: Article

Fire Safety Index for High-Rise Buildings in the Emirate of Sharjah, UAE

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Abstract: The purpose of this paper is to develop an index system for measuring the compliance of high-rise residential buildings with fire requirements and also to develop an index system for measuring the fire response efficiency, which is linked to the index of compliance with fire requirements. The higher the compliance rate, the greater the chance of a successful response. The two systems depend on the automation of the firefighting system management processes using the techniques of the fourth industrial revolution and developed based on the consultation of subject matter experts in the field. The main elements of the indexes were identified, which were based mainly on several variables, including the fire administrative system, the firefighting system, the residents, the location of the high-rise residential buildings from the fire extinguishing station, and the height of the high-rise residential building. The two systems can contribute to improving emergency preparedness in high-rise residential buildings in the Emirate of Sharjah and are also considered as a measurement index for compliance with fire requirements in the Emirate of Sharjah.

Keywords: fire factor; residential buildings; fire accidents

1. Introduction

The Emirate of Sharjah is the third in the ranking of the UAE in terms of the number of high-rise residential buildings, and based on the analysis of accidents in the previous nine years, an increase in fire accidents in residential buildings was observed, which confirms the need to improve the fire management system in high-rise residential buildings and to develop an index system that monitors Compliance with fire requirements by high-rise residential buildings would help determine the required minimum requirements. Compliance falls under one of the variables that affect the success of the fire response process. A system for measuring response efficiency based on compliance rate, number of floors, and geographical location would contribute to improving the fire management system in the Emirate of Sharjah.

2. Methods

A literature review was carried out to identify the factors affecting the fire prevention management systems in HRBs. We then presented the factors from the literature review to subject matter experts in fire prevention management systems, who are from different stakeholders, in order to identify the critical factors affecting the fire prevention management systems in HRBs in the Emirate of Sharjah, according to weight provided by experts the index provided to the compliance index and response index together, the index validated by experts.

3. Literature Review

Building functional diversification, making Fire Prevention is more complex. For the layers and sizes of high-rise buildings, high concentration of people and property make the firefighting and evacuation operations very difficult when in fire [1], The most crucial aspect of a building's safety in the face of fire is the possibility of safe escape. An important

 doi:10.20944/preprints202212.0537.v1

precondition is that its fire safety facilities enable independent and adequate fire response performances by the building's occupants [2], nowadays, country like china think more to use IR 4.0 in the fire management, The intelligent evacuation guidance system (IEGS) is a new concept and product in China, using an intelligent inducing algorithm to get dynamic evacuation routes and improving evacuation efficiency [3], The accurate prediction of occupant evacuation is important in the evaluation of performance and risk analysis of buildings where large number of people may gather or emergency evacuation may be needed. Owing to the importance of life safety, especially as performance-based fire codes are adopted, the prediction of occupant evacuation has been one of the most critical parts of fire risk analysis. As a result, a large number of evacuation models have been proposed to meet the demand [4], The fire safety can be defined as a set of practices to prevent fires, manage fire growth, and manage the fire effects either intentionally or unintentionally while keeping the resulting losses at an acceptable level [5], Fire safety for existing buildings decreases over time. In order to ensure the safety of buildings, hardware upgrades and fire safety management measures are essential [6].

4. Results

The fire protection component consists of setting the protection tools which improve the firefighting performance through classifying the residential buildings into skyscrapers, high-rise buildings, low and medium buildings, and villas; putting the fire protection control according to specific criteria, which calculates the wait for building certificate of completion by 15 points, the fire suppression system by 30 points, the fire alarm system by 15 points, and the fire extinguisher by 5 pints and the other items according to the following tables, which is evaluated the points according to the importance and the consequence in the fire protection as shown in Table 1 HRBFI components

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Table 2 HRBFI components

No.	Item	Weight
1.	Comply with the requirements of UAE Fire and Life Safety Code of Practice and obtain the completion certificate from the Sharjah Civil Defence Authority.	15
2.1	Fire hose reel tested periodically	1
2.2	All pumps energized 24/7	1
2.3	All pumps in the auto position	2
2.4	The diesel pump tested weekly.	2
2.5	The battery tested periodically.	1
2.6	The specific water related to fire system is maintained, monitored daily and data recorded.	4
2.7	All suppression system connected with 24/7 Aman Early Warning System.	4
2.8	The annual maintenance contract signed with approve maintenance contractor.	4
2.9	The maintenance carried out each three months and recorded.	3
2.10	Certificate of compliance issued annually.	4
2.11	Residential building insured.	4

