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URBAN FIRE DISASTER RESPONSE DELAY MODEL REVISITED

*Sulaiman Yunus

Department of Geography, Bayero University Kano

*Corresponding Author Email Address: syunus.geog@buk.edu.ng

ABSTRACT

This study revisits and updates the Response Delay Model (RDM) to address the critical issue of delays in urban fire disaster emergency responses. This model aims to streamline response times, ensuring faster and more efficient emergency interventions in urban settings. The objective is to improve the effectiveness of urban fire disaster response systems by systematically identifying, quantifying, and addressing the key delay factors that occur throughout the response process. The research identifies gaps and synthesises current knowledge on fire disaster response through a systematic review of existing literature, including empirical studies and theoretical models. The RDM is a novel model that categorises delays into pre-notification and intra-reflex sequence delays. It introduces metrics to quantify these delays and proposes strategies for mitigation, emphasizing the critical stages where interventions can reduce response delay times. The model's application is to enhance the efficiency and effectiveness of urban fire disaster management, ultimately reducing the resultant impact on lives, property, and economic losses. It is recommended that emergency response agencies utilize this model to pinpoint critical stages of delay, enabling targeted interventions to reduce response delay times and enhance urban fire disaster response efficiency.

Keywords*:* Delay moment, fire disaster, pre-notification delay, reflex sequence, response, response delay moment.

INTRODUCTION

Fire disasters are among the most frequent and devastating calamities affecting cities worldwide. They pose significant hazards to people, property, and the environment, resulting in psychological damage, physical injuries, deaths, and substantial economic losses (Gernay et al., 2016; Kwon et al. 2024). In developing countries like Nigeria, major fire incidents have led to the destruction of lives, properties, and considerable financial losses, highlighting the critical need for improved fire safety measures and disaster preparedness (World Bank, 2023; Safavian, 2023). Urban areas are particularly vulnerable to fire disasters due to high population densities, inadequate infrastructure, and limited resources for effective firefighting (Gernay et al., 2016; Ahmat et al. 2023). These cities experience varying intensities of fire damage both spatially and temporally, leading to increased risks, loss of lives, injuries, and property damage valued at billions of dollars (Xiong et al. 2017; National Safety Council, 2023). For example, urban centers often face challenges such as congested housing, poor urban planning, and insufficient emergency services, which exacerbate the impact of fire outbreaks (World Bank, 2023).

In addition to the immediate physical destruction, fire disasters have long-term psychological effects on survivors, including trauma and anxiety, which can hinder recovery and resilience (Mishra et al., 2020). Moreover, fires contribute to environmental degradation by releasing pollutants into the air and damaging ecosystems, further complicating recovery efforts in affected areas (Reid et al., 2016). The environmental consequences of urban fires also highlight the need for sustainable development practices and effective urban planning to mitigate future risks (Gernay et al., 2016). Given the significant challenges posed by delays in emergency responses, this research seeks to deliver a model contributing to response delays and to propose solutions that enhance the efficiency and effectiveness of fire disaster management. By focusing on the quantification of delays and their sources, this study contributes valuable insights to the field of emergency management, ultimately supporting improvements in fire response strategies.

Addressing these challenges requires a multi-faceted approach involving government policies, community engagement, and technological innovations (World Bank, 2023). Implementing stricter building codes, enhancing public awareness, and investing in modern firefighting equipment are essential steps to reduce the vulnerability of urban areas to fire disasters (National Safety Council, 2023). Additionally, leveraging technology such as early warning systems and geographic information systems (GIS) can improve fire detection and response times, potentially saving lives and minimizing damage (Gernay et al., 2016). Numerous studies have examined fire disasters using a variety of methodologies and approaches across different locations (Adamu & Yunus, 2016; Oladokun et al., 2012; Oladokun & Emanuel, 2014; Adekunle et al., 2016; Ayuba et al. 2016; Isa et al. 2016; Ogundele et al., 2013; Dogondaji et al., 2017; Kihila, 2017; Yunus 2019a, 2019b, 2023; Li et al. 2011; Yunus and Falola 2022; Mao et al. 2020; Yu et al. 2020; Zhang et al. 2018; Zhibang et al. 2018; Chhetri et al. 2017 Kiran and Corcoran 2017; Khan et al. 2020; Oppong et al. 2017; Yao et al. 2018; Nowell et al. 2018; Mantra, 2020; Falola and Agbola 2022; Abdulsalam, Kabir & Arafat, 2016; Zhu et al., 2018; Dube, 2018; Ejeta, Ardalan & Paton, 2015; Makachia, Gatebe & Makhonge, 2014; Yagoub & Jalil, 2014). These studies utilized data from various sources, including historical fire response data, fire department incident reports, surveys and interviews with firefighters and other stakeholders, and government publications. Various analytical methods and tools were employed to analyze the collected data, identifying patterns and correlations while considering factors such as geographic location, level of preparedness, technological advancement, socio-economic conditions, and environmental factors.

