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Response Delay Model: Bridging the Gap in Urban Fire Disaster Response System

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***Abstract*—**The need for modeling response to urban fire disaster cannot be over emphasized, as recurrent fire outbreaks have gutted most cities of the world. This necessitated the need for a prompt and efficient response system in order to mitigate the impact of the disaster. Promptness, as a function of time, is seen to be the fundamental determinant for efficiency of a response system and magnitude of a fire disaster. Delay, as a result of several factors, is one of the major determinants of promptgness of a response system and also the magnitude of a fire disaster. Response Delay Model (RDM) intends to bridge the gap in urban fire disaster response system through incorporating and synchronizing the delay moments in measuring the overall efficiency of a response system and determining the magnitude of a fire disaster. The model identified two delay moments (pre-notification and Intra-reflex sequence delay) that can be elastic and collectively plays a significant role in influencing the efficiency of a response system. Due to variation in the elasticity of the delay moments, the model provides for measuring the length of delays in order to arrive at a standard average delay moment for different parts of the world, putting into consideration geographic location, level of preparedness and awareness, technological advancement, socio-economic and environmental factors. It is recommended that participatory researches should be embarked on locally and globally to determine standard average delay moments within each phase of the system so as to enable determining the efficiency of response systems and predicting fire disaster magnitudes.

***Keywords*—**Delay moment, fire disaster, reflex sequence, response, response delay moment.

I. Introduction

THE need for the use of models in urban fire disaster management cannot be overemphasized as they are used to describe, examine, and understand the nature of disasters and how to overcome them [1]. Models are used today for many purposes including shaping the lives of human societies and managing various forms of disasters in almost all cities across the globe. It simplifies one's understanding of how things happen, for what purpose and how problems affecting people and their environment can be solved [2]. It was also noted that models in the field of disaster management are based on the understanding that disasters are temporary interruptions to development processes, and also the job of disaster practitioners is to take appropriate action to return to the normal the course of development [3]. This suggests that models are there to be implemented and enforced or communities would continue to suffer huge losses [2].

As such, four major reasons to demonstrate the purpose of models in disaster management were proffered [4]. The reasons are as follows:

- Models can be used to simplify complex events through distinguishing between critical elements.
- Comparing actual conditions with a theoretical model can lead to an improved understanding of the prevailing disaster situation,
- The presence of a model for disaster management is also an essential element in quantifying disaster situations or events.
- When documented, models help to establish a common understanding between various stakeholders involved in managing disasters.

By closely scrutinizing the four main conditions of models given by [4], one is rightly tempted to conclude that the use of models in disaster management cannot be over emphasized. Several models have been developed over time to address various aspects of disaster among which are [5]-[10]. However none of these models seeks to address delay in responding to urban fire disaster. This necessitates developing the RDM in order to address the types, causes, extent, and consequences of delays attributed to fire disaster.

Fire disaster is a common and one of the most devastating disasters affecting almost all cities across the globe [1]. Fire, usually poses hazard to people, properties and environment, resulting in psychological damage, physical injuries, death and significant economic losses. For example, in 2006, it was found that on the average, one person is lost in a fire accident approximately every 162 min and one person get injured every 32 min in the United States [11]. According to the National Fire Protection Association (NFPA) [12] of the US, there were about 15,925 injuries, 3,240 deaths, and $11.5 billion costs of property damage caused by 1.24 million fires in total in 2013 [13]. In 2017, NFPA reported that the public fire departments responded to 1,319,500 fires, with a slight decrease of about 2% from the previous year. At every 24 seconds, at least a fire department responds to a fire somewhere in the nation. Fire outbreak occurs in structures and homes at the rate of one every 63 seconds and 88 seconds, respectively. Fire outbreaks in homes accounted for 77% of all fire deaths in 2017 with a decrease of 4% compared to the previous year. The same fire outbreaks were responsible for 10,600 civilian injuries in 2017. Property damage recorded was estimated at about $23 billion including a $10 billion loss in wildfires in Northern California. About 22,500 structure fires were set intentionally in 2017, which shows an increase of about 13% compared to the previous year [14]. Also, the Ministry of Housing, Communities and Local Governments, formerly known as Department of Communities and Local Governments [15],

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stated that, there was an estimated total of about 212,500 fires during 2013-2014, causing about 322 deaths and more than 9,700 casualties.