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3.1	Fire alarm system working and the fire panel energized 24/7.	1
3.2	Fire alarm system working and the fire panel energized 24/7 without fault or fake fire.	5
3.3	Fire alarm system working and the fire panel energized 24/7 without fault or fake fire, and connected with 24/7 Aman Early Warning System.	7
3.4	Fire alarm tested connectivity with the 24/7 Aman Early Warning System each three months.	2
4.1	The fire extinguisher fixed according to the requirements mentioned in the UAE Fire and Life Safety Code of Practice.	3
4.2	The fire extinguisher fixed according to the requirements mentioned in the UAE Fire and Life Safety Code of Practice, maintained periodically and recorded.	2
5.1	Exit sign fixed according to the requirements mentioned in the UAE Fire and Life Safety Code of Practice, maintained periodically and recorded.	1
5.2	Assembly point fixed according to the requirements mentioned in the UAE Fire and Life Safety Code of Practice.	1
6.1	Install the Gas system sensor in all kitchen and connected to Fire Alarm System.	2
6.2	Lifts connected with fire alarm System.	1
8.1	There is no parking for 15 meters around the residential building.	3
9.1	Waste management removed daily once or several times according to the amount of the garbage.	2
9.2	Housekeeping carried out properly daily once or several times according to the need of the building status.	2
9.3	Exit root free from obstruction.	2
10.1	Services room free from fire hazards.	1
11.1	Competent fire risk professional in place.	2
11.2	Fire risk assessment carried out.	1
11.3	The control of fire risk assessment effective , monitored and reviewed	1
11.4	Implement the fire safety management system and recruits Competent fire risk professional	2
12.1	Fire accident, Near miss and minor fire accident monitored, recorded, and analyzed.	1
12.2	Fire accident, Near miss and minor fire accident monitored, recorded, analyzed and investigated.	1
12.3	Fire accident, Near miss and minor fire accident monitored, recorded, analyzed, investigated, and reported to relative authorities.	1
12.4	Fire accident, Near miss and minor fire accident monitored, recorded, analyzed, investigated, reported to relative authorities and the report of accident shared through the residents.	1

 doi:10.20944/preprints202212.0537.v1

12.5	Fire accident, Near miss and minor fire accident monitored, recorded, analyzed, investigated, reported to relative authorities , the report of accident shared through the residents and to the public.	1
13.1	Resident data collected which include the phone number, quantity, language, nationalities, ages for the purpose of risk assessments and the awareness.	0.5
13.2	Provide systematic awareness program for all the residents by their languages.	1
13.3	Use the IR 4.0 technology to provide fire awareness program for all the residents by their languages.	1
13.4	Provide fire awareness program for the new comer.	1
13.5	Emergency layout contact number fixed inside each flat and in the corridors.	0.5
13.6	Fire drill carried out each 3 month by the attendance of civil defense.	0.5
13.7	resident monitoring system counting	0.5
14.1	All employees working in the residential building attend approved firefighting training.	3
14.2	All employees working in the residential building attend approved firefighting training and attend refresh training each two years.	1
	Total points	100

The residential buildings are classified into three categories Category as the UAE ministerial resolution 505 year 2012, describes a residential building with a height of 23 metres to 46 metres or from floors 7th to 15th; category two describes a residential building with a height of 46 metres to 90 metres or from floors 16th to 30th; and category three describes a residential building with a height of 90 metres or from floors above 31th.

The residential buildings that achieve a score below the minimum points for each category are considered at high risk because the fire protection still needs improvements to be capable of fighting the fire and the possibility of fire accidents is still high. The residential building that achieved the minimum points is considered to meet the minimum requirements for fire protection. A residential building that meets more than the minimum requirements is considered to have proper fire procedures as shown in Table 4 HRBFI response assumption.