Despite these contributions, many studies have neglected to measure the fundamental factor influencing the magnitude of fire disasters: response delay. Current models, such as hazard mitigation models (UNISDR, 2015; Cutter et al., 2000), vulnerability assessment models (Birkmann et al., 2013; Fekete, 2015), disaster risk assessment models (IPCC, 2014; GFDRR, 2018), and emergency response models (Red Cross, 2019; European Commission, 2012), focus on various disaster management aspects but fail to address delays in urban fire disaster response. This gap necessitates the need of the RDM to identify and measure the types, sources, causes, extent, and consequences of delays in urban fire disaster responses, ultimately enhancing disaster resilience and response efficiency.

The National Fire Protection Association (NFPA 1710) has established estimated times for each phase of the emergency response sequence; however, it does not account for pre-notification delays and their effects on initiating the response reflex system or determining the severity of a fire disaster. The Response Delay Model (RDM) addresses this gap by considering any additional time taken—from before emergency notification to during and even after the notification—as a delay. This includes timeframes ranging from a second to an indefinite period, regardless of the phase, source, or nature of the issue causing the delay. This aspect of the model is innovative, as it not only identifies delays but also facilitates their estimation. While delays can vary based on factors such as location, awareness, technological advancements, preparedness, and the commitment of response departments and governance systems, the RDM is designed to be flexible. It allows for the computation and estimation of delays irrespective of these variables. Despite the importance of understanding the sources and quantification of response delays, particularly in relation to the standards established by the NFPA, there has been limited exploration in this area. This study aims to fill this research gap by providing a comprehensive analysis of the factors contributing to response delays in fire emergencies. By refining the RDM and applying it to real-world scenarios, the research will enhance our understanding of how delays impact emergency response effectiveness. In summary, the RDM offers a novel approach to assessing response delays by incorporating pre-notification times and recognizing their significance in the overall emergency response process. This study seeks to contribute valuable insights that can inform improvements in fire disaster management practices.

The primary aim of the Response Delay Model (RDM) is to enhance the efficiency of urban fire disaster response systems by systematically identifying, measuring, and mitigating delay moments within the response process. This is to reduce the overall response time, thereby minimizing the impact and severity of fire disasters in urban settings. However, the objectives include reintroducing the Response Delay Model and its assumptions. Secondly, identify and categorize the various delay types and factors contributing to the delays in urban fire disaster response systems. Third, it seeks to develop a standardized methodology (average delay metrics) for quantifying pre-notification and intra-reflex sequence delays. The overall aim of the Response Delay Model is to improve predictive capabilities for fire disaster outcomes based on measured delay moments, aiding in proactive planning and resource allocation.

REVIEW METHODS

The method is based on a comprehensive review and synthesis of existing literature on urban fire disaster response and delay. The first step involves identifying the relevant databases and sources. Key databases such as PubMed, JSTOR, Google Scholar, and ScienceDirect, along with institutional repositories, were utilized to ensure comprehensive coverage. Specific journals related to disaster management, urban fire disaster, fire disaster response, and emergency response, like the International Journal of Disaster Risk Reduction and Journal of Urban Affairs, were also targeted. A systematic search strategy is employed using relevant keywords and search strings such as "fire disaster response", "response delay model", "urban fire emergency", "fire response time", and "emergency response efficiency". Boolean operators (AND, OR, NOT) were used to refine the searches (e.g., "fire disaster response AND urban areas", "response delay model OR emergency response time"). Full-text articles were accessed through institutional subscriptions and the articles were downloaded and saved in a structured digital library using reference management software (Mendeley).