In parts of developing countries, for example, it was revealed that in South Africa a total of about 35,000 fires were reported in 2008, which led to about 380 fatalities and more than ZAR 2.3 billion (*Zuid-Afrikaanse Rand*) in financial losses [16]. In 2009, more than 40,000 fires were reported which resulted in 376 fatalities and ZAR 4 billion in financial losses. While in 2010, similar statistics with a high number of fatalities and large financial losses were experienced. These statistics clearly indicate that serious attention needed to be given to fire service response and recovery systems. The National Bureau of Statistics [17] reported cases of fire disaster in 2013, 2014 and 2015, which shows that Lagos state had the highest occurrence, while Ogun State recorded the highest number of affected persons in 2013, Sokoto state recorded the highest in 2014 and Niger State in 2015. In Kano state, according to [18], there were about 936 deaths as a result of fire outbreaks between 2008 and 2012. The study further stated that 2008 recorded the highest property loss, followed by 2009, 2012 and 2010. The least estimated property loss was recorded in 2011. The total estimated property lost for the year 2012 in Kano state was N 6.53 billion while 195 lives were lost [19]. Similar trend of recurrence is experienced in subsequent years up to the present time.

Several studies have been conducted globally on fire disaster using different approaches and methodologies to address issues relating to the causes, consequences, characterization, preparedness, response, risk and vulnerability, suitability analysis for locating new fire response infrastructures, temporal and spatial pattern analysis of fires. Some of the studies include: [18], [20]-[45]. Much of these studies have neglected measuring one of the fundamental factor influencing the magnitude of fire disaster and efficiency of a response system, which is delay. Delay in the process of responding to fire disaster is categorized into two (pre-notification and intra reflex sequence delays) and depends on many factors including the level of awareness and preparedness by both the stakeholders (i.e. the fire service and general public), technological advancement, geographic location, socio-economic and environmental factors. Pre-notification delays are usually the commonest and attributed to the public fundamentally due to many factors, for example, the lack of possession/access to emergency response numbers as identified by [46] and [1]. The extent of the delay defines its elasticity and also determines the onset of the response reflex sequence. On the other hand, delays also arise within each phase of the response reflex sequence depending on the peculiarity of the phase and preparedness level of the fire service. These delays together determine the efficiency of a response system and the magnitude of a fire disaster and are however neglected by most studies. RDM intends to bridge this gap by providing for identifying the nature, describing the causes and measuring these delays and their extent based on locational, technological, environmental, socio-economic factors, level of awareness and preparedness and their influence in determining the magnitude of a fire disaster and efficiency of a response system.

II. Fire Disaster Response and Governance

Response is the most sensational stage of a disaster reduction and management system [47]. It is the action taken immediately during and just after a disaster, which if severe or prolonged, can exceed the capacity of first responders, local fire fighters or law enforcement officials. Such incidents range widely in size, location, cause, and effect, but nearly all have an environmental component. Optimum utilization of the time in responding to a disaster serves as a measure of effectiveness of any emergency response system [48]. Fire disaster response time refers the time that begins when units (firefighters, law enforcement officials, and medical personnel) en route to the emergency incident and ends when units arrive at the scene according to [49]. The response time is distributed as dispatch time, turnout time and travel time to the fire incident scene which are described as follows [26]:

- Dispatch time starts form the moment of receipt of the emergency alarm at the answering point to the time when sufficient information about the point of incidence is known and applicable units are notified of the emergency [49].
- Turnout time begins from the moment units are notified of the incidence to the beginning of travel time [49]. Turnout time is approximately 80 seconds according to the NFPA [50].
- Travel time is the time taken in minutes from when the first vehicle is dispatched to the time when the first vehicle arrives at the emergency scene. This, according to [50], lasts for 240 seconds. Therefore the total response time is about 5 minutes 20 seconds, excluding the dispatch time.
- Arrival time is when the first vehicle of the unit arrived at the scene of fire disaster.

In emergency analysis, quicker response will save more lives and properties from losses and damages [27]. In other words, response time is a critical component in the control and mitigation of an emergency incident [26]. Response time is also defined as a primary benchmark which serves as a function of area coverage, traffic infrastructure capacity, equipment and number of staff to respond [51]. There are various factors influencing the response time, among which include location/distance, accessibility, population and building stock [26]. Other factors that are directly related to overall response times include physical site characteristics, traffic volume and speeds. Average travel speed can determine the extent of coverage area according to a given response time. In order to determine the average speed it may be useful to classify the roads as major and residential or minor roads, as well as taking into account of the impact of the time of day (peak and non-peak hours) [26]. Disaster response procedure requires personnel to: identify the range of problems and set priorities, generate appropriate solutions to identified problems, implement agreed solutions within tight timelines, monitor and review the situation, actions taken, keep comprehensive records of information received, decisions taken, actions performed [52]. The efficiency of the overall response activity depends on the efficiency of the prevailing governance. Four key roles of urban governance were identified [53], from which the roles of urban disaster governance were derived. Efficiency in response management depends on the following identified roles of governance:

- Play a critical role in shaping the physical and social character of urban disaster response structures and facilities.
- Influence the quality and efficiency of response and recovery systems.
- Manage and coordinate resources allocation and distribution for efficient response management.
- Influences participation of civil societies and the public in decision making and disaster response activities.

