemented for detector/sprinkler activation studies, smoke control system design, performance-based fire safety designs, and industrial/residential reconstructions stated in Table 4. It will also prove an effective tool in fire scene reconstruction and fire investigation.

Application area	Cases	Substances
Reconstruction and investigation fire scene	The fires in the World Trade Center Towers (2005) using computer simulation.	Propagation of smoke Temperature the layout of structure and fuel visibility interviews with successful witnesses and evacuees
	The fire dynamics	Temperature CO_2 and CO Concentration

	simulation at 3146 Cherry Raod N.E., Washington, DC, May 30, 1999	
	Arson fire scene (2006) reconstruction using Fire dynamics Simulator (FDS) and Experiment Techniques	The layout of the building Metallographic analysis Temperature fire and smoke profile of simulation Interviews with successful evacuees and witnesses timeline
	A new accident analysis and investigation model for the complex building fire using numerical reconstruction Multi-storey residential building (2019)	Fire scene Fire origin Material analysis Large-eddy simulation Fire accident computational simulation Computer-aided fire scene reconstruction
Performance-based fire safety design	Fast speed train station Taiwan 2003	CO_2 and CO Concentration Descending Temperature Time of smoke layer Visibility
	Taipei Arena, 2000	Temperature descending Time of smoke layer Smoke layer time CO_2 and CO Concentration Temperature Visibility
	Taipei financial center (Taipei 101), 2003	Descending Smoke layer time
	Miramar Entertainment Park, 2004	CO_2 and CO Concentration Temperature Visibility Descending

Table 4: Cases of FDS applications

5. CONCLUSION

This research contributes to predicting the fire scene using different techniques and simulation experiments, therefore enhancing the work of fire scene investigation. The most important conclusion is:

(1) Fire simulation can promote knowledge and information on fire spread and growth, movement and smoke production, which are all required to the investigation of the fire, in both causes and the safety of property and life. A computer simulation supports the reconstruction fire scene can also provide important information to fire administration and code.

(2) Efficiently segregation fire prevention zones can minimize the expansion of fires, and insulation materials provide fire resistance level, which became crucial to understand the phenomenonof fire prevention. Material such as calcium silicate boards, fire clay and fire resistance doors provide better resistance to fire spread and reduce the damages and injuries.

(3) The storage of combustible materials should comply with standard regulations and inventory items must be carefully controlled. During the fire accidents, these appropriate factors suppress the spread of fireand provide a predominant internal fire prevention system tothe workplace. In spite of this, an inadequate fire prevention system allows the spread of fire in less time, leading to losses and injuries. Furthermore, the foundation of effective intervals must be compulsory between storage areas to minimize the speed of fire spread, thereby evacuation times and lengthening rescue.

(4) The study highlights the need for accident forecasting, assessment consequence, and development of up-to-date emergency preparedness and disaster management plans in the textile manufacturing industries.

Appendix A. Questionnaire

University Science and Technology of China, Hefei
Survey

Section A: Personal Information
Gender:
Age:
Marital status:

Education:

Section B: Fire safety measures
Please tick the best answer, which FSM is present in your industry.

S.no.	Statement	Strongly agree	Agree	Neutral	Disagree	Strongly disagree
i	Availability of iron burglar windows	5	4	3	2	1
ii	Exit doors were locked.	5	4	3	2	1
iii	Availability of timber structure floor.	5	4	3	2	1
iv	There is adequate fire alarm system in the production area. There is presence of hazardous material in the floor?	5	4	3	2	1
v	Declaration of emergency exit sign on wall.	5	4	3	2	1
vi	Is the factory provide you fire safety equipment in place?	5	4	3	2	1
vii	There is adequate emergency lighting at the production area.	5	4	3	2	1
viii	There are adequate fire safety equipment, fire extinguisher and fire hose reel. There are adequate , fire extinguisher	5	4	3	2	1
ix	There is adequate accident prevention measures.	5	4	3	2	1
x	Availability of a fire safety department	5	4	3	2	1
Xi	Availability of external staircase?	5	4	3	2	1
xii	There are adequate and fire hose reel	5	4	3	2	1
xiii	Is there any external staircase for emergency	5	4	3	2	1
xiv	There are adequate , fire extinguisher	5	4	3	2	1
xv	Availability of fire hose reel	5	4	3	2	1

Thanks for your co-operation

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