The selection process involves setting clear inclusion and exclusion criteria. Inclusion criteria include articles published in peer-reviewed journals within the last 10-15 years, studies focusing on fire disaster response times, delays, and efficiency in urban settings, and articles presenting models, case studies, or empirical data on emergency response. Exclusion criteria involve articles that do not specifically address response times or delays in fire disaster management, studies focused on rural or non-urban settings unless they provide significant insights applicable to urban contexts, and publications without empirical data, theoretical frameworks, or practical applications (e.g., opinion pieces, editorial notes). The selection process was based on an initial screening where titles and abstracts were reviewed to identify relevant articles, excluding those that do not meet the inclusion criteria. This was followed by a full-text review to confirm relevance and inclusion, and data extraction using a standardized form to ensure consistency and completeness.

Synthesizing the information involves thematic and comparative analysis. Extracted data was grouped into thematic categories such as causes of response delays, types of delays, methodologies used, proposed models, and recommendations, to identify common themes, patterns, and gaps in the existing literature. Comparative analysis was conducted to identify consistent results and discrepancies across different studies, analyzing how different methodologies and contexts influence the outcomes related to response delays. Insights from the synthesized literature were integrated to update and refine the Response Delay Model. The reviewed findings and recommendations highlighted the need for the RDM, which seeks to identify the sources, types, and extent of delays in fire disaster response to mitigate the resultant impacts. The model categorizes delays into two primary types: pre-notification delays (the time from the fire's onset to the notification of emergency response departments) and intra-reflex sequence delays (the time from the dispatch of responders to their arrival at the scene and the commencement of firefighting activities). This categorization helps focus on the critical stages where delays can occur, providing a targeted approach to improving fire disaster response efficiency.

Understanding the Concepts of Response and Delay Response

In the context of fire disasters, response refers to the immediate actions taken by fire departments, emergency medical services, law enforcement, and other agencies to address the fire incident, protect lives, mitigate property damage, and stabilize the situation (NFPA, 2021). Response is the most critical stage of a disaster reduction and management system (Adeyinka et al., 2022). It encompasses actions taken immediately during and just after a disaster. If the disaster is severe or prolonged, it can exceed the capacity of first responders, local firefighters, or law enforcement officials. Key objectives include extinguishing the fire to prevent further spread, conducting rescue operations to save individuals at risk, providing urgent medical care to the injured, safely evacuating people from hazardous areas, and ensuring the scene is safe by addressing any additional hazards (NFPA, 2023). Efficient and effective response efforts are crucial in minimizing the impact of fire disasters, significantly reducing fatalities, injuries, and property damage. Optimum utilization of the time in responding to a disaster serves as a measure of effectiveness of any emergency response system (Smith et al., 2018).

Fire disaster response time

Fire disaster response time refers to the period that begins when units (firefighters, law enforcement officials, and medical personnel) are en route to the emergency incident and ends when units arrive at the scene (NFPA, 2023). ire disaster response time is the duration it takes for emergency responders, such as fire departments, to react to a fire incident from the moment they are notified until they arrive at the scene and begin firefighting activities. It is a critical metric in emergency management, as shorter response times can significantly reduce the damage caused by fires, save lives, and minimize property loss. Efforts to improve response time focus on enhancing detection systems, optimizing dispatch protocols, improving infrastructure and road networks, and ensuring that fire stations are strategically located. Fire disaster response time is divided into dispatch, turnout, travel, arrival, setting-up, and extinguishing time (NFPA 1710):

a) Dispatch time starts from the moment the emergency alarm is received 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. This typically lasts for 120 minutes (NFPA, 2023).
b) Turnout time begins from the moment units are notified of the incident to the beginning of travel time (Johnson & Wang, 2019). Turnout time is approximately 80 seconds (NFPA, 2021).
c) Travel time is the time taken from when the first vehicle is dispatched to when the first vehicle arrives at the emergency scene. This typically lasts for 240 seconds (NFPA, 2021). Therefore, the total response time is about 5 minutes and 20 seconds, excluding the dispatch time.
d) Arrival time is when the first vehicle of the unit arrives at the scene of the fire disaster. At the arrival, it takes approximately about 60 seconds to properly position the apparatus for setting-up to begin.
e) Setting-up time begins when the first vehicle of the unit arrives and is properly positioned at the fire scene and ends when firefighting activities commence. This period involves connecting hoses and kitting up to initiate the firefighting process. This process approximately takes 60 seconds to complete.
f) Extinguishing time begins immediately after the setup is complete and continues until the fire is fully extinguished.