Table 3 HRBFI category

No.	Item	Full points	Minimum CAT-1	Minimum CAT-2	Minimum CAT-3
1.	Certificate of completion	15	15	15	15
2.	Fire suppression system	30	30	30	30
3.	Fire Alarm System	15	13	15	15
4.	The fire extinguisher	5	5	5	5
5.	Exit sign & assembly point	2	1	1	1
6.	Gas system and lifts	3	2	2	2

 doi:10.20944/preprints202212.0537.v1

7.	Parking around the building	3	3	3	3
8.	Waste and housekeeping and exit roots	6	6	6	6
9.	Services room	1	1	1	1
10.	Fire Risk Control	6	2	4	6
11.	Accidents Management	5	1	2	3
12.	Residents	5	1	2	3
13.	Employees	4	3	3	3
	Total points	100	83	89	93

The presence of complete and advanced equipment contributes to fighting and controlling the fire. The selection of equipment is an important element in the firefighting process, as is the identification and testing of advanced specifications and ensuring their suitability to the environment and the nature of the Emirate of Sharjah, the technology used in firefighting determines the effectiveness of carrying out the task of fighting. Using the latest and most advanced technology contributes to building a strong firefighting wall and reducing the rate of fires in the Emirate of Sharjah, Preventive maintenance is necessary to maintain the serviceability of fire-fighting systems. The absence or poor quality of preventive maintenance makes the first firewall weak, and the fire-fighting system may be unable to deal with fires. Continuously operating the fire pumps in automatic mode and ensuring the serviceability of the bare minimum the water in the water tank contributes to fighting any fire that might happen in the facility. The serviceability of the alarms is important to alerting residents in the event of a fire, especially in high-rise building.

4.1. Digitalized Services

By using the technologies of the Fourth Industrial Revolution, the Sharjah Civil Defense Authority (SCDA) can provide distinguished, accurate, and fast services based on the data collected by the early warning system Aman, which can be used to perform a self-examination of the fire and alarm systems in residential buildings.

Based on the system's data and other criteria, it is possible to provide electronic and self-compliance certificate issuance services. The system can also perform self-monitoring procedures to measure the level of compliance of residential buildings with fire requirements and take actions to inform the building management electronically without human intervention in the reporting process, digitalizing all other services provided by the SCDA could have a significant impact if the technologies of the Fourth Industrial Revolution are used, such as artificial intelligence, robotics, big data, and the Internet of Things.

Based on the data collected electronically related to the High Rise Building Fire Index and the efficiency of response of each building, the SCDA can decide the level of compliance, which varies from one building to another according to the geographical location and the height of the building. The data taken electronically from Sharjah Electricity, Water, and Gas Authority will provide a proper estimation of the number of residents in each building, which will add value to the fire prevention procedures.

4.2. Emergency Response

 doi:10.20944/preprints202212.0537.v1

Emergency response may be applied to reduce the residual risk of escalation and to obtain an improved prevention of fire escalation. Actually, emergency response can reduce accident losses, and previous studies evidenced its role in preventing domino effects [7], Minnesota fire department regulation definition Fire response means any deployment of firefighting personnel and/or equipment to extinguish a fire or perform any preventative measure in an effort to protect equipment, life, or property in an area threatened by fire. It also includes the deployment of firefighting personnel and/or equipment to provide fire suppression, rescue, extrication, or any other services related to fire and rescue as may occasionally occur. Emergency response is restricted by many factors, and emergency resource (including emergency personnel) is an important factor influencing emergency response efficiency and even whether an emergency response can be carried out. The quantity, scheduling, and allocation of emergency resources may influence emergency response. Emergency resource allocation is to arrange the resources required for emergency response in order to deal with unexpected events, so that the emergency response process can be carried out efficiently [8]. Building fire emergencies are considered a high-risk domain for significant loss of lives and property. Accurate information and Situational Awareness (SA) enable fire responders to make timely decisions and perform safe operations during fire emergencies [9]. Manoj and Baker stated that technological issues could cause fatalities in emergencies. The critical issues are related to a lack of critical information sharing, a lack of communication systems, and a lack of decision support systems [10].

4.3. Automated Fire response system

The last firewall for fighting fire comes from the competent authority to implement rescue and fire extinguishing operations. The UAE Fire and Life Safety Code of Practice specified a period of eight minutes, which is the distance between any center of the Authority Civil Defense and the location of the fire. Of course, this time period can be less depending on the time of the accident and the traffic jam, but the eight-minute period will not be enough to control the fire without control measures before the arrival of the firefighting teams, so the validity of the alarm and fire systems, and training of residents and workers is important.