For this reason, understanding the standardized element of response time is important in order to measure its effectiveness and identify the factors hindering it [26]. In attempt to measure the efficiency of response system to fire disaster, RDM is developed to identify and categorize delays based on their nature, sources, length, and influencing factors. The RDM intends to bridge a very important gap through synchronizing the pre-notification delays and intra reflex sequence delays in measuring the overall efficiency of a response system. Most studies, as stated earlier, concentrated on the response reflex sequence in measuring the efficiency of a response system thereby neglecting the moments prior to the commencement of the reflex sequence. This moment is tagged as the pre-notification moment and is seen as a fundamental determinant of the magnitude of a fire disaster and also a measure to the efficiency of a response system.

III. RDM

Delay is defined as a period of time by which something is late or postponed. It is also the act of postponing, hindering or causing something to occur more slowly than normal. In the context of response to fire disaster, delay is a period of time by which the sequence of a normal response system is late or postponed. This is as a result of introducing some factors that hinders the smooth flow of the normal process. The RDM is interested in identifying the sources, causes and measuring the extents of these delay time, especially as it hinders promptness in responding to a fire disaster. The model identified delay (from several sources) as one of the key factor influencing the efficiency of a response system and also determining the magnitude of fire disaster in all cities across the globe. Studies such as [1] have identified pre-notification delay as a major factor that increases the length of the burning time and also determine the commencement of the response reflex sequence. This is why measuring the efficiency of a response system is not complete without putting into consideration these delays, their sources, extent and the factors influencing them including geographical location, socio-economic, environmental, technological advancement, level of preparedness, awareness and lack of possession of emergency alerting numbers. Unlike in most of developed countries that have simple and centralized emergency response numbers, in most developing countries, the emergency numbers are not simple and centralized, and in most cases difficult to access due to many factors. This, among other factors makes the pre-notification delays in most African and other developing countries longer than in most of the developed countries. The other component of delay identified by the model is intra reflex sequence delay (starting from dispatch, turn-out, travel and setup time) which also contributes in affecting promptness in a response system. The efficiency of fire disaster response system is measured based on optimum utilization of time from the onset of the disaster to the point of extinguishing it. Therefore, time is seen to be central in measuring the efficiency of a response system. The longer the time it takes to respond to a fire disaster, the greater its magnitude and vice versa.

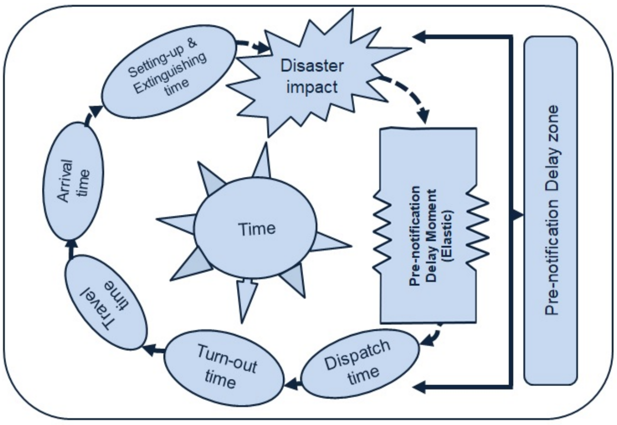

Fig. 1 RDM (2019)

The RDM specifically addresses two 'delay moments' which arise from the onset of the fire disaster to the time of accessing emergency alert numbers to notify the response department or alternatively physical travel to the station, and the other which is commonly attributed to phases of the intra reflex sequence. These are added delay time introduced to the overall response system prior to the commencement and within the fire disaster response reflex sequence. The length of the added time varies and depends on many factors as mentioned earlier. The model stressed on the need for bridging the communication gap existing between the masses (as component of the system) and the fire disaster response department, on one hand, and the preparedness level of the response department, on the other hand, in determining the efficiency of the response system and magnitude of fire disaster. It also provides for the quantification of delay moment within the pre-notification and intra reflex sequence phase. The RDM, as represented in Fig. 1, incorporates pre-notification delay referred to as 'abnormal delay' and intra reflex sequence delay (normal delay) as the key parameters in defining the magnitude and the overall efficiency of a fire disaster response system.

A. Types of Delay in RDM

The RDM categorized delays into two and also emphasizes on synchronizing and incorporating them with other factors to define the efficiency of a response system.

i. Pre-notification Delay, which refers to the 'delay moment' that starts from the onset of the fire to the point of notifying the emergency response department through either telecommunication or physical travel. It terminates when the response department is informed about the location of the incidence. The length of the pre-notification delay is elastic (ranges from 0 seconds to 10s of minutes) and depends on many factors including; level of awareness and preparedness, access to emergency alerting numbers, geographical location, socio-economic and environmental factors. This type of delay is tagged as 'abnormal' because its duration can hardly be predetermined and has greater influence on the magnitude of the fire disaster than the intra reflex delay. One important characteristic of the pre-notification delay is its elasticity. This is why the standard length of the delay is yet to be determined. Therefore, more researches are needed to enable estimation of the length of the delay so as to arrive at a standard average pre-notification delay time at the local and global scale.
ii. Intra Reflex Sequence Delay includes all the delays that may arise at the phase level of the reflex sequence which might be as a result of similar factors as stated in the re-notification delay. The extent of these delays can also hardly be predetermined, although the required standard time at each phase of the sequence has been estimated and defined by various countries and organizations. Although, delay in one phase of the sequence can be compensated with the activities of subsequent phases, the overall delay still has an influence on the efficiency of the response system. This type of delay is tagged a 'normal delay' which usually does not last long depending on the nature and extent of the problem encountered. The extent of the delay at each of the phases has also not been standardized. Hence, the need for more researches especially focusing on measuring the delay moments so as to enable forecasting and quantifying damages even prior to the commencement of a response mission.

B. Assumptions of the RDM

This RDM is developed based on the following assumptions:

i. Pre-notification and intra reflex sequence delays are the major types of delays in urban fire disaster response system.
ii. These delays are the major determinants of the magnitude of a fire disaster and the efficiency of a response system.
iii. This model is applicable in measuring the efficiency of response systems of other forms of disasters (natural and anthropogenic) that require rapid response system.
iv. Time is central and determines the length of the delay moments.
v. The length of the delay moments is elastic.
vi. Level of awareness and preparedness, socio-economic, demographic, locational, technological advancement and environmental variables can influence the length of the pre-notification delay.
vii. RDM measures the efficiency of a response system at various scales (i.e. micro or local, national and international levels).

C. Measuring Delay in RDM

Measuring the length of the delays within a response system is paramount because it helps in determining the efficiency of the system and also helps in predicting the likely consequence of a particular fire outbreak. RDM provides for measuring the extent of each identified delay mathematically using the following components:

i. Total Response Time (T_{rt}): the total time taken in responding to a fire disaster from the onset of the fire to the time of arriving the scene. This includes the delays at the pre-notification and intra reflex sequence phases. Total Response Time is calculated using:

$$T_{rt} = P_d + I_d + R_t$$

where, Pd is the pre-notification delay, Id is the intra reflex sequence delay and Rt is the standard response time for the particular station.

ii. Response Delay (R_d): the sum of the delay experienced during a fire outbreak irrespective of the source. This can be calculated through:

$$Rd = T_{rt} - (P_d + I_d)$$

where, T_{rt} is the total response time plus the delays, P_d is the pre-notification time and I_d is the intra reflex sequence delay.

iii. Intra Reflex Sequence Delay: the time difference between the dispatch time (D_t) and the arrival time (A_t) minus the standard response time of the station (R_t).

$$I_d = (A_t - D_t) - R_t$$

where, A_t is the arrival time, D_t is the dispatch time, and R_t is the standard response time for the particular station.

iv. Pre-notification Delay: the time difference between the dispatch time (D_t) and estimated fire onset time (O_t). This is represented by:

$$Pd = D_t - O_t$$

where, D_t is the dispatch time and O_t is the estimated time for the fire onset.

Further complex measurements can also be done especially at micro levels of each of the broadly identified phases of delay by the model. For example, physical travel unlike telecommunicating to report an outbreak to an emergency station will require the incorporation of additional component (distance) in measuring the extent of a pre-notification delay.

IV. Conclusion and Recommendation

In conclusion, delay in a fire disaster response system is inevitable irrespective of whether in developed or developing nation. The length of the delays however depends on many factors including level of preparedness, awareness, technological advancement, physical locational, socio-economic and environmental factors among others. Determining the efficiency of a response system requires measuring and synchronizing delay moments (within each phase of the response system) into the normal reflex sequence in order to arrive at a standard average delay for different locations. This model therefore is very important as it bridges the gap through incorporating and synchronizing the two major delay moments in measuring the efficiency of a response system and determining the magnitude of a fire disaster. It is therefore recommended that studies need to be conducted at the local and global scale, so as to determine the standard average delay moments for different location and also identify the most influencing delay amongst the delays identified by the model. This should be based on some of the influencing factors identified including; levels of preparedness, awareness, technological advancement, social-economic and environmental factors. Additionally, studies on modeling expected delays within each of the phases should be embarked on in order to enable forecasting in advance the length of delays so as to enable estimation of damages by a fire disaster. Finally, fire response departments should update their method of record entry about a fire disaster through incorporating a column for entering the estimated or actual time for the onset of each fire disaster. This will help in improving the precision of calculating the extent of especially pre-notification delay moment.

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