In emergency analysis, quicker response saves more lives and properties from losses and damages (Miller et al., 2017). In other words, response time is a critical component in the control and mitigation of an emergency incident (Smith et al., 2018). Response time is also defined as a primary benchmark that serves as a function of area coverage, traffic infrastructure capacity, equipment, and number of staff available to respond (Adams & Kumar, 2020). Various factors influence the response time, including location/distance, accessibility, population, and building stock (Smith et al., 2018). Other factors directly related to overall response times include physical site characteristics, traffic volume, and speeds. Average travel speed can determine the extent of the coverage area according to a given response time. To determine the average speed, it may be useful to classify roads as major and residential or minor roads, and account for the impact of the time of day (peak and non-peak hours) (Smith et al., 2018). Understanding the standardized elements of response time is important to measure its effectiveness and identify the factors hindering it (Smith et al., 2018).

Delay

Delay refers to the time lag that occurs at various stages of the emergency response process, significantly impacting the overall effectiveness of response efforts (Yunus, 2019a). It is defined as a period during which something is late or postponed, often caused by hindering factors that slow down the normal process (Jafari et al., 2021). In the context of fire disaster response, delay specifically refers to the period by which the normal response system is late or postponed due to various obstructive factors, such as inadequate resources, poor communication, and geographical challenges (Adamu & Yunus, 2020). The Response Delay Model (RDM) aims to identify the sources, causes, and measure the extent of these delays, particularly as they hinder prompt responses to fire disasters. Based on the response delay model, delay in responding to fire disasters is categorized into two types (pre-notification and intra-reflex sequence delays) and depends on many factors, including the level of awareness and preparedness by stakeholders (i.e., the fire service and the general public), technological advancement, geographic location, and socio-economic and environmental factors.

Delays in fire disaster response can have significant and far-reaching effects. These delays can result in increased damage to property, higher economic losses, and a greater risk to human life (Liew, 2023). For instance, longer response times can lead to the fire spreading more extensively, making it more challenging to control and extinguish. This not only exacerbates property damage but also increases the likelihood of injuries and fatalities among residents and first responders (Adamu & Yunus, 2020). Delays can also compromise the safety of evacuees and limit their chances of escaping unharmed (Gernay et al., 2016). Additionally, prolonged exposure to smoke and toxic fumes can cause severe health issues, including respiratory problems and long-term illnesses (Reid et al., 2016).

Furthermore, the longer the fire burns, the greater the environmental impact, as more pollutants are released into the air, harming surrounding ecosystems (Mishra et al., 2020). The efficiency of emergency services is also undermined, leading to a potential loss of public trust and confidence in their ability to manage such crises (World Bank, 2023). Therefore, minimizing delays in fire disaster response is crucial for mitigating these adverse effects and ensuring a swift and effective resolution to such emergencies (National Safety Council, 2023). Addressing the challenges posed by response delays requires a comprehensive understanding of the factors contributing to these delays. Research indicates that factors such as inadequate training, poor communication, and insufficient resources can significantly hinder timely responses (Adamu & Yunus, 2020). Additionally, urban planning and infrastructure deficiencies can exacerbate response times, particularly in densely populated areas (Gernay et al., 2016). Implementing effective strategies to reduce response delays is essential for improving overall fire disaster management.

Response Delay Model (RDM)

Attempting to measure the efficiency of the response system to fire disasters, prompted the need for the Response Delay Model (RDM) which identifies and categorize delays based on their nature, sources, length, and causes. The RDM aims to bridge a significant gap by synchronizing delays in measuring the overall efficiency of a response system. Most studies have neglected the moments before 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 a measure of the efficiency of a response system (Figure 1). The RDM provides for measuring these delays and their extent depending on locational, technological, environmental, and socio-economic factors, as well as the level of awareness and preparedness and their influence in determining the magnitude of a fire disaster and the efficiency of a response system. RDM sees delay as a significant factor that increases burning time and determines the commencement of the response reflex sequence. Therefore, measuring the efficiency of a response system is incomplete without considering these delays, their sources, extent, and influencing factors.

The RDM provides for quantification of the length of pre-notification and intra-reflex sequence delays (Yunus, 2019a and Yunus, 2019b). This involves calculating the time taken after incident to emergency notification and the added time intervals between each critical stages in the response process based on the NFPA 1710 estimated standards (NFPA, 2021). By quantifying these delays, the model provided a clear picture of where and how delays impact the overall response time. It establishes standardized average delay metrics which as benchmarks for evaluating and comparing the efficiency of fire disaster response systems globally. Simulations are conducted to test the model's predictive capabilities. These simulations help in understanding how different delay factors impact the overall response time and the severity of fire disasters. By simulating various scenarios, the model predicted potential outcomes and provided insights into how to mitigate delays.