The response to fire accidents is very critical in the fire management system framework. The fire accident is considered a failure in the fire prevention & fire protection, which is concluded as a fire accident. The failure may be lack of training, failure in firefighting systems, fire alarm systems, awareness, or training, the immediate action to control the failure is to respond to the fire accident in time to control the fire before it effects the lives of people or damages the building, the framework implemented in the Emirate of Sharjah depends partially on the digital response, automatic response to the fire decreases the duration time to reach the fire and provides accurate information about the residential building, It provides information such as the number of stories, occupants number, the accurate location, the story of fire. The response to fire will be effective if classified according to the type of building, the number of floors, the area of the building, the access to the building, the fire protection index, the time of the fire accident, light or night.

4.4. Response effectiveness

The response will be affected by the residential building index. If the building is below the minimum points, the following assumptions should be in place as shown in Table 4 HRBFI response assumption:

Table 4 HRBFI response assumption

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Item	Full points	Minimum points
Certificate of completion	15	It's mandatory.
Fire suppression system	30	The system failed, and the water tank capacity was below the required volume to extinguish the fire. The fire pumps are not working.
Fire Alarm System	15	The fire alarm was not working, and some residents were unaware of the fire.
The fire extinguisher	5	The fire extinguisher may not be maintained and may not be serviceable for use.
Exit sign & assembly point	2	If the exit signs are not lit, the residents may fail to reach the exit routes.
Gas system and lifts	3	Some residents may try to use lifts. Gas systems that are not linked to a fire alarm system will be turned on. During a fire, it will be more dangerous.
Parking around the building	3	The area around the building is less than 15 meters, which is obstructing the rescue procedures.
Waste and housekeeping and exit roots	6	Waste and garbage will be fuel for the fire to burn more.
Services room	1	Fire may be burned inside the service rooms, which may affect the electricity, water, or ignite gas.
Fire Risk Control	6	Without fire risk control, it means the hazard is not identified and not controlled.
Accidents Management	5	The cause of the accident may have been unknown at the time of the response due to a lack of data.
Residents	5	Residents are not aware of the response procedures.
employees	4	Employees not trained may play negative roles during the response.
Total points	100	

To measure the effectiveness of response and rescue, it is required to calculate several variables according to the high rise building fire index, the floor number, and the distance from the nearest fire station. As shown in the Table 5 HRBFI response details.

Table 5 HRBFI response details

HRBFI	Floors			Distance		
70%	15%			15%		
	Cat (1)	Cat (2)	Cat (3)	Zone (1)	Zone (2)	Zone (3)
	15%	10%	5%	15%	10%	5%

Distance zones according to the distance from the fire station to the location of residential buildings; zone one for the distance of 5 kilometres and below; zone two for the distance of 10 kilometres and below; zone three for the distance greater than 10 kilometres.

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The maximum points for response and rescue efficiency for the residential building to achieve depends on the summation points for the table. For the building to achieve a minimum score in HRBFI, the response efficiency percentage will be at the level of 68% of the lowest acceptable response for the building affected by the location and the height is maximum as shown in Table 6 Response calculation sample.

Table 6 Response calculation sample

HRBFI			Floors			Distance			Response efficiency %
			15%			15%			
			Cat (1)	Cat (2)	Cat (3)	Zone (1)	Zone (2)	Zone (3)	
Sample	SCORE	70%	15%	10%	5%	15%	10%	5%	
Sample (1)	100	70	15	0	0	15	0	0	100
Sample (2)	100	70	0	10	0	0	10	0	90
Sample (3)	100	70	0	0	5	0	0	5	80
Sample (4)	83	58	15	0	0	15	0	0	88
Sample (5)	83	58	0	10	0	0	10	0	78
Sample (6)	83	58	0	0	5	0	0	5	68
Sample (7)	100	70	15	0	0	15	0	0	100
Sample (8)	100	70	0	10	0	0	10	0	90
Sample (9)	100	70	0	0	5	0	0	5	80
Sample (10)	89	62	15	0	0	15	0	0	92
Sample (11)	89	62	0	10	0	0	10	0	82
Sample (12)	89	62	0	0	5	0	0	5	72
Sample (13)	100	70	15	0	0	15	0	0	100
Sample (14)	100	70	0	10	0	0	10	0	90
Sample (15)	100	70	0	0	5	0	0	5	80
Sample (16)	93	65	15	0	0	15	0	0	95
Sample (17)	93	65	0	10	0	0	10	0	85
Sample (18)	93	65	0	0	5	0	0	5	75

Automatic fire response decreases the response time, provides enough information to make the right decision, improves the quality of response, decreases the possibility of injury and fatality, decreases the time of extinguishing the fire, and decreases the possible damage to the building or the assets, the response tools, such as trucks, equipment, and communication systems, should be prepared to support the digital response to use the technology as effectively as possible to improve the quality of the response.

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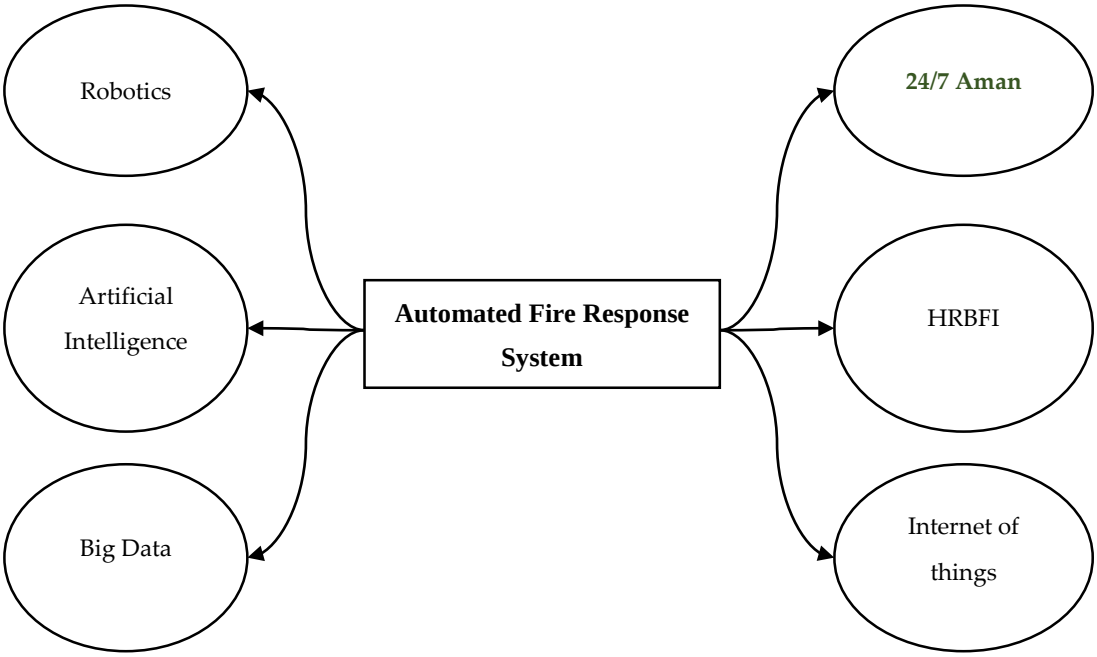

Figure 1 Automated Fire Response System

The above information will be of added value to Civil Defense in taking decisions when receiving a fire report as shown in Figure 1 Automated Fire Response System. The automatic response will allow the decision maker to view the above data and take the right decision related to rescue and response procedures, or the system to take a decision by itself according to saved data.

4.5. The early warning system 24/7 Aman

It is necessary to develop a scientific and reasonable method to raise on-site early warning of the fire in order to facilitate wise decisions on the evacuation of firefighters at the most appropriate time, which may greatly enhance the efficiency of the firefighters' rescue [11], The serious fire accidents happen frequently every year worldwide, which kill many lives and result in a significant property loss. The sensitive fire alarm systems (FASs) that can timely detect the early fire and immediately give the alarm are therefore urgently needed [12], A rapid, accurate and early warning detection system for fires has been shown to be a very effective method for minimizing casualties and property damage, especially in buildings [13].

The early warning system 24/7 Aman provides a real-time reporting mechanism for fire incidents and works to provide accurate data on the geographical location of the residential building to facilitate the access process as soon as possible. It also provides data on the number of floors in the building and the number of residents, which helps civil defence officials take appropriate decisions and to work out a response that is appropriate to the size of the fire, the selection of the appropriate rescue equipment, and the required number of fire-fighters.

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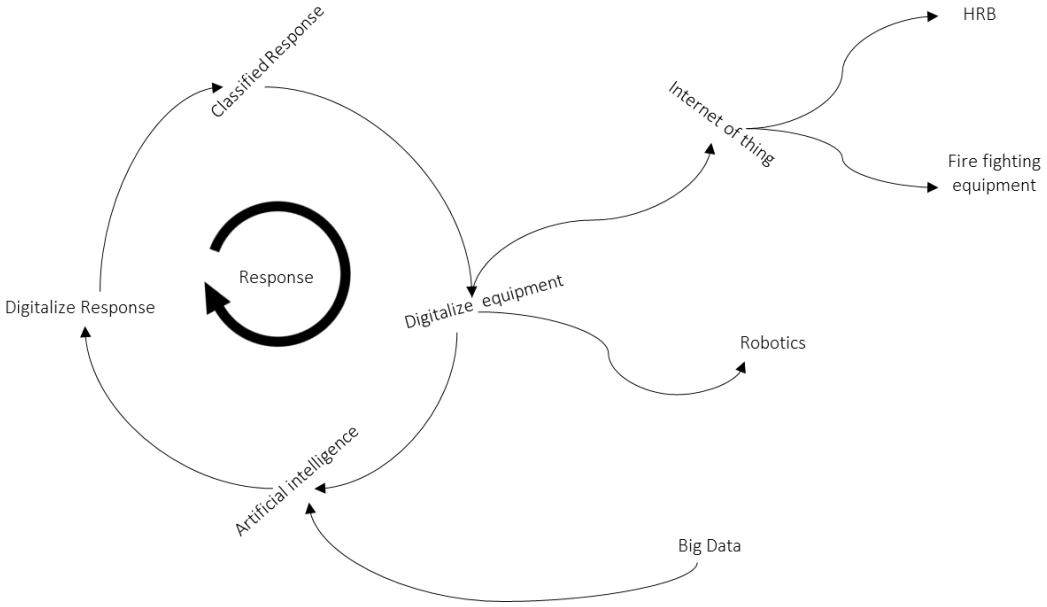

Figure 2 Response flowchart

4.6. HRBFI compliance

Compliance based on response index HRBFI which provides data on the building's compliance with the requirements of fire legislation. Residential buildings with the lowest compliance rate must expect complex rescue and firefighting operations where all necessary precautions must be taken for the success of the response. Buildings that achieve a high compliance rate have preventive measures that will help with the success of the response and fire control.

4.7. Internet of Things

The Internet of Things (IoT) is an organization comprised of interconnected gadgets. These gadgets are equipped for detecting their current circumstance and sharing and handling information that can be made accessible to an assortment of utilizations [14], The Internet of Things (IoT) is a term that is frequently used in the current digital era. It is defined as a system of integrated or interconnected sensor nodes/actuators that receives, measures, generates, publishes, and intelligently shares information or details among other sensor nodes [15].

The operations of controlling fire and alarm systems can be self-controlled by taking advantage of the Internet of Things, which enables it to perform initial response procedures without human intervention; control fire systems; partial and complete evacuation; control energy sources; count the number of people; and predict the people inside the building who were not evacuated as shown in Figure 2 Response flowchart.

4.8. Robots

At the same time, robots can play a vital role in evacuation operations. They can reach areas that are not accessible to humans during a fire, and they can also self-control to evacuate the injured and carry out complex extinguishing operations, which reduces human losses and improves the efficiency of the response.

 doi:10.20944/preprints202212.0537.v1

4.9. Artificial intelligence

Artificial Intelligence is one of the key research techniques which several researchers have analysed and proved to be the best in improving the performance of detecting fire hazard in smart cities [16],

Artificial intelligence (Machine learning) techniques can contribute to predicting accidents before they occur, and can predict the movement of fire in the building and determine the core of the flame to combat it. And artificial intelligence can contribute to identifying people who are likely not to evacuate, or places that could be dangerous for firefighters to enter.

4.10. Big data

With the development of digital technology, big data has a significant impact on the operation, cooperation, and strategy of different fields in digital economy Big data refers to real-time, large amounts of structured, semi-structured, and unstructured data, which are converted into value by specific technologies and analytical methods [17].

Big data can provide important information to predict or control fire accidents. This data can be collected from social media, or from devices used in the residential building, or from mobile phones, all of which can provide important data, contributing to the success of the response process. Save comfort and reduce losses as much as possible.

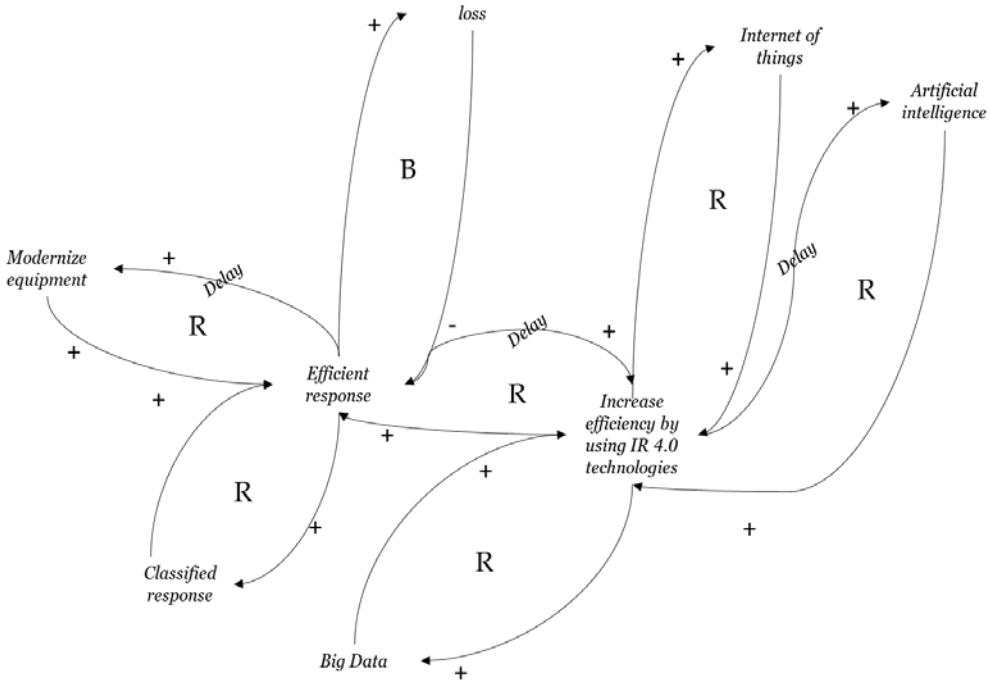

Figure 3 efficiency response

Efficient response depends on the modernized technology used; modern equipment directly contributes to increased response efficiency in a reinforcing loop, a classified response improves response efficiency by gathering information and clarifying the resources needed to make the right decision at the time of the response, By using IR 4.0 technologies Increase response efficiency; IR 4.0 considers the critical elements in the response part when relying on reflection directly, making the response more accurate more easily and relying on machines rather than humans, Using big data, artificial intelligence, and the Internet of Things, it is possible to reduce the operability of errors, increasing response efficiency and contributing to minimizing possible losses in a balance loop as shown in Figure 3 efficiency response.

5. Conclusions

According to the literature review, and consultations with subject matter experts in the field of fire in the Emirate of Sharjah, 14 components were selected as the main index for HRBFI, the residential building classified into 3 categories the minimum requirements were identifies to compliance to fire legislation in the Emirate of Sharjah as category one minimum points is 83, category 2 minimum points 89, category 3 minimum points 93.

To measure the effectiveness of response and rescue the HRBFI considered as 70% of successes of the response and 15% for the location of residential building to the near fire station and 15% for the category of the building based on the height,

Author Contributions:

Musab Omar: Writing – original draft, Visualization, Investigation, Data curation. DR.Abdelgadir Mahmoud: Supervision, Methodology, Conceptualization. DR. Sa'ardin Bin Abdul Aziz: review & Validation, all authors have read and agreed to the published version of the manuscript.

Funding:

This research received no external funding.

Informed Consent Statement:

Study did not involve humans.

Data Availability Statement:

The data presented in this study are available on reasonable request from the corresponding author.

Conflicts of Interest:

The authors declare no conflict of interest.

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