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THE INTERNET OF THINGS (IOT) IN DISASTER RESPONSE

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THE INTERNET OF THINGS (IOT) IN DISASTER RESPONSE

by

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December 2022

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Disaster management is a complex practice that relies on access to and the usability of critical information to develop strategies for effective decision-making. The emergence of wearable internet of things (IoT) technology has attracted the interests of several major industries, making it one of the fastest-growing technologies to date. This thesis asks, How can disaster management incorporate wearable IoT technology in operations and decision-making practices in disaster response? How IoT is applied in other prominent industries, including construction, manufacturing and distribution, the Department of Defense, and public safety, provides a basis for furthering its application to challenges affecting agency coordination. The critical needs of disaster intelligence in the context of hurricanes, structural collapses, and wildfires are scrutinized to identify gaps that wearable technology could address in terms of information-sharing in multi-agency coordination and the decision-making practices that routinely occur in disaster response. Last, the specifics of wearable technology from the perspective of the private consumer and commercial industry illustrate its potential to improve disaster response but also acknowledge certain limitations including technical capabilities and information privacy and security.

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THE INTERNET OF THINGS (IOT) IN DISASTER RESPONSE

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ABSTRACT

Disaster management is a complex practice that relies on access to and the usability of critical information to develop strategies for effective decision-making. The emergence of wearable internet of things (IoT) technology has attracted the interests of several major industries, making it one of the fastest-growing technologies to date. This thesis asks, How can disaster management incorporate wearable IoT technology in operations and decision-making practices in disaster response? How IoT is applied in other prominent industries, including construction, manufacturing and distribution, the Department of Defense, and public safety, provides a basis for furthering its application to challenges affecting agency coordination. The critical needs of disaster intelligence in the context of hurricanes, structural collapses, and wildfires are scrutinized to identify gaps that wearable technology could address in terms of information-sharing in multi-agency coordination and the decision-making practices that routinely occur in disaster response. Last, the specifics of wearable technology from the perspective of the private consumer and commercial industry illustrate its potential to improve disaster response but also acknowledge certain limitations including technical capabilities and information privacy and security.

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LIST OF ACRONYMS AND ABBREVIATIONS

DOD	Department of Defense
EMAC	Emergency Management Assistance Compact
FASTER	First Responders Advanced technologies for Safe and efficient Emergency Response
FEMA	Federal Emergency Management Agency
GPS	Global Positioning System
IC	incident commander
IoBT	internet of battlefield things
IoMT	internet of military things
IoT	internet of things
IoWT	internet of wearable things
IT	information technology
LPWAN	low-power wide-area network
NGO	non-governmental organization
OSHA	Occupational Safety and Health Administration
PPE	personal protective equipment
RFID	radio-frequency identification device
SWOT	strengths, weaknesses, opportunities, and threats

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EXECUTIVE SUMMARY

This thesis explores the emergence of the internet of things (IoT), specifically in wearable technology, and assesses its potential for applications in emergency disaster response. It also identifies and discusses different barriers that preclude efficient strategies for effective decision-making in disaster management, such as managing large amounts of data generated during an event, vetting the integration and aggregation of critical information from various sources, and coordinating a multi-agency response to major disasters. Furthermore, understanding how IoT is applied in other prominent industries, including construction, manufacturing and distribution, the Department of Defense (DOD), and public safety, provides a basis for furthering its application to challenges affecting agency coordination in disaster response.

Next, this thesis focuses on the current state of IoT and discusses its prevalence in various major industries. IoT has been well received in several industries, such as construction, manufacturing, distribution, and the DOD due to its capabilities in improving work productivity, enhancing operational efficacy, and fostering safer work environments. In terms of work productivity, private companies that have implemented wearable technology into the workspace, such as DHL, have experienced a significant increase in productivity by eliminating antiquated manual work practices to streamline production output.[1] The military has also benefited from wearables by deploying this technology on the battlefield to enhance the effectiveness of frontline forces through what is been termed the "internet of battlefield things."[2] In this manner, the military can better track assets operating down range, so the operational commander can provide real-time feedback about the movement of an oppositional force, allowing frontline forces a unique opportunity to make adjustments to attain a position of advantage.[3] Regarding safety in the workplace,

[1] "DHL Supply Chain Makes Smart Glasses New Standard in Logistics," DHL Global, August 2, 2017, https://www.dhl.com/global-en/home/press/press-archive/2017/dhl-supply-chain-makes-smart-glasses-new-standard-in-logistics.html.

[2] James Jin Kang et al., "No Soldiers Left Behind: An IoT-Based Low-Power Military Mobile Health System Design," *IEEE Access* 8 (2020): 201498–515, https://doi.org/10.1109/ACCESS.2020.3035812.

[3] Kang et al.

both construction and manufacturing have used wearable technology to monitor the real-time conditions of workers and the environments they operate in.[4] These industries have applied wearable technology primarily for biometric monitoring, which tracks an individual's heart rate, body and ambient temperature, and rate of exertion. Such applications prevent personnel injuries proactively, thus reducing associated downtime in the workplace.[5]

Then, this thesis analyzes difficulties in managing critical information and the subsequent effects that interfere with multi-agency coordination during an emergency disaster response. Moreover, it outlines how this dynamic has manifested in three distinct disaster environments: hurricanes, structural collapses, and wildfires. Applying the concepts developed by Bharosa, Lee, and Janssen, which classify multi-agency coordination into three categories—the micro perspective, the intermediate perspective, and the macro perspective—provides a deeper understanding of the issues at each level.[6] Subsequently using the same framework to examine the three unique environments of hurricanes, structural collapses, and wildfires allows for a systematic critique that exposes specific vulnerabilities in the potential use of wearable technology.

The penultimate chapter of this thesis concentrates on wearable technology and discusses its current composition in both the consumer market and professional industries. Furthermore, it explains the technology's potential benefits and the perceived pain points commonly associated with information privacy and security. Of the many advantages of wearables, researchers contend that the inherent qualities of wearables far exceed those of more traditional mobile IoT devices, especially during a disaster, when a user is more likely

[4] Vishal Patel et al., "Trends in Workplace Wearable Technologies and Connected-Worker Solutions for Next-Generation Occupational Safety, Health, and Productivity," *Advanced Intelligent Systems* 4, no. 1 (January 2022): 1–30, https://doi.org/10.1002/aisy.202100099.

[5] Patel et al.

[6] Nitesh Bharosa, JinKyu Lee, and Marijn Janssen, "Challenges and Obstacles in Sharing and Coordinating Information during Multi-Agency Disaster Response: Propositions from Field Exercises," *Information Systems Frontiers* 12, no. 1 (March 2010): 49–65, https://doi.org/10.1007/s10796-009-9174-z.

to misplace one's mobile device during the chaos.[7] Conversely, wearable technology is integrated into body-worn devices that stay with the user.[8]

This thesis closes with findings, recommendations, and considerations for future research. The first section presents a strengths, weaknesses, opportunities, and threats (SWOT) analysis as a framework to identify pertinent facts relating to the advancement of wearable technology in disaster response. The foremost strength of wearables is their inherent ability to maintain constant contact with a user. The three weaknesses of wearables reflect current limitations of their technical capabilities, including limited battery life, challenges with sustaining network connectivity, and inaccurate analytics. The opportunities discovered for wearables in disaster response involve the integration of wearables with cloud computing to improve information-sharing for multi-agency collaboration. The threats highlight issues concerning information privacy and security and describe the effects from both the perspective of the consumer and instances of operational security. This thesis offers three recommendations for the application of wearable technology in disaster response relating to the following areas: a supplemental layer of emergency communications, applications for emergency responder use, and wearables for multi-agency collaboration in disaster response. Potential areas for future research involve hybrid networks for enhanced connectivity, concerns for information security and personal privacy, and a means for dealing with big data.

[7] John W. Cheng and Hitoshi Mitomo, "The Underlying Factors of the Perceived Usefulness of Using Smart Wearable Devices for Disaster Applications," *Telematics and Informatics* 34, no. 2 (May 2017): 528–39, https://doi.org/10.1016/j.tele.2016.09.010.

[8] Albert Opher et al., *Leveraging Wearables and the Internet of Things to Disrupt, Transform, and Unlock Value: Predictions on the Future of Wearables and IoT in the Enterprise* (Somers, NY: IBM Corporation, 2017), https://www.ibm.com/downloads/cas/O50QV9NK.

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I. INTRODUCTION

In recent years, the internet of things (IoT) has become a leading technology that has improved many aspects of people's lives. The IoT concept originated in 1982 with a group of graduate students attending Carnegie Mellon University and has since evolved into an aggregate for collecting various forms of information.[1] IoT is a system of physical components equipped with sensors and software that interface with the internet to exchange various forms of data. Given its rapid expansion over the last several years, many experts working in multiple disciplines have embraced this technology in connecting the world through ubiquitous devices.

Innovators in disaster management have been applying IoT technology to protect communities using prevention and early detection systems, such as monitoring air quality in industrial facilities, surveilling agricultural production and supply, and monitoring patients in healthcare remotely.[2] These systems consist primarily of stationary devices that capture and consistently monitor conditions in fixed locations. With IoT technology expanding in portable devices and wearable items such as smartwatches and smartphones, disaster management could significantly optimize operations and enhance decision-making practices.

Professionals in disaster management often face recurring issues with capturing accurate and real-time data during rapidly evolving incidents that significantly impede the development of effective response strategies. As Sun, Bocchini, and Davison point out, many disaster response managers are looking for innovative solutions to improve the qualitative and quantitative means of capturing the vital information needed to conceptualize well-informed strategies for mitigating an array of hazards.[3] This research

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[1] P. V. Dudhe et al., "Internet of Things (IOT): An Overview and Its Applications," in *Proceedings of the 2017 International Conference on Energy, Communication, Data Analytics and Soft Computing* (Piscataway, NJ: IEEE, 2017), 2650–53, https://doi.org/10.1109/ICECDS.2017.8389935.

[2] Dudhe et al.

[3] Wenjuan Sun, Paolo Bocchini, and Brian D. Davison, "Applications of Artificial Intelligence for Disaster Management," *Natural Hazards* 103, no. 3 (September 2020): 2631–89, https://doi.org/10.1007/s11069-020-04124-3.

focuses on the potential of IoT's wearable technology and explores ways to best implement this technology into the strategic and operational practices of disaster response.

A. RESEARCH QUESTION

How can disaster management incorporate wearable IoT technology in operations and decision-making practices in disaster response?

B. LITERATURE REVIEW

This literature review delves into the scholarly research on IoT technology and explores ways this technology can improve the practice of emergency disaster response. To better understand how IoT can improve practices in disaster management, one must first recognize the impact of this technology and examine its viability moving forward. First, this review investigates current challenges in disaster management, specifically in collecting and sharing the information used to develop response strategies. Second, it presents how emergency management can implement IoT to offer potential solutions. Finally, it discusses certain limitations and relevant pain points using this technology. For this section, a pain point in the IoT field is best understood as anything that prohibits the conceptual integration and physical use of IoT in disaster response.

1. Challenges in Disaster Response

Disaster management is a complex practice that depends on access to and the usability of critical information to develop strategies for effective decision-making. How this information is managed and applied poses many multifaceted challenges. Li and Lv pinpoint one key challenge of big data analytics: managing large amounts of data created by a disastrous event.[4] In this way, a vital component of disaster management is extracting useful information from that stream to aid decision-making.

Unsurprisingly, scholars' debate whether systems can efficiently analyze big data to equip decision-makers in a timely way. Tan et al. argue that big data creates unique

[4] Xiaohan Li and Yang Lv, "Big Data-Driven Disaster Management: A Key Approach for Smart Humanitarian Activity," in *Proceedings of the 21st International Conference on Communication Technology* (Piscataway, NJ: IEEE, 2021), 1449–54, https://doi.org/10.1109/ICCT52962.2021.9657900.

opportunities for mass communication, but Mehrotra et al. contend that handling vast amounts of information during an event can overwhelm most analytic systems.[5] Currently, conventional methods for managing mass information cannot keep pace with the increasing demands of big data.[6] Moreover, standard data storage methods have limitations that reduce the likelihood of combining data from different sources. Although these capabilities exist, increasing the probability of data integration and aggregation for improved decision-making requires better ways to manage disaster information.[7]

2. IoT Solutions in Disaster Response

As IoT technology continues to grow, so does the appreciation of its overall utility. As a result, many experts recognize its expanding potential and willingly invest capital to advance the application of IoT in disaster management. Several scholars have recently suggested that advancements in science and technology are changing disaster response. In various analytical fields, crowdsourcing has become an effective means of examining large amounts of information from user-generated content, accessible through various social media outlets.[8] Han at el. argue that "the power of social media in disaster relief cannot be ignored in the disaster-affected area because posted User Generated Content may provide valuable information for disaster response which might remain unexploited."[9] In terms of technology, IoT uses radio-frequency identification devices (RFIDs) to locate and establish a network for rendering aid to people in need. Smartphones, for example, have become essential to average consumers and effectively collect information and advance new methods of short-form communication. Han et al. assert that IoT technology and the

[5] Ling Tan et al., "Can We Detect Trends in Natural Disaster Management with Artificial Intelligence? A Review of Modeling Practices," *Natural Hazards* 107, no. 3 (July 2021): 2389–417, https://doi.org/10.1007/s11069-020-04429-3.

[6] Sharad Mehrotra et al., "Technological Challenges in Emergency Response," *IEEE Intelligent Systems* 28, no. 4 (July 2013): 5–8, https://doi.org/10.1109/MIS.2013.118.

[7] Mehrotra et al.

[8] Shuihua Han et al., "Harnessing the Power of Crowdsourcing and Internet of Things in Disaster Response," *Annals of Operations Research* 283, no. 1–2 (December 2019): 1175–90, https://doi.org/10.1007/s10479-018-2884-1.

[9] Han et al., 1176.

concept of crowdsourcing have, separately, improved disaster response.[10] Han et al. maintain that the collective arrangement of crowdsourcing and extracting data from IoT can improve disaster response, and new research suggests great value from this data aggregation, which will significantly benefit disaster response.

3. Challenges in IoT

Regarding IoT, most experts readily agree that its lack of maturity remains a severe security risk with many vulnerabilities. In recent discussions of public trust in IoT, one debate addresses the need for standardization to resolve these concerns. On the one hand, Al-Qaseemi et al. posit that IoT experts lack consensus on standardization because the complex technology comprises numerous languages, protocols, and standards. From this perspective, Al-Qaseemi et al. assert that "few hope that a single standard will ever become dominant in the way standards like Wi-Fi and DVD have. . . . Part of that is the challenge of IoT itself."[11] On the other hand, however, Singh et al. warn that significant efforts have taken place recently to discuss various ideas of IoT standardization. Singh et al. point out that "such developments raise the hope of universal IoT standards in the near future."[12] According to this view, researchers acknowledge the significance of standardizing IoT. In sum, researchers have not decided whether the standardization of IoT should precede the further development of IoT security or simultaneously evolve with it.

4. Conclusion

Despite the challenges of IoT, most experts in disaster management still agree that IoT has tremendous potential in disaster response and advocate further studies on how to best use this technology. According to Ying Ma et al., many experts in disaster management suggest that existing systems need reform, and the versatile nature of IoT's

[10] Han et al.

[11] Sarah A. Al-Qaseemi et al., "IoT Architecture Challenges and Issues: Lack of Standardization," in *Proceedings of the 2016 Future Technologies Conference* (Piscataway, NJ: IEEE, 2016), 731, https://doi.org/10.1109/FTC.2016.7821686.

[12] Vaibhav Pratap Singh et al., "IoT Standardization Efforts—An Analysis," in *Proceedings of the 2017 International Conference on Smart Technologies for Smart Nation* (Piscataway, NJ: IEEE, 2017), 1083, https://doi.org/10.1109/SmartTechCon.2017.8358536.

network architecture and technological advancements will improve the efficacy of disaster response.[13]

C. RESEARCH DESIGN

This thesis analyzed opportunities presented by specific wearable IoT technologies and explores their potential in emergency disaster response. The Federal Emergency Management Agency (FEMA), specifically in its disaster management and response mission, relies heavily on accurate and current information to effectively develop strategies that mitigate various threats and bolster the response of physical emergency assets. Phones, watches, and other wearable and mobile devices have the potential to improve current methods of data collection, thereby increasing the efficiency and effectiveness of disaster response.

This thesis analyzed data in three different mission environments—hurricanes, structural collapses, and wildland fires—to identify shortfalls and gaps in decision-making practices within disaster management. The three environments were selected for their relevance in modern-day catastrophes, their frequency of occurrence, and their propensity to overwhelm systems requiring a multi-agency response. This research then examined the potential of specific wearable devices to fill those gaps by providing needed and timely information. This process also revealed obstacles to using this technology, including limitations of the technology itself, privacy and legal concerns related to access or use of the data, issues related to the management of abundant data, and the need to organize the data to make it useful.

The research involved examining technical reports and scholarly journals for a definition of IoT and revealed important issues that pertain to the implementation of this revolutionary yet controversial technology. This process identified the most critical data types associated with and needed in an emergency response. It also examined market research and investigated the specifications of existing wearable and mobile devices to determine which technology types offer the most promise in terms of usable data for

[13] Ying Ma et al., "Internet of Things Applications in Public Safety Management: A Survey," *Library Hi Tech* 38, no. 1 (2018): 133–44, https://doi.org/10.1108/LHT-12-2017-0275.

disaster response. Furthermore, I explored how specific wearable devices could integrate with the information gaps found in case studies by providing timely access to information and identifying barriers that limit this application.

In my research, I used after-action reports and incident action plans to establish a baseline for examining mission sets and objectives and understand the desired outcomes in specific mission environments. This research also scrutinized the information channels from a command-and-control perspective to determine which characteristics either enabled or inhibited good strategy and decision-making.

D. CHAPTER ROADMAP

This thesis explores the emergence of IoT, specifically in wearable technology, and assesses its potential for applications in emergency disaster response. Chapter II focuses on the current state of IoT and discusses its prevalence in various major industries. Chapter III analyzes difficulties in managing critical information and the subsequent effects that interfere with multi-agency coordination during an emergency disaster response. Moreover, it outlines how this dynamic has manifested in three distinct disaster environments: hurricanes, structural collapses, and wildfires. Chapter IV concentrates on wearable technology and discusses its current composition in both the consumer market and professional industries. Furthermore, it explains the technology's potential benefits and the perceived pain points commonly associated with information privacy and security. Chapter V presents a strengths, weaknesses, opportunities, and threats (SWOT) analysis to identify pertinent considerations in advancing wearable technology in disaster response; offers recommendations; and highlights considerations for future research.

II. CURRENT DISPOSITION OF WEARABLE IOT IN MAJOR INDUSTRIES

IoT technology offers many possibilities, and experts are excited about the ways this technology can improve people's lives. Thus, IoT technology is steadily advancing as engineers pursue new ways of refining this technology to meet the needs of industry and consumer product interfaces. Exploring the spaces in which this technology has already been used helps to identify other opportunities to improve disaster response. Several major industries have broadened the understanding of IoT's capabilities and have already invested heavily in the technology. This chapter focuses on six major industries: occupational safety and health, manufacturing and distribution, the military, public safety, law enforcement and criminal investigations, and healthcare. This examination demonstrates how this technology not only increases work efficiency and product output but also prevents harm and saves lives.

Developers are currently expanding the capabilities of IoT by focusing their efforts in areas that include 5G network capabilities, augmented reality, and enhanced robotics. Since 2020, engineers have made significant improvements with IoT technology by integrating 5G next-generation network technology.[14] Harnessing the capabilities of 5G will significantly increase the efficiency and effectiveness of IoT through the subsequent means of edge computing. Edge computing is a sophisticated computing platform that decreases the latent speed of devices operating in proximity to the end-user, resulting in optimized efficiency and operational performance. This is a significant achievement that will accelerate the evolution of a new generation of IoT products.[15] According to a recent IBM Newsroom publication, the industry anticipates that "5G will enable new use cases in remote monitoring and visual inspection, autonomous operations in large-scale remote

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[14] Suresh Borkar and Himangi Pande, "Application of 5G Next Generation Network to Internet of Things," in *Proceedings of the 2016 International Conference on Internet of Things and Applications* (Piscataway, NJ: IEEE, 2016), 443–47, https://doi.org/10.1109/IOTA.2016.7562769.

[15] Rishi Vaish and Sky Matthews, "5G Will Accelerate a New Wave of IoT Applications," IBM Newsroom, accessed January 3, 2022, https://newsroom.ibm.com/5G-accelerate-IOT.

environments such as mines, connected vehicles and more."[16] For the industrial applications explored in this chapter, such advancements mean that the future will see the development of ever-more accurate, efficient, and reliable devices that can serve as sensors to inform the decision-making processes used in high-risk or high-reliability environments where individual safety is paramount.

A. OCCUPATIONAL SAFETY AND HEALTH

According to research provided by the International Labor Organization, workplace injuries and illnesses account for approximately 2.78 million deaths and 374 non-lethal incidents each year.[17] To make matters worse, it is estimated that the consequences of these issues are costing U.S. companies approximately $1 billion each week due to workplace injuries that diminish productivity and create tremendous financial burdens with increased medical premiums, workers compensation claims, and litigation processes that are expensive and waste valuable time.[18] The occupational safety and health industry is exploring new and innovative solutions to offset the implications of these issues through the implementation of IoT in one of the largest U.S. industries, construction.

The construction industry is one of the biggest industries in the United States and is the most important due to its direct significance in the U.S. economy.[19] Unfortunately, this industry is one of the most dangerous, and many workers have been affected by common job-related injuries and fatalities directly attributed to the arduous and hazardous work conditions in various environments. Citing Department of Labor statistics, Costin, Wehle and Adibfar highlight that a staggering 971 construction workers were killed on the job in the United States, accounting for 20 percent of workplace fatalities across all

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[16] Vaish and Matthews.

[17] Vishal Patel et al., "Trends in Workplace Wearable Technologies and Connected-Worker Solutions for Next-Generation Occupational Safety, Health, and Productivity," *Advanced Intelligent Systems* 4, no. 1 (January 2022): 1–30, https://doi.org/10.1002/aisy.202100099.

[18] Patel et al.

[19] Aaron Costin, Andrew Wehle, and Alireza Adibfar, "Leading Indicators—A Conceptual IoT-Based Framework to Produce Active Leading Indicators for Construction Safety," *Safety* 5, no. 4 (2019): 1–26, https://doi.org/10.3390/safety5040086.

industries in 2017.[20] This figure is worth noting considering the significant impacts that job-related injuries or fatalities have on a project. These types of incidents can pose many significant challenges that either overburden or cripple companies while inflicting undue harm to surrounding communities, thus incentivizing the construction industry to invest in new and innovative ways to prevent construction accidents through early mitigation. Many in the construction industry have adopted new initiatives for improving work conditions and ensuring the safety of their employees, one of which integrates IoT technology. Costin, Wehle, and Adibfar assert that "information and communication technologies (ICTs), such as [IoT] . . . , cyber-physical-social systems, Big Data, artificial intelligence (AI), and . . . machine learning are starting to be adopted in the construction industry to ultimately increase the efficiency, safety, and quality of construction projects."[21]

One application in the construction industry is wearable IoT-based physiological monitoring to assess a worker's exposure to heat stress using wireless body area sensor networks.[22] These devices are attached, in various manners and capture real-time information about workers' locations and their responses to environmental exposures. This application requires the use of three sensors embedded in a wearable item such as an armband that is unintrusive to a worker. These three sensors include a photoplethysmography device, which measures the volume of blood flow; an accelerometer, which determines asset location; and a thermometer, which monitors skin temperature. These sensors correspond with a web-based application that can be accessed using a smart device with relative accuracy.[23]

In addition to the more traditional use cases of wearables as previously mentioned, innovators are expanding the application of IoT to wearable optical assist devices. Developers are experimenting with eyewear equipped with IoT, referred to as smart-

[20] Costin, Wehle, and Adibfar, 1.

[21] Costin, Wehle, and Adibfar, 6.

[22] Jung Hoon Kim et al., "Development of an IoT-Based Construction Worker Physiological Data Monitoring Platform at High Temperatures," *Sensors* 20, no. 19 (2020): 1–17, https://doi.org/10.3390/s20195682.

[23] Kim et al.

glasses, to enhance various worksite practices.[24] These smart-glasses are used to replicate visual information remotely, tracking personnel and other physical resources to enhance work efficiency and reduce the likelihood of costly human errors.[25] For instance, a user donning smart-glasses has the unique ability to readily access information like construction plans that can be overlayed in any geographic space for an improved visual reference.[26]

B. MANUFACTURING AND DISTRIBUTION

IoT is also being applied in other fields that rely heavily on manual labor, such as manufacturing and distribution, through *key enabling technologies*. Patel et al. describe these technologies as a network of "workplace wearables (i.e., smart on-body accessories and personal protective equipment) [that] track the activities, behavior and body status of individual workers."[27] The information collected from these devices may provide further insight into developing better proactive measures that prevent injuries before they occur. These devices can provide specific details that detect inefficient work postures, actions causing overexertion, and repetitive movements contributing to physical exhaustion and a decline in mental cognition. These potentials for injury directly correlate with a worker's moods and emotions affected by stress and the frequency of a worker's downtime.[28]

Along with ensuring personnel safety, IoT is also making an impact in manufacturing and distribution by improving the efficiency of the workforce. In a March 2022 article, GXO, a prominent world leader in logistic solutions, evaluated a device called ProGlove, a wearable technology that incorporates the use of a wireless headset in conjunction with a hand-worn bar code scanner.[29] ProGlove collects information from the

[24] Maya Menon, "Innovations in Wearable Technology and How They Are Transforming the Construction Industry," Visilean, May 9, 2022, https://visilean.com/innovations-in-wearable-construction-technology/.

[25] Menon.

[26] "Top 6 Wearable Technology in the Construction Field," Constructor, accessed December 7, 2022, https://theconstructor.org/construction/top-wearable-technology-construction/156302/.

[27] Patel et al., "Trends in Workplace Wearable Technologies," 1.

[28] Patel et al.

[29] "You Wear It Well: Wearable Technology Hits the Mark," Inbound Logistics, March 2022, https://www.inboundlogistics.com/articles/you-wear-it-well-wearable-technology-hits-the-mark/.

hand-worn scanner and displays the relevant information on the headset's display, greatly reducing the time it takes to process the information about a given product.[30] A spokesperson for GXO states that "the benefits of ProGlove improve the health and safety of our employees thanks to its ergonomic design, while improving efficiency by 10% and reducing errors by approximately 75% during inventory picking."[31] ProGlove is another example of how wearable IoT is transforming the way workers interact in the work environment.

It is a standard practice, enforced by the Occupational Safety and Health Administration (OSHA), for an employer to provide the appropriate personal protective equipment (PPE) to employees operating in hazardous work environments. These may include essential items, such as hard hats, safety vests, harnesses, protective eyewear, and hearing protection. Researchers have realized there is potential in this space for IoT technology to capture a broader range of information that will develop better metrics for assessing internal and external workloads encountered by individuals working in strenuous environments.[32]

Major companies like Honeywell and 3M have been developing lines of PPE that integrate IoT technology with OSHA-required safety systems commonly used at construction work sites. One device developed by Honeywell, called the Guardhat, uses sensors integrated into an American National Standards Institute–rated hardhat.[33] In addition to protecting a worker against accidental impacts, the Guardhat collects real-time information for location and situational awareness systems. The real-time location system can be used either indoors or outdoors and operates using the Global Positioning System (GPS). The asset-tracking feature uses a combination of Bluetooth low-energy technology and RFIDs to track assets continuously and provide feedback that alerts on-site personnel of restrictions in hazardous areas.[34] The Guardhat's real-time situational awareness feature

[30] Inbound Logistics.

[31] Inbound Logistics.

[32] Patel et al., "Trends in Workplace Wearable Technologies."

[33] "Home Page," Guardhat, accessed July 31, 2022, https://www.guardhat.com/.

[34] Patel et al., "Trends in Workplace Wearable Technologies."

operates through human-to-machine interactions that prevent accidents by alerting users to hazardous environmental factors and traffic patterns of heavy machinery and tracking workers' compliance with PPE requirements. Sensors worn on helmets may provide immediate alerts to expedite patient treatment, stabilize an incident, and prevent the escalation of a hazardous situation that might affect additional personnel working in the vicinity.[35]

Another product from Honeywell is the BioHarness.[36] BioHarness is a physiological monitoring system consisting of wireless sensors that measure a user's pulse, respiration, level of activity, and approximate location. BioHarness uses a network of proprietary components such as the Raelink3 wireless transmitter, ProRAE guardian software, and RFID tags that collectively provide a continuous stream of information that can be accessed from a remote location. These devices are interoperable with any of Honeywell's safety systems and provide valuable information about an asset's location, usage, and track performance issues encountered in the field. BioHarness can rapidly assess the physical output of a user, thereby allowing administrative authorities the unique ability to modify unsafe behaviors.

Having access to this type of information provides better situational awareness for the employee and the supervisor who can monitor performance remotely. Such real-time information allows supervisors to adjust a work environment to ensure safe practices and increase workplace productivity. Researchers believe that the impacts of wearable IoT in occupational safety will improve workers' career longevity through better preventive measures developed through the research obtained from the devices.[37]

C. MILITARY

Various military units have worked in conjunction with private industries to explore new uses for IoT that will improve mission readiness and enhance capabilities on the

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[35] Patel et al.

[36] James A. Johnstone et al., "Bioharness Multivariable Monitoring Device: Part I: Validity," *Journal of Sports Science & Medicine* 11, no. 3 (2012): 400–408, https://core.ac.uk/download/pdf/216991406.pdf.

[37] Patel et al., "Trends in Workplace Wearable Technologies."

battlefield. The military has embraced IoT technology for several years and, in various ways, paved the way for improving operational security by minimizing the unintentional occurrence of transmitting sensitive information via verbal communication and enhancing the accuracy of real-time information for better decision-making in the battle space.

IoT and low-power wide-area network (LPWAN) technologies have emerged to meet the needs of the military due to their unique adaptability in the dynamic environments of military operations. The Human Performance Network, established by the Australian Department of Defense, has been researching the effectiveness of pairing these technologies to replace previous generations of sensor networks with limited capacity and versatility.[38] By integrating IoT with LPWAN, the military will create new and promising opportunities to monitor soldiers' activities in austere conditions and improve mission performance, thereby contributing to the success of military operations.

Recently, private industry has explored ways to apply this technology in new wearable formats. One variation, the wireless body area network, embeds antennas in wearable textiles as part of a body-centric communication device.[39] Describing the requirements of this solution, Sanjit Varma et al. assert that "an antenna is one of the key components of the wearable communication device. . . . [The] wearable antenna should be very compact, low profile, lightweight, mechanically robust, efficient and preferably flexible to suit the conformal structure of the body surface."[40] Their research suggests the use of two textile-based antennas, a loop and dipole, that can be integrated into commercially available fabrics and can be affixed to various surfaces positioned close to the human body.

Such innovations will improve metrics for monitoring personnel and equipment. This concept is also known as the internet of military things (IoMT) or the internet of

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[38] James Jin Kang et al., "No Soldiers Left Behind: An IoT-Based Low-Power Military Mobile Health System Design," *IEEE Access* 8 (2020): 201498–515, https://doi.org/10.1109/ACCESS.2020.3035812.

[39] Sanjit Varma et al., "Design and Performance Analysis of Compact Wearable Textile Antennas for IoT and Body-Centric Communication Applications," ed. Sachin Kumar, *International Journal of Antennas and Propagation* 2021 (2021): 1–12, https://doi.org/10.1155/2021/7698765.

[40] Varma et al., 1.

battlefield things (IoBT).[41] Kang et al. explain that "the primary goals of IoMT and IoBT are to: 1) improve the performance of soldiers; 2) allow for rapid identification of the enemy using Edge computing, and 3) identify and detect real-time changes to health conditions."[42] IoBT's appeal has expanded to many facets of the military, including land, naval, and airborne forces.[43] IoBT's pairing with edge computing is revolutionizing the battlespace with improved methods of communication that enhance situational awareness for more precise decision-making.[44] The adaptable nature of IoBT makes it a logical solution for the unique demands of modern-day warfare, which largely involves the application of strategic decentralized concepts. Many of the IoT concepts that have applicability to warfare are just as useful for emergency response and other public safety environments.

D. PUBLIC SAFETY

Engineers working alongside industry professionals have identified specific uses for IoT technology in public safety management, which has yielded promising results and created new opportunities for bolder future endeavors. One area of public safety showing encouraging outcomes with IoT is the fire service, specifically structural firefighting. Structural firefighting presents many risks that can cause either serious injury or, worse, the loss of life. One of the most significant challenges routinely encountered in structural firefighting is ensuring a reliable and consistent means for accurately reporting personnel accountability.

One way that IoT has been applied in the fire service is through RFIDs. An RFID is a short-range radio wave technology that consists of a tag and a reader. In structural firefighting, firefighters operating inside a structure are equipped with an RFID tag typically integrated into their self-contained breathing apparatuses. The incident

[41] Kang et al., "No Soldiers Left Behind."

[42] Kang et al., 3.

[43] Pradip Kumar Sharma et al., "Wearable Computing for Defence Automation: Opportunities and Challenges in 5G Network," *IEEE Access* 8 (2020): 65993–6002, https://doi.org/10.1109/ACCESS.2020.2985313.

[44] Sharma et al.

commander (IC) controls an external antenna that emits a signal corresponding with the RFID tag. With this RFID technology, the IC can remotely identify any firefighter by name and unit designation and obtain the firefighter's approximate location while operating in a structure, thereby significantly improving the critical practice of personnel accountability. Furthermore, the IC can receive additional information such as the firefighter's air supply and initiate an emergency evacuation when an incident becomes unstable.

In addition to improving the safety of firefighters, RFID technology has also been adapted to assess the efficacy of tactical procedures used by firefighters operating in hazardous environments. A study published in 2015 assessed the efficacy of RFID technology in recording the time and movement patterns of trainees performing victim search techniques inside a training structure that replicated the conditions of a real-world structural fire.[45] The study demonstrated that RFID is an effective tool for evaluating training, and the results of the assessment were used to provide insight for improvements to essential firefighting practices.[46] Both instances demonstrate how IoT technology has been applied differently in the fire service. IoT has made a difference by improving many practices, such as firefighter safety and personnel accountability, and may someday be credited for saving lives.

The fire service uses IoT mostly as a way of monitoring the safety and effectiveness of its workforce. However, one characteristic of IoT that may be of greater value is its unique ability to capture information passively as a form of surveillance.

E. LAW ENFORCEMENT AND CRIMINAL INVESTIGATIONS

Law enforcement and crime scene investigators have also fully embraced the growing potential of IoT. In recent years, law enforcement officers across the nation have relied heavily on supplemental body cameras to obtain a third-person perspective to assess officers' engagement with the public. Footage from these cameras has been used routinely in court proceedings as a legitimate source of circumstantial evidence.

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[45] Gary Li-Kai Hsiao et al., "Firefighter Wayfinding in Dark Environments Monitored by RFID," *Fire Technology* 52, no. 1 (January 2016): 273–79, https://doi.org/10.1007/s10694-015-0477-y.

[46] Hsiao et al.

In addition to body cameras, some commercial gun manufacturers have researched the application of smart sensors embedded in firearms, called IoT-enabled firearms.[47] In the realm of crime scene investigations, professionals have employed IoT technology to enhance forensic analysis, using more efficient methods to reduce the manpower required to process a scene, thereby preserving the integrity of crime scenes to build stronger cases. For instance, crime scene investigators can procure digital traces imprinted by various web-based electronic devices that can determine a person's movement, location, and time, which can help identify an individual's affiliation with criminal activity.[48]

Wearable IoT has proven its value through various law enforcement applications. Perhaps its biggest contribution has been body-worn cameras with frontline law enforcement officers. These devices continue to be used in retrospect either as a supplemental means of collecting evidence or in new training methods that incorporate after-action reviews to assess and modify field tactics. However, these devices have not yet reached their full potential but could improve practices in different applications, such as disaster response. Transitioning the application of body-worn cameras from passive surveillance to an active real-time analytical tool worn by emergency responders would have significant value in disaster response by creating new opportunities for decision-makers to acquire real-time information and provide better guidance for operations on the ground.

Another point to consider with the use of body-worn cameras is the expectation of personal privacy and the contexts in which certain liberties may be disregarded, as in law enforcement. However, in other instances, such as healthcare, personal privacy rights are strictly enforced under law. The next section addresses the use of wearables in healthcare that provides some insight on the topic of privacy, which is relevant to subsequent chapters of this thesis.

[47] Frank Landman, "A Look at How the IoT Is Transforming Law Enforcement for the Better," *ReadWrite* (blog), September 17, 2020, ProQuest.

[48] Joao Marcos do Valle et al., "Using Traces from IoT Devices to Solve Criminal Cases," in *Proceedings of the 6th World Forum on Internet of Things* (Piscataway, NJ: IEEE, 2020), 1–6, https://doi.org/10.1109/WF-IoT48130.2020.9221265.

F. HEALTHCARE

Another primary application of IoT is in the field of healthcare. Experts in this industry recognize the importance of IoT technology and have already experienced profits through increased work efficiency and the critical conservation of scarce resources. Healthcare has employed the use of IoT in several ways, the most remarkable of which are improved patient tracking, information management, and enhanced patient assessment protocols. One example impacting patient healthcare is a capsulized sensor that patients can ingest for definitive pharmaceutical treatments. Patients ingest an encapsulated microscopic sensor that reacts with an external device to detect the presence of prescribed medications and further analyze the patient's physiological responses. Philip et al. assert that "the implementation of this technology will have a massive impact in the healthcare sector as it will eliminate the complications caused by medical non-adherence. . . . The amount of wasted medicines and economical loss incurred will also be reduced."[49]

A similar technology has been applied in the study of human performance. In some instances, health experts and researchers have partnered with branches of the military, as well as the fire service, to use this form of IoT technology to enhance physiological assessment methods. This application of IoT provides a more in-depth understanding of the human body's response to extreme physical and environmental stress. With these improved methods, experts can establish safer health standards and develop regimens better suited for sustaining optimal human performance.

G. CONCLUSION

This chapter served as an overview of the current uses of wearable IoT in several major industries and provided good examples of how this technology can enhance job performance, improve personnel safety, and create new opportunities for refining a variety of decision-making practices. However, despite the optimism surrounding the emergence of this new technology, some scholars are skeptical about how this technology is advancing in other applications and what the potential consequences are involving the risks to

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[49] Vinu Philip et al., "A Review on Latest Internet of Things Based Healthcare Applications," *International Journal of Computer Science and Information Security* 15, no. 1 (January 2017): 8.

information security and privacy.[50] The following chapter examines the critical needs of disaster intelligence to explore opportunities for the application of wearable IoT in disaster management and response.

[50] Teklay Gebremichael et al., "Security and Privacy in the Industrial Internet of Things: Current Standards and Future Challenges," *IEEE Access* 8 (2020): 152351–66, https://doi.org/10.1109/ACCESS.2020.3016937.

III. CRITICAL NEEDS IN DISASTER INTELLIGENCE

One of the most significant challenges in disaster response deals with the management of critical information and its subsequent effects on the coordination of various organizations coalesced in a multi-agency response. Despite repeated attempts to improve these crucial aspects of disaster management, many scholars are still not satisfied and advocate advancing modern practices.[51] In recent years, many professionals, acutely aware of these challenges, have suggested that these recurring issues are inherent in the unpredictable and complex nature of disastrous events, which necessitate the collaboration of different professional organizations.[52] Moreover, several studies have validated these claims, implying that the lack of information-sharing and insufficient intra- and inter-agency coordination during a multi-agency response are responsible for poor decision-making practices and the unproductive actions that follow in the process.[53] If not executed correctly, the complicated task of managing the roles and expectations of various agencies could prove counter-productive and inhibit effective actions. This chapter focuses on the challenges encountered with multi-agency coordination during disastrous events and explores the concerns of experts regarding the various ways these elements manifest in three major types of incidents: hurricanes, structural collapses, and wildland fires.

A. INFORMATION-SHARING AND MULTI-AGENCY COORDINATION

The significance of information-sharing cannot be overstated. The overwhelming array of complexities that manifest during a crisis can make it difficult for anyone to fully comprehend the entirety of a situation.[54] Various elements of disaster management rely on accurate and relevant data to avoid disastrous pitfalls such as the misappropriation of

[51] Nitesh Bharosa, JinKyu Lee, and Marijn Janssen, "Challenges and Obstacles in Sharing and Coordinating Information during Multi-Agency Disaster Response: Propositions from Field Exercises," *Information Systems Frontiers* 12, no. 1 (March 2010): 49–65, https://doi.org/10.1007/s10796-009-9174-z.

[52] Bharosa, Lee, and Janssen.

[53] Bharosa, Lee, and Janssen.

[54] David A. McEntire, "Coordinating Multi-organisational Responses to Disaster: Lessons from the March 28, 2000, Fort Worth Tornado," *Disaster Prevention and Management: An International Journal* 11, no. 5 (December 2002): 369–79, https://doi.org/10.1108/09653560210453416.

critical lifesaving resources and ineffective strategies that impact emergency relief efforts, which may perpetuate a threat, thereby putting more lives at risk.[55]

To gain a better understanding of the processes, it is imperative to elaborate on the varying degrees of coordination that occur during an event and identify the deficiencies that negatively affect the coordination and exchange of information. Bharosa, Lee, and Janssen have developed a pragmatic approach that categorizes deficiencies into three basic levels: the micro perspective, the intermediate perspective, and the macro perspective.[56] The micro perspective, also referred to as the individual perspective, pertains to the collaboration of individual actors. This level has obstacles that involve urgent time-sensitive matters and the abundant flow of information that may be irrelevant or inaccurate by the time decisive actions come to fruition.[57] These complex situations often result in individual actors experiencing cognitive overload due to the persistent nature and evolving patterns of emergency information.[58]

The intermediate level, also referred to as the agency perspective, deals with the coordination of various agencies that often have cultural and bureaucratic differences.[59] At this level, during major events, agencies with different backgrounds are brought together for their unique capabilities and expected to interact for a common purpose. Challenges commonly arise as the result of cultural differences. For instance, Bharosa, Lee, and Janssen argue that "some relief agencies are highly disciplined, others disorderly; some have a highly hierarchical structure, while others are more informal and egalitarian."[60] Although these differences may be of no concern in normal situations, scholars insist that during a disaster, collaborative relationships become strained and often break down from the dynamics of an emergency event.[61]

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[55] Bharosa, Lee, and Janssen, "Challenges and Obstacles in Sharing and Coordinating Information."

[56] Bharosa, Lee, and Janssen.

[57] Bharosa, Lee, and Janssen.

[58] Bharosa, Lee, and Janssen.

[59] Bharosa, Lee, and Janssen.

[60] Bharosa, Lee, and Janssen, 51.

[61] Bharosa, Lee, and Janssen.

The macro level, also called the community level, is perhaps the most challenging level of coordination due to unfamiliarity with the interdependent nature of large-scale incidents.[62] The community level comprises several different relief agencies that ordinarily function independently. However, in a disaster situation, these agencies must coordinate their efforts through a complex network of multi-level and multi-organizational systems and procedures to attain a unified perspective and accomplish a common goal.[63] This is a significant pain point that presents many challenges with the circulation of critical information.[64] Moreover, the coordination of different agencies is facilitated not by a lead official but by a group of predetermined leaders who may not be aware of other agency leaders and their responsibilities.[65] The transparent flow of information is essential to any decision-making process in that it provides situational awareness that facilitates a shared understanding of the goals and objectives established in a multi-agency disaster response. Furthermore, the more precise and well-timed the delivery of information, the more effective and efficient the subsequent actions will be, which in some cases could mean the difference of life or death. Experts have realized the effects of these issues and determined that there is a need for improved channels of communication in disaster management.[66]

Information technology (IT) is one tool for improving the interactions of multiple agencies working together during a complex crisis. Bharosa, Lee, and Janssen assert that "technological aspects of Inter-Organizational Information-Sharing Systems . . . can enable or impede the coordination and sharing of disaster-related information."[67] IT is capable of enhancing the levels of information-sharing through continued exploration. Bharosa, Lee,

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[62] Gregory A. Bigley and Karlene H. Roberts, "The Incident Command System: High-Reliability Organizing for Complex and Volatile Task Environments," *Academy of Management* 44, no. 6 (December 2001): 1281–99, https://doi.org/10.5465/3069401.

[63] Karl E. Weick and Kathleen M. Sutcliffe, *Managing the Unexpected: Resilient Performance in an Age of Uncertainty*, 2nd ed. (San Francisco: Jossey-Bass, 2007).

[64] Bharosa, Lee, and Janssen, "Challenges and Obstacles in Sharing and Coordinating Information."

[65] Bharosa, Lee, and Janssen.

[66] Bharosa, Lee, and Janssen.

[67] Bharosa, Lee, and Janssen, 51.

and Janssen also contend that "IT can be used to make sure that everyone receives the relevant information at the right time."[68]

Integrating IoT with a better understanding of the challenges often encountered in a multi-agency disaster response will enhance capabilities by eliminating redundant elements that inhibit efficient ways of disseminating critical information.

B. DECISION-MAKING IN DISASTER RESPONSE

This section discusses and analyzes common challenges encountered in the response to catastrophic disasters. Applying Bharosa, Lee, and Janssen's framework, this analysis highlights specific deficiencies in the collection and dissemination of critical information and examines the common challenges associated with each type of disaster.

1. Hurricanes

Developing strategies for a hurricane response typically begins at the micro level with the actions of local or jurisdictional agencies. At this level, local emergency management agencies work in conjunction with public safety to begin preparations before the onset of a hurricane. This initial stage is commonly referred to as the pre-incident response phase and occurs under normal operations. During this phase, the primary agency conducts an initial threat assessment to determine a hurricane's potential impact and intensity.[69] In most cases, local agencies have ample time to prepare for the onset of a hurricane and strategically pre-stage resources several days in advance.[70] This information is imperative for the development of actionable strategies and requires a careful analysis of real-time information over prolonged periods. Threat assessments require various informational domains that typically include geographical, meteorological, and

[68] Bharosa, Lee, and Janssen, 51.

[69] Michael K. Lindell, Carla S. Prater, and Walter Gillis Peacock, "Organizational Communication and Decision Making for Hurricane Emergencies," *Natural Hazards Review* 8, no. 3 (August 2007): 50–60, https://doi.org/10.1061/(ASCE)1527-6988(2007)8:3(50).

[70] Lindell, Prater, and Peacock.

environmental factors.[71] A common obstacle encountered in most hurricane responses is the ability to capture accurate information that defines the full scope of an event and maintains a consistent flow of information through feedback on the actions and decisions being made to mitigate an incident. Such feedback is crucial in allowing decision-makers to modify plans to meet the evolving circumstances of a dynamic event.[72]

The transition to the intermediate level can quickly escalate when a hurricane response evolves beyond the capabilities of local jurisdictions and necessitates the involvement of multiple state agencies, as in the case of a large-scale hurricane.[73] At the intermediate level, agencies typically of similar size, capabilities, and resources coordinate a response under the oversight of a designated authority such as a state emergency operations center. A good example of this type of collaboration is through the Emergency Management Assistance Compact (EMAC), a national model used for coordinating the collaboration of various state level agencies for responses to natural and human-made disasters.[74] It originated in 1993 as a result of then-Florida Governor Lawton Chile's criticism of the inadequate response to Hurricane Andrew. The U.S. Congress approved EMAC and made it a public law that now encompasses all 50 states, as well as the U.S. Virgin Islands, Puerto Rico, and the District of Columbia.[75] Under the framework of EMAC, states are permitted to provide assistance to one another before the involvement of FEMA.[76] Although this framework has improved the coordination of state and local agencies, major challenges persist with a state's capacity to acquire the appropriate

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[71] Eleftherios Iakovou and Christos Douligeris, "An Information Management System for the Emergency Management of Hurricane Disasters," *International Journal of Risk Assessment and Management* 2, no. 3–4 (2001): 243–62, https://doi.org/10.1504/IJRAM.2001.001508.

[72] Iakovou and Douligeris.

[73] Naim Kapucu, Maria-Elena Augustin, and Vener Garayev, "Interstate Partnerships in Emergency Management: Emergency Management Assistance Compact in Response to Catastrophic Disasters," *Public Administration Review* 69, no. 2 (March 2009): 297–313, https://doi.org/10.1111/j.1540-6210.2008.01975.x.

[74] Kapucu, Augustin, and Garayev.

[75] Kapucu, Augustin, and Garayev.

[76] Kapucu, Augustin, and Garayev.

resources for collaboration at this level, particularly in the use of technology for effective inter-agency communication.[77]

When the effects of a hurricane overwhelm both local and state resources, federal aid is made available at the request of the state or lead authority of an incident. The involvement of local, state, and federal agencies signifies the reach of macro-level coordination.

2. Structural Collapse

Much like a hurricane, the same efforts of coordination apply to a structural collapse at the micro and intermediate levels. However, the biggest difference is the magnitude and sudden nature of these incidents, thus prompting immediate action at the macro level. Whether a structural collapse is triggered by a human-made event like the attacks on the World Trade Center in New York City on September 11, 2001, or the result of a natural catastrophe, such as the 2010 earthquake that decimated the island of Haiti, these events often provide no notice and make assembling emergency assets for a rapid response extremely difficult. The most unique challenges associated with a structural collapse are the numerous agencies involved at the macro level and the arduous task of conducting a fully comprehensive analysis of the various hazards that exist in this environment.[78]

On average, there are eight different organizations involved in a large structural collapse incident. The criteria for such a response are determined by the type of event and the specific capabilities of each agency selected to engage.[79] The needed responders may include firefighters, law enforcement, emergency medical services, urban search-and-rescue teams, emergency managers, skilled support (e.g., construction or public works), private-sector agencies, and volunteers.[80]

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[77] Kapucu, Augustin, and Garayev.

[78] Henry H. Willis et al., *Protecting Emergency Responders: Personal Protective Equipment Guidelines for Structural Collapse Events*, vol. 4 (Santa Monica, CA: RAND Corporation, 2006), https://www.rand.org/pubs/monographs/MG425.html.

[79] Willis et al.

[80] Willis et al.

A structural collapse of any size and proportion is riddled with complexities that can quickly overwhelm any agency. These incidents present many environmental hazards that can drastically vary from one geographic section to another within the same incident. The area directly involved is commonly referred to as the hot zone and presents the greatest threat to emergency workers.[81] This is where emergency workers require the most protection, as they are task saturated and cannot maintain the appropriate level of awareness while vulnerable to hazards such as falling objects, unstable work surfaces, electricity, and fire.[82]

Another significant challenge involves maintaining accurate information with critical mission sets like victim locations and hazard identification. Vetting information from multiple sources and cross-referencing findings are time consuming, labor-intensive tasks. IoT would be beneficial in combining various sources of information into one information platform with visual references to track vital information as the incident's terrain changes.

3. Wildfires

Wildfires are considered among the worst natural and human-made disasters challenging the United States today.[83] Experts claim that factors including climate change and diminished land management practices have played a major role in these disasters' developing into more complex events that require the collaboration of many different agencies at the macro level. Today, the negative implications of these disasters have reached over a billion dollars in economic damages and claimed the lives of many.[84]

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[81] Willis et al.

[82] Willis et al.

[83] James R. Karels and Monica Corbin, *Wildland Urban Interface: A Look at Issues and Resolutions* (Emmitsburg, MD: U.S. Fire Administration, 2022), https://www.usfa.fema.gov/downloads/pdf/publications/wui-issues-resolutions-report.pdf.

[84] Office of the Chief Economist, U.S. Department of Agriculture., "Notice of Request for Public Comment on the Executive Order on Tackling the Climate Crisis at Home and Abroad," *Federal Register* 86 (March 16, 2021): 14403–4, https://www.federalregister.gov/documents/2021/03/16/2021-05287/notice-of-request-for-public-comment-on-the-executive-order-on-tackling-the-climate-crisis-at-home.

FEMA in conjunction with the U.S. Fire Administration published a report in June 2022 that discusses several challenges existing in modern wildland mitigation practices. One challenge is a need to improve accountability for various firefighting resources, as well as upgrade insufficient real-time fire modeling, in the wildland–urban interface. Such an improvement would advance modern capabilities to better support, integrate, and provide more relevant information that helps keep firefighters informed, accounted for, and safe.[85] In response, the report offers two recommendations. The first is to implement a new generation of support tools to update the antiquated Rothermel model, the current fire decision-making support framework.[86] The report also recommends using existing technology developed by the DOD and the National Institute for Standards and Technology as a more efficient way to upgrade existing technology. Another recommendation discusses the importance of creating standardized protocols for accountability and resource tracking and developing a schedule for inter-agency integration at the micro and intermediate levels of coordination for emergency responses to wildland and structural fire services.[87]

Another challenge addressed is the need for enhanced planning and communication practices from the state, local, territorial, and tribal leadership and federal agencies to inform the public of emergency warnings and evacuations.[88] One recommendation offered in the report mentions the integration of geofence technology, capable of notifying all electronic devices within a specific geographical radius.[89] This technology would be a redundant form of communication, secondary to FEMA's Integrated Public Alert and Warning System.

C. CONCLUSION

The issues discussed in this chapter have highlighted some common themes with challenges in disaster intelligence and analyzed how they are prevalent in three major types

[85] Karels and Corbin, *Wildland Urban Interface*.

[86] Karels and Corbin.

[87] Karels and Corbin.

[88] Karels and Corbin.

[89] Karels and Corbin.

of disasters. Recognizing the gaps that exist in modern practices will create an opportunity to explore how IoT can be utilized to correct or improve certain aspects to enhance the capabilities of emergency disaster response.

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IV. EXPLORING THE POTENTIAL OF WEARABLE IOT TECHNOLOGY

The future of IoT is wearables. The growth of IoT wearable technology has surpassed smartphones, making it the fastest-growing technological innovation to date.[90] Significant advancements in the realm of wearable technology have garnered the attention of consumers, investors, and major manufacturers, putting this technology at the forefront of leading innovations with enormous potential to change the way people interact with the world around them.[91] This chapter focuses on the contemporary uses of wearable IoT in both the commercial and private sectors and explores its feasibility in the application of disaster response.

A. THE INDUSTRY OF WEARABLE IOT

This new iteration of IoT, called the internet of wearable things (IoWT), is evolving and on course to transform modern business practices across several major industries worldwide. IoWT, more commonly referred to as wearables, is the current generation of wearable technology that incorporates the use of body-worn devices augmented with modern ancillary technologies to improve both workforce and lifestyle practices associated with real-time monitoring, remote collaboration, personalized perspectives, and enhanced capabilities.[92] Much like the smartphone changed the way people communicated 20 years ago, it is anticipated that IoWT will have a significant impact on both the sociocultural and technological aspects of people's lives.[93] Compared to today's smartphones and tablets, the benefits of wearables far exceed the technologies to which most people have grown

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[90] Samreen Shaik, "Wearable Tech: Just an Artifice?," TECHx, September 1, 2020, https://techxmedia.com/wearable-technology-just-an-artfice/.

[91] Shaik.

[92] Albert Opher et al., *Leveraging Wearables and the Internet of Things to Disrupt, Transform, and Unlock Value: Predictions on the Future of Wearables and IoT in the Enterprise* (Somers, NY: IBM Corporation, 2017), https://www.ibm.com/downloads/cas/O50QV9NK.

[93] Aleksandr Ometov et al., "A Survey on Wearable Technology: History, State-of-the-Art and Current Challenges," *Computer Networks* 193 (2021): 1–37, https://doi.org/10.1016/j.comnet.2021.108074.

accustomed, with improved monitoring and scanning capabilities, including biofeedback and other sensory physiological analytics.[94]

Historically, wearables have been a solution to challenges in healthcare.[95] Researchers claim that, on average, people are more reactive than proactive in dealing with physical ailments or injuries.[96] Moreover, individuals are more likely to schedule a doctor's visit only after the onset of a sickness or injury. Wearables were first developed to provide continuous health monitoring to predict the onset of a disease or illness. In some cases, these devices automatically alert health care professionals if an issue reaches a critical threshold.[97]

Since their introduction in the healthcare industry, wearables have expanded to seven different categories, with an increasing range of applications and capabilities. These seven categories include head-worn, chest- and neck-worn, arm- and wrist-worn, leg- and ankle-worn, hearables, and most recently smart clothing.[98] As defined by Ometov et al., "the terms wearables, wearable devices, or also wearable technology refer to small electronic and mobile devices, or computers with wireless communications capability that are incorporated into gadgets, accessories, or clothes, which can be worn on the human body, or even invasive versions such as micro-chips or smart tattoos."[99] IoWT uses compact portable electronic devices that are small enough to be integrated into wearable accessories like jewelry and textiles that communicate wirelessly to a network.[100]

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[94] Saad Khan et al., "Biometric Systems Utilising Health Data from Wearable Devices: Applications and Future Challenges in Computer Security," *ACM Computing Surveys* 53, no. 4 (July 2021): 1–29, https://doi.org/10.1145/3400030.

[95] Ometov et al., "A Survey on Wearable Technology."

[96] Ometov et al.

[97] Ometov et al.

[98] Opher et al., *Leveraging Wearables and the Internet of Things*.

[99] Ometov et al., "A Survey on Wearable Technology," 1.

[100] Tony Luczak et al., "State-of-the-Art Review of Athletic Wearable Technology: What 113 Strength and Conditioning Coaches and Athletic Trainers from the USA Said about Technology in Sports," *International Journal of Sports Science & Coaching* 15, no. 1 (2020): 26–40, https://doi.org/10.1177/1747954119885244.

Regarding terminology, this technology is commonly given one of three labels: wearables, wearable devices, or wearable technology. These terms denote accessories that are intended for external use distinct from primary articles of clothing or bodily protection, including smartwatches, wrist bands, smart-glasses, chest straps, and other various clip-ons (see Figure 1).[101]

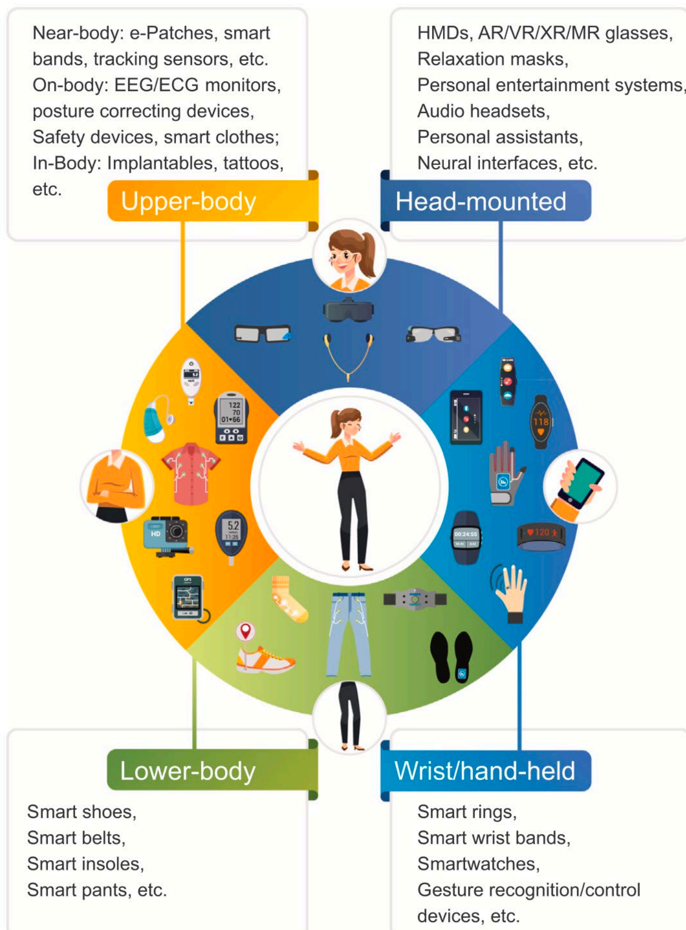

Figure 1. Classification of Wearable Devices Based on Body Location.[102]

[101] Suranga Seneviratne et al., "A Survey of Wearable Devices and Challenges," *IEEE Communications Surveys & Tutorials* 19, no. 4 (2017): 2573–620, https://doi.org/10.1109/COMST.2017.2731979.

[102] Source: Ometov et al., "A Survey on Wearable Technology," 6.

The industry of IoWT has grown exponentially in recent years and experts anticipate that it will continue to grow as the technology advances. A report published by NASDAQ in May 2022 revealed,

> During 2021, shipments of wearables for the full year totaled 533.6 million units, an increase of 20% over 2020, according to the International Data Corporation (IDC). The shipment of wearable devices hovered around 80–85 million units back in 2015. The global wearable technology market size is projected to grow from 116.2 billion in 2021 to 265.4 billion by 2026.[103]

With major manufacturers now noticing an increase in consumer demand, corporations like Apple and Samsung are devoting substantial resources to progressing IoWT, which has inspired many other tech companies to follow their lead. The top five manufacturers of wearable IoT devices as of May 2022 are Apple, Xiaomi, Samsung, Huawei, and Imagine Marketing. All these companies have experienced varying degrees of success, mostly in the form of smartwatches, but as the corporate competition increases, so does the need for innovation. As a result, many companies are branching out to discover the next best IoT wearable device.

1. IoWT for the Consumer

Wearables have been gaining more notoriety among various consumer markets, largely due to the technology's accessibility and affordability.[104] Currently, the most popular personal consumer products consist of conventional platforms relatively accessible to the general public, such as sports trackers, smartwatches, heart-rate monitors, and body-worn cameras. Commonly, people use the combination of an activity tracker and a smartphone, which poses certain limitations. In this current configuration, these devices passively capture a narrow margin of information typically in the form of steps and heart rate that corresponds with a localized short-range communication system called

[103] Prableen Bajpai, "An Overview of the Top 5 Wearable Companies," NASDAQ, May 25, 2022, https://www.nasdaq.com/articles/an-overview-of-the-top-5-wearables-companies.

[104] John W. Cheng and Hitoshi Mitomo, "The Underlying Factors of the Perceived Usefulness of Using Smart Wearable Devices for Disaster Applications," *Telematics and Informatics* 34, no. 2 (May 2017): 528–39, https://doi.org/10.1016/j.tele.2016.09.010.

Bluetooth.[105] Nonetheless, wearables are a remarkable improvement from the previous generations of IoT and are enhancing the users' experience by acquiring and aggregating different forms of data.[106]

Another segment of the consumer market that has widened the commercial appeal of wearables comprises several major companies including Disney and DHL. In 2013, Disney first released its Magic-Band, which allows visitors to have a more personalized experience at any Disney theme park. Disney's Magic-Band is a small wrist-worn wearable used in its theme parks to provide a more enticing experience through seamless access to reservations for transportation and lodging, no wait time at popular theme park attractions, and food delivered anywhere on location.[107] Kuang highlights the benefits of this wearable for Disney and its guests: "Magic Kingdom accommodated 3,000 additional daily guests and reduced the park entry time by 25% during the 2015 holiday season."[108]

The international commercial courier service DHL has also taken steps to incorporate the use of wearables in its business operations. DHL replaced antiquated practices involving paper trails and manual tracking methods with smart-glasses equipped with augmented reality (AR) that display product locations, thereby increasing operational efficiency by 25 percent.[109] Other industry leaders have realized the potential of IoWT and begun implementing applications that enhance an enterprise's activity by streamlining operations and performance.[110] In 2017, IBM reported that more than 75 percent of

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[105] Seneviratne et al., "A Survey of Wearable Devices and Challenges."

[106] Jun Zhou et al., "4S: A Secure and Privacy-Preserving Key Management Scheme for Cloud-Assisted Wireless Body Area Network in m-Healthcare Social Networks," *Information Sciences* 314 (September 2015): 255–76, https://doi.org/10.1016/j.ins.2014.09.003.

[107] Cliff Kuang, "Disney's $1 Billion Bet on a Magical Wristband," *Wired*, March 18, 2015, https://www.wired.com/2015/03/disney-magicband/.

[108] Kuang.

[109] DHL Global, "DHL Supply Chain Makes Smart Glasses."

[110] Opher et al., *Leveraging Wearables and the Internet of Things*.

corporate adopters have attributed improvements in their business performance to the technology.[111]

The combined success of both the commercial and private sector has advanced the concept of IoWT beyond mere fitness trackers. Ometov et al. point out that in addition to the obvious applications, "the upcoming generation of wearables will also involve augmented-, virtual-, mixed-, and enhanced-reality devices, various smart clothes, and industrial wearable equipment."[112]

2. Security and Privacy Concerns

Wearable technology has many benefits that enhance both personal and professional domains, but it also presents new challenges with security and privacy that are uniquely complex and difficult to analyze.[113] Perhaps one of the most significant challenges regarding the security and privacy of wearable devices is the consumer's misconception about the collection and transfer of personal information. Wearable devices are engineered to provide a continuous flow of information with specific criteria that identify one user from another. For instance, certain individualistic behaviors such as walking speed, movement patterns, and stride can all be used as identifiers in data generated by daily activities.[114] Most consumers are not aware of these risks, which raises a major concern for consumer safety. Wearable devices are capable of collecting exorbitant sensitive information, ranging from financial information, to geolocation, to biometric data. As a result, the Federal Trade Commission has dedicated substantial time and resources to investigating various privacy issues associated with wearable technology.[115]

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[111] "Wearables in the Enterprise Are Driving Improved Business Performance," Salesforce, April 22, 2015, https://investor.salesforce.com/press-releases/press-release-details/2015/Wearables-in-the-Enterprise-are-Driving-Improved-Business-Performance/default.aspx.

[112] Ometov et al., "A Survey on Wearable Technology," 2.

[113] Haider Raad, *Fundamentals of IoT and Wearable Technology Design* (Hoboken, NJ: Wiley, 2020), https://doi.org/10.1002/9781119617570.

[114] Seham Abd Elkader, Michael Barlow, and Erandi Lakshika, "Wearable Sensors for Recognizing Individuals Undertaking Daily Activities," in *Proceedings of the 2018 ACM International Symposium on Wearable Computers* (New York: Association for Computing Machinery, 2018), 64–67, https://doi.org/10.1145/3267242.3267245.

[115] Raad, *Fundamentals of IoT and Wearable Technology Design*.

Conversely, Lowens et al. conducted a study involving a survey of 32 test subjects that evaluated their understanding of the security and privacy risks of wearable technology. Even with an adequate understanding of the potential risks, they still did not consider their daily activities to be personal or sensitive information.[116] Moreover, an inadvertent finding from the same study revealed that many of the subjects had a "don't care" or "nothing to hide" mentality when they discussed the privacy risks associated with wearable devices.[117]

3. General Use in Disaster Response

For the past several years, IoT has substantiated its value primarily in the form of smartphones and, in the process, established its relevance in practical applications during disaster response. Smartphones have and continue to be an invaluable tool for ensuring the safety and welfare of countless citizens who are subjected to natural atrocities, such as the 2011 Tōhoku earthquake and tsunami. On record as the fourth largest in history, this earthquake devastated the city of Sendai and triggered a tsunami that crippled the country's infrastructure, leading to the meltdown of three nuclear reactors at the Fukushima Daiichi Nuclear Power Plant.[118] Japanese citizens effected by this crisis resorted to smartphones as an alternate means of receiving and disseminating critical information when traditional forms of emergency communication were ineffective. However, despite the remarkable capabilities of smartphones, some experts now believe that wearables possess features that far exceed the capabilities of the former.[119] Moreover, scholars infer that the two foremost limitations of smartphones are their relatively short battery life and, in a sudden or no-notice event, the ease with which a user can either misplace or lose the device.[120]

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[116] Prerit Datta, Akbar Siami Namin, and Moitrayee Chatterjee, "A Survey of Privacy Concerns in Wearable Devices," in *Proceedings of the 2018 International Conference on Big Data* (Piscataway, NJ: IEEE, 2018), 4549–53, https://doi.org/10.1109/BigData.2018.8622110.

[117] Datta, Namin, and Chatterjee, 4550.

[118] "Mar 11, 2011 CE: Tohoku Earthquake and Tsunami," National Geographic Society, September 27, 2022, https://education.nationalgeographic.org/resource/tohoku-earthquake-and-tsunami.

[119] Cheng and Mitomo, "The Underlying Factors of the Perceived Usefulness."

[120] Cheng and Mitomo.

The inherent features of wearables resolve these issues, thereby making them a logical solution for applications in disaster response. Many scholars agree that wearable technology can improve practices in disaster response. For general consumers, wearables are a viable option for enhancing methods of emergency alerting. For instance, wearable data could be acquisitioned to determine the location and environmental factors of a subject.[121] Wearables fashioned with movement and location sensors have the unique ability to direct a user to the appropriate evacuation route or area of safe refuge. Moreover, these devices could also help locate and reunite friends and family members who are separated during an event.[122] Despite the potential of wearables in disaster response, other experts proclaim that the legitimacy of this technology is contingent on public trust. As such, various governmental and non-governmental organizations (NGOs) hoping to implement wearables in disaster response should prioritize tasks that promote public acceptance and entice consumer interest.[123]

a. Hurricanes

Wearables have enormous potential for public use in the preparation phase of hurricane disaster response. One characteristic that distinguishes hurricanes from any other disaster is experts' ability to forecast and approximate the likely effects of a hurricane. Typically, the progression of a hurricane is identified early, which in most cases allows decision-makers to plan ahead and allocate the appropriate resources to prepare for the onset of the hurricane. However, the inaccuracy of the meteorological prediction models used to identify a storm's trajectory can be problematic, as they can lead to delays in initiating critical actions to safeguard communities. Such was the case in September 2022, when Hurricane Ian created major problems for the southern Atlantic region of the United States. The Category 3 storm system devastated the central part of Florida with high winds and rainfall that triggered a series of immense storm surges. In some instances, the storm surges were recorded as high as 18 feet, which some experts now believe may have been

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[121] Cheng and Mitomo.

[122] Cheng and Mitomo.

[123] Cheng and Mitomo.

responsible for most of the deaths caused by drowning.[124] In all, Hurricane Ian claimed the lives of 119 civilians.[125] Consequently, Florida emergency managers, who were responsible for initiating emergency alerts and the order for public evacuations, faced intense criticism for their delayed decisive actions and failure to notify and safely evacuate the region in a timely manner.[126]

Like so many other hurricane disasters, the decision to evacuate communities can be abrupt due to the unpredictable nature of a hurricane. As a result, the existing methods of emergency alerting can be sudden, causing many to be either ill-informed or completely unaware of how an event is progressing. Wearables have the potential to form another layer of technology to aid traditional channels of emergency communication. Furthermore, the inherent capabilities of wearable devices, such as GPS-enabled location, can be used to provide segments of a community with better directions for emergency evacuations.

b. Structural Collapses

The potential benefits of wearables in structural collapses are similar to those previously mentioned in hurricane disaster response. However, the most notable difference lies in the unpredictability of such events, such as the 2021 Champlain Towers South building collapse in Surfside, Florida. The 12-story residential building was near full occupancy when the south tower collapsed during the early morning hours of June 24. What is now considered the deadliest structural collapse in U.S. history killed 98 people and left only four survivors. More than a year later, new reports have revealed there had been a small window of opportunity to save more lives. A June 2022 *New York Times* article suggested seven minutes elapsed between the time someone first realized there was an issue with the structure and the collapse of the tower and pool deck.[127] Baker and

[124] Greg Allen, "As Ian's Death Toll Rises, Questions Swirl on Why More Floridians Didn't Evacuate," NPR, October 8, 2022, https://www.npr.org/2022/10/08/1127501943/hurricane-ian-florida-delayed-evacuations-lee-county.

[125] Allen.

[126] Allen.

[127] Mike Baker and Patricia Mazzei, "One Button Could Have 'Saved More Lives' in Florida Condo Collapse," *New York Times*, June 23, 2022, https://www.nytimes.com/2022/06/23/us/surfside-condo-collapse-alarm.html.

Mazzei further suggest that despite the on-duty security guard's failed attempts to manually activate an audible premises alarm, many residents were likely never alerted and remained asleep during the event, which may have contributed to the significantly high death toll.[128]

Wearables are an excellent tool for personal alerting. For example, a smartwatch can emit both an auditory and vibrating alert that can be felt whenever activated. These devices can be integrated into a network as location-specific warning devices that not only alert the wearers but can inform others on the network about their location and status.

c. Wildfires

Wearables can also be used to enhance the public's situational awareness during wildfires. Wildfires are spontaneous events that often occur as a result of lightning strikes, unauthorized burning practices, or uncontrolled prescribed land-burning.[129] Nonetheless, these incidents can have disastrous effects on both the environment and surrounding suburban populations. A report published by the Congressional Research Service in October 2022 indicates that in 2021 close to 6,000 structures were destroyed by wildfires in the United States, of which 60 percent were residential structures.[130] In the report, Hoover and Hanson state that some of the most pressing issues facing Congress regarding the threat of wildfires are the "strategies and resources used for wildfire prevention, mitigation, and management of the impact of wildfires on both the quality of life and the economics of communities surrounding wildfire activities."[131] In terms of quality of life, one area gaining notoriety is the harmful impacts of wildfires on air quality. Researchers have recently discovered that, in the past decade, a considerable number of people from all age groups have experienced an unhealthy level of air quality directly attributed to smoke from wildfires.[132]

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[128] Baker and Mazzei.

[129] Katie Hoover and Laura A. Hanson, *Wildfire Statistics*, IF10244 (Washington, DC: Congressional Research Service, 2022), https://sgp.fas.org/crs/misc/IF10244.pdf.

[130] Hoover and Hanson, 2.

[131] Hoover and Hanson, 2.

[132] Mira Rojanasakul, "Wildfire Smoke Is Erasing Progress on Clean Air," *New York Times*, September 22, 2022, https://www.nytimes.com/interactive/2022/09/22/climate/wildfire-smoke-pollution.html.

For almost a year, a team of researchers from Oakland University and the University of Michigan have been exploring ways to better protect communities from air pollution using wearable technology. Backed by federal grant funding, the team has focused its efforts on developing a personalized wearable device in hopes of augmenting future smartwatches to help monitor a person's exposure to harmful pollutants and avoid areas that are too dangerous for inhabitants from such environmental factors as wildfires.[133]

B. IOWT FOR THE EMERGENCY RESPONDER

Emergency responders are often the first ones to arrive at the scene of major incidents to perform lifesaving practices in some of the most challenging environments. These highly skilled professionals, typically comprising law enforcement, firefighters, and emergency medical personnel, encounter an array of hazardous conditions commonly resulting from instances involving the collapsed structures of an earthquake, the devastating flood waters of a hurricane, or the catastrophic impacts of wildfires.[134] Nevertheless, emergency responders operating in these conditions rely on critical information not only to optimize their job performance but also to protect them from the inherent environmental dangers and reduce the likelihood of personal injury.[135]

Operating in a hazardous environment, such as that of a natural disaster, often imposes harsh restrictions that can greatly diminish the efficacy of emergency operations. Thus, such operations require maintaining accurate information that depicts hazardous areas to be avoided by emergency responders or determining the precise location of a citizen in distress.[136] Furthermore, the dynamic nature of these events compels emergency responders to remain vigilant of the constant changes in their surroundings while achieving

[133] "Creating Wearables to Test for Dangerous Pollutants," Michigan State University, College of Engineering, Future Engineers, November 2021, https://www.egr.msu.edu/future-engineer/news/creating-wearables-test-dangerous-pollutants.

[134] Evangelos Katsadouros et al., "Introducing the Architecture of FASTER: A Digital Ecosystem for First Responder Teams," *Information* 13, no. 3 (2022): 1–14, https://doi.org/10.3390/info13030115.

[135] Katsadouros et al.

[136] Katsadouros et al.

difficult operational objectives.[137] Wearables are a promising solution for emergency responders in disaster response. These devices offer unique capabilities that could lessen the burden of peripheral tasks and improve the focus on evolving demands of emergency operations.[138]

A European project called the First Responders Advanced Technologies for Safe and Efficient Emergency Response (FASTER) is attempting to address the aforementioned concerns for emergency responders in disaster response. Through the development and implementation of state-of-the-art technologies, scholars hope to improve current practices in data collection, operational capabilities, and tactical situational awareness.[139] The FASTER architecture is divided into six distinct categories, each one addressing a specific technology that experts believe is advantageous for disaster response. Table 1 depicts the architecture, which recommends critical requirements of operational information and viable solutions using wearables, as well as other relevant emerging technologies.

[137] Zachary O. Toups and Andruid Kerne, "Implicit Coordination in Firefighting Practice: Design Implications for Teaching Fire Emergency Responders," in *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (New York: Association for Computing Machinery, 2007), 707–16, https://doi.org/10.1145/1240624.1240734.

[138] Sultan A. Alharthi et al., "Designing Future Disaster Response Team Wearables from a Grounding in Practice," in *Proceedings of the Technology, Mind, and Society* (New York: Association for Computing Machinery, 2018), 1–6, https://doi.org/10.1145/3183654.3183662.

[139] Katsadouros et al., "Introducing the Architecture of FASTER."

Table 1. First-Responder Communication Gaps and FASTER's Solutions.[140]

A/A	Requirement/Capability Gap	Categories of Tools Used to Meet the Requirement	FASTER Solution/Tool
1	The ability to know the location of responders and their proximity to threats and hazards in real time	Categories 1 (Situational awareness), 2 (Mobile and Wearable Technologies), 6 (Common Operational Picture)	• Augmented Reality (AR) for Operational Support (Category 1), • Mission management and Progress Monitoring (Category 6), • Smart Wearables and Textiles (Category 2), • Portable Control Center (Category 6)
2	The ability to detect, monitor, and analyze passive and active threats and hazards at incident scenes in real time	• Categories 1 (Situational awareness), 2 (Mobile and Wearable Technologies), 3 (Body and Gesture based UI), 4 (Autonomous Vehicles) and 6 (Common Operational Picture)	• Augmented Reality (AR) for Operational Support (Category 1), • Extended Vision Technologies using Commercial Light-Weight UAVs (Category 3), • Animal Wearable for Behavior Recognition (Category 2), • Gesture-based UxV (Category 3), • Robotic Platform (Category 4), • Swarm operational capabilities to allow complex tasks (Category 4), • Portable control center, social media analysis (Category 6)
3	The ability to rapidly identify hazardous agents and contaminants	• Categories 1 (Situational awareness), 2 (Mobile and Wearable Technologies) and 4 (Autonomous Vehicles)	• Augmented Reality (AR) for Operational Support (Category 1), • Smart wearables and textiles (Category 2), • Robotic Platform (Category 4)
4	The ability to incorporate information from multiple and non-traditional sources into incident command operations	• Categories 2 (Mobile and Wearable Technologies), 5 (Resilient Communications Support) and 6 (Common Operational Picture)	• Sensory data fusion (Category 2), • Blockchain distributed network (Distributed Ledger Technology) (Category 5), • Portable control center (Category 6), • Social media analysis (Category 6)
5	The ability to maintain interoperable communications with responders in any environmental conditions	• Categories 1 (Situational awareness), 3 (Body and Gesture based UI), 5 (Resilient Communications Support) and 6 (Common Operational Picture)	• Augmented Reality (AR) for Operational Support (Category 1), • Mission management and Progress Monitoring (Category 6), • Hand gesture recognition for remote FRs communication (Category 3), • Swarm operational capabilities to allow complex tasks (Category 5), • Emergency communication box (Category 5), • 5G-enabled communication infrastructure (Category 5), • Communication mesh through opportunistic relay services (Category 5), • Blockchain distributed network (Distributed Ledger Technology) (Category 5)

[140] Source: Katsadouros et al