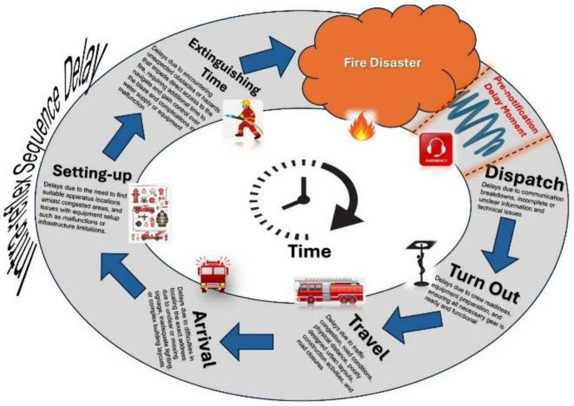


Figure 1 Response Delay Model

The Response Delay Model (RDM) specifically addresses two types of delays: pre-notification delay and intra-reflex sequence delay. The pre-notification delays occur from the onset of a fire disaster to the time of accessing emergency alert numbers to notify the response department, or alternatively, physical travel to the station. While the intra-reflex sequence delay arise within each phase of the response reflex sequence, depending on the peculiarity of the phase and the preparedness level of the fire service. These delays include at notification, dispatch, turnout, travel, arrival, setup time and extinguishing stages (Figure 1). The model emphasizes that time is a crucial factor in evaluating the effectiveness of a response system. The longer time it takes to respond to a fire disaster, the greater its magnitude, and vice versa.

The Response Delay Model (RDM) is developed based on the following assumptions:

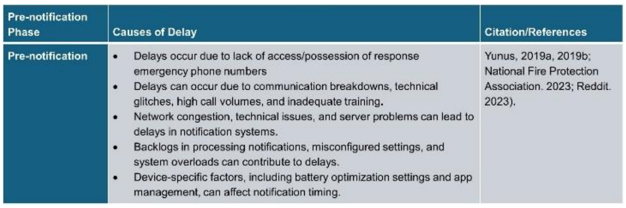
a) Pre-notification and intra-reflex sequence delays are the primary types of delays in urban fire disaster response systems.
b) These delays are major determinants of the magnitude of a fire disaster and the efficiency of a response system.
c) This model is applicable for measuring the efficiency of response systems for other forms of disasters (both natural and anthropogenic) that require rapid response.
d) Time is central and determines the length of the delay moments.
e) The length of the delay moments is elastic.
f) Variables such as level of awareness and preparedness, socio-economic, demographic, locational, technological advancement, and environmental factors can influence the length of the pre-notification delay.
g) The RDM measures the efficiency of a response system at various scales (micro or local, national, and international levels).

Types and Causes of Delays in the RDM

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

a) *Pre-notification Delay*

Pre-notification delay refers to the time from the onset of the fire to the point of notifying the emergency response department through either telecommunication or physical travel. This delay ends when the response department is informed about the location of the incident. Pre-notification delays, often the most common, are primarily due to factors such as the lack of possession/access to emergency response numbers (Okeke, 2020; Yunus, 2019b). The extent of the delay defines its elasticity and also determines the onset of the response reflex sequence. The length of pre-notification delay is variable and depends on many factors including the level of awareness and preparedness, access to emergency alerting numbers, geographical location, and socio-economic and environmental factors. This delay is termed 'abnormal' because its duration can hardly be predetermined and it has a significant influence on the magnitude of the fire disaster. More research is needed to estimate the length of this delay and establish a standard average pre-notification delay time at both local and global scales. Box 1 presents the various causes of pre-notification delays.



Pre-notification Phase	Causes of Delay	Citation/References
Pre-notification	• Delays occur due to lack of access/possession of response emergency phone numbers • Delays can occur due to communication breakdowns, technical glitches, high call volumes, and inadequate training. • Network congestion, technical issues, and server problems can lead to delays in notification systems. • Backlogs in processing notifications, misconfigured settings, and system overloads can contribute to delays. • Device-specific factors, including battery optimization settings and app management, can affect notification timing.	Yunus, 2019a, 2019b; National Fire Protection Association. 2023; Reddit. 2023).

Box 1: Causes of pre-notification delays

b) *Intra-Reflex Sequence Delay*

Intra-reflex sequence delay includes all the delays (added time) that may arise at each phase of the reflex sequence in addition to the NFPA 1710 standard estimated time. These delays might result from factors similar to those causing pre-notification delays. Although the required standard time for each phase of the sequence has been estimated and defined by various countries and organizations, this model uses the NFPA 1710 which is the baseline for the estimation of added time delay. This type of delay is termed 'normal delay' and usually does not last long, depending on the nature and extent of the encountered problems. While the intra-reflex sequence delay refers to that which occurs within and between the phases of the response process. These include:

i. Dispatch Delay: This occurs between the receipt of the emergency call by the dispatch center and the dispatching of the fire response units. Contributing factors can include communication inefficiencies, procedural delays, and the time needed to mobilize and deploy resources (NFPA, 2021).
ii. Turnout Delay: This is the period from the dispatch notification to the moment fire response units begin their journey to the fire scene. Delays in this phase can be due to firefighters preparing and gearing up, potential confusion or miscommunication, and logistical challenges within the fire station (NFPA, 2021).
iii. Travel Delay: This refers to the time taken for fire response units to travel from their location to the scene of the fire. Factors influencing travel delay include traffic conditions, distance, road infrastructure, and the navigational efficiency of the response units (NFPA, 2021).
iv. Arrival and Setup Delay: This is the time taken after arriving at the scene to set up equipment and begin firefighting operations. Contributing factors can include finding suitable positions for firefighting apparatus, connecting hoses, and coordinating with other emergency services on site (Department for Communities and Local Government, 2015).
v. Extinguishing Delay: This covers the duration from the commencement of firefighting operations to the complete extinguishment of the fire. Delays can be influenced by the fire's intensity, the availability and functionality of

firefighting equipment, water supply issues, and the complexity of the fire situation (Karter & Stein, 2008).

The extent of the delay at each phase has initially not been standardized by any study, highlighting the significance of the RDM which provided metrics for measuring averages of these delay moments to enable forecasting and quantifying damages even before the commencement of a response mission. Box 2 summarises the various common causes of delays at each phase of the response reflex sequence.

Reflex Sequence Phase	Causes of Delay
Dispatch Phase	Delays during dispatch time are caused by communication breakdowns, incomplete information from callers, technical issues, resource allocation challenges, real-time traffic analysis, geographical difficulties, human error, interagency coordination, insufficient training, high call volumes, language barriers, and verification processes (NFPA, 2023).
Turn-out Phase	Delays during turn-out time are caused by crew readiness, equipment preparation, internal station logistics, staffing levels, communication delays, lack of training, poorly maintained vehicles, and varying activity levels at different times of day (Smith & Brown, 2020; Evans & Lee, 2022; Davis & Chen, 2019; Anderson et al., 2021; Thomas & Garcia, 2020; Williams & Clark, 2021; Martinez & Wong, 2019).
Travel	Delays during travel time are attributed to traffic congestion, road conditions, physical distance, poorly designed urban layouts, construction activities, navigation errors, weather conditions, mechanical issues, and delays at traffic signals (Evans & Lee, 2022; Smith & Brown, 2020; Johnson & Brown, 2021; Davis & Chen, 2019; Williams & Clark, 2021; Anderson et al., 2021).
Arrival Phase	Delays during arrival time are caused by difficulties in locating addresses, congested streets, communication breakdowns, environmental conditions, and the need to navigate around obstructions (Smith & Brown, 2020; Johnson & Brown, 2021; Evans & Lee, 2022; Davis & Chen, 2019; Anderson et al., 2021; Williams & Clark, 2021).
Setting-up Phase	Delays during setting-up time include finding suitable locations, equipment setup issues, safety checks, coordination challenges, and environmental factors (Smith & Brown, 2020; Johnson & Brown, 2021; Evans & Lee, 2022; Davis & Chen, 2019; Anderson et al., 2021; Williams & Clark, 2021).
Extinguishing Phase	Delays during extinguishing time can stem from unexpected obstacles, complications in water supply, equipment malfunctions, fire complexity, and coordination challenges (Smith & Brown, 2020; Johnson & Brown, 2021; Evans & Lee, 2022; Davis & Chen, 2019; Anderson et al., 2021; Williams & Clark, 2021).

Box 2: Table 1: Causes of Intra-reflex Sequence Delay

In developed countries, emergency response numbers are often simple and centralized (for example 911 is a popular emergency code in United States of America), facilitating quick access. However, in many developing countries, emergency numbers are not as straightforward or centralized, and access is often difficult due to various factors. This makes pre-notification delays in many African and other developing countries longer than in most developed countries (Adeyinka et al., 2022). The model highlights the need to bridge this gap to enhance the efficiency level of the response department and the magnitude of fire disasters. The RDM provides for the quantification of delay moments within both the pre-notification and intra-reflex sequence phases. As illustrated in Figure 1, the model incorporates pre-notification delay (referred to as 'abnormal delay') and intra-reflex sequence delay (normal delay) as key parameters.

Measuring the Pre-notification and Intra-reflex Sequence Delays

The Response Delay Model (RDM) offers a mathematical framework for quantifying each identified delay, using the established NFPA 1710 standard as a baseline (NFPA, 2021). The following components are used:

a) Total Response Time (T_{rt}):

The total time taken (min/sec) to respond to a fire disaster, from the onset of the fire to the time when it is completely extinguished. This includes delays at the pre-notification and intra-reflex sequence phases. Total Response Time is calculated using:

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

where R_t is the response time (min/sec) to a particular fire disaster scene, P_d is the pre-notification delay and I_d is the intra-reflex sequence delay.

b) Response Delay (R_d):

The sum of the delays experienced during a fire outbreak, irrespective of the source. This can be calculated through:

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

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

c) Intra-Reflex Sequence Delay (I_d):

The added time (min/sec) from the onset of each phase of the reflex sequence to the beginning of the next one. It is the time difference between the actual time taken and NFPA 1710 estimated time at each phase of the reflex sequence. Calculation of the Intra-Reflex Sequence Delay (I_d) comprised of the following:

$I_d = (AD_t - ED_t) + (AT_t - ET_t) + (AT_{rt} - ET_{rt}) + (AA_t - EA_t) + (AS_t - ES_t) + (AE_t - EE_t)$

where AD_t is the actual dispatch time and ED_t is the NFPA estimated dispatch time, AT_t is the actual turnout time and ET_t is the estimated turnout time, AT_{rt} is the actual travel time and ET_{rt} is the estimated travel time, AA_t is the actual arrival time and EA_t is the estimated arrival time, AS_t is the actual setting-up time and ES_t is the estimated setting-up time and finally AE_t is the actual extinguishing time and EE_t is the estimated extinguishing time.

d) Pre-notification Delay (P_d):

The time difference between the dispatch time (D_t) and the estimated fire onset time (EO_t). This is represented by:

$P_d = D_t - EO_t$

where D_t is the dispatch time (min/sec) and EO_t is the estimated fire onset time (min/sec).

Further complex measurements can also be made, 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 incorporating an additional component (distance) in measuring the extent of a pre-notification delay.

Discussion and New Insights from the RDM

Response Delay Model (RDM) represents a significant advancement in the field of urban fire disaster response. Traditional response systems often overlook the critical impact of various delay moments on overall response efficiency and disaster outcomes. The RDM addresses this gap by providing a comprehensive framework for identifying, measuring, and mitigating delays, particularly pre-notification and intra-reflex sequence delays (Yunus, 2019a). This approach allows for a more granular understanding of where and why delays occur, enabling fire departments to implement targeted improvements. The model's emphasis on standardizing delay metrics across different geographic and socio-economic contexts also facilitates more consistent and comparable evaluations of response systems globally.

Recent studies support the need for such detailed analyses. For instance, a study by Evarts (2018) highlighted the variability in fire response times due to factors such as geographic location and technological infrastructure. By incorporating these factors into its delay measurements, the RDM provides a more accurate reflection of real-world conditions. This aligns with findings from the National Fire Protection Association (NFPA, 2010), which reported significant disparities in response times and fire outcomes based on regional differences in preparedness and resources. The RDM’s methodology for quantifying delays and establishing standardized metrics can help bridge these gaps, ensuring more equitable and effective fire disaster responses.

New Insights

The introduction of the RDM offers new insights into how urban fire disaster response systems can be optimized. One of the key revelations is the importance of pre-notification delays, which are often influenced by public awareness and accessibility of emergency services. For example, Yunus (2019b) notes that improving community awareness and simplifying emergency communication channels can significantly reduce these delays. This is further supported by Karter and Stein (2008), who found that delays in emergency notifications were a major factor in the severity of fire incidents. By focusing on reducing these delays, the RDM suggests that even small improvements in public communication can lead to substantial gains in response efficiency.

Additionally, the RDM's approach to measuring intra-reflex sequence delays sheds light on the operational efficiencies within fire departments. By analyzing delays from dispatch to arrival and setup, the model identifies critical bottlenecks that can be addressed through better training, resource allocation, and technology upgrades. This insight is particularly valuable in urban settings where rapid response times are crucial due to high population densities and infrastructure complexities. Studies have shown that targeted investments in these areas can lead to marked improvements in response times and outcomes.

Finally, the Response Delay Model offers a robust framework for enhancing urban fire disaster responses by systematically addressing delay moments. Its comprehensive methodology and emphasis on standardization provide valuable tools for both local and global applications. Future research and implementation of the RDM could lead to significant advancements in fire disaster management, ultimately saving lives and reducing economic losses. The model's insights into pre-notification and intra-reflex sequence delays highlight the importance of continuous improvement and adaptation in response strategies, ensuring that urban fire response systems remain effective in an ever-changing environment.

CONCLUSION AND RECOMMENDATION

Delay in fire disaster response systems is an unavoidable reality, irrespective of whether the context is a developed or developing nation. The duration and impact of these delays are influenced by multiple factors, including levels of preparedness, public awareness, technological advancements, physical location, socio-economic conditions, and environmental variables. To accurately determine the efficiency of a fire response system, it is essential to measure and synchronize delay moments within each phase of the response process, integrating them into the normal reflex sequence. This integration is critical to establishing a standardized average delay for various locations, which in turn can significantly enhance the overall effectiveness of fire disaster management strategies.

The Response Delay Model (RDM) plays a pivotal role in bridging existing gaps by incorporating and synchronizing the two major delay moments—pre-notification and intra-reflex sequence delays—into the evaluation of response system efficiency and fire disaster magnitude. By doing so, the model not only provides a framework for assessing current response capabilities but also offers insights into potential improvements that can be made to reduce delays and enhance promptness in emergency situations. The model emphasizes the importance of continuous measurement and synchronization of delay moments to achieve a more accurate and comprehensive understanding of response system performance.

Recommendation

a) Local and Global Studies: It is essential to conduct extensive studies at both local and global scales to standardized average delay moments for different regions. These studies should focus on identifying the most influential delays as defined by the Response Delay Model (RDM), taking into account a range of factors such as preparedness levels, public awareness, technological advancements, and socio-economic and environmental conditions. This comprehensive approach will help in understanding the variability of delays and devising strategies to minimize them effectively.

b) Modeling Expected Delays: Research efforts should be concentrated on modeling expected delays within each phase of the response system. This will facilitate better forecasting and estimation of potential fire disaster damages. Developing predictive tools that incorporate these models can greatly assist fire departments in anticipating and mitigating delays before they escalate, thereby enhancing the overall efficiency of the response system.

c) Improving Preparedness and Awareness: Implementing educational campaigns to raise public awareness about fire hazards and emergency procedures is vital. Ensuring that communities are well-informed about the importance of quick notification and the availability of emergency response resources will significantly enhance preparedness levels. These campaigns should be ongoing and adapted to address the evolving needs of different communities.

d) Investing in Technological Advancements: Allocating resources for the acquisition and implementation of advanced technologies can streamline communication and reduce response times. Investing in training programs that equip response teams with the necessary skills to utilize these technologies effectively is equally important. Embracing technological advancements will lead to more efficient and effective fire disaster management.

e) Socio-Economic and Environmental Considerations: Response strategies should be tailored to address the specific socio-economic and environmental conditions of different regions. Ensuring that response plans are adaptable and inclusive, taking into account the unique challenges faced by various communities, will enhance their effectiveness. This approach will help in developing robust and resilient fire response systems.

f) Continuous Improvement Framework: Establishing a continuous improvement framework within fire response departments is essential to regularly evaluate and enhance response strategies. Using data collected from real incidents to refine and adjust protocols will ensure that response systems remain effective and responsive to evolving needs. This iterative process of evaluation and improvement will lead to sustained enhancements in fire disaster response efficiency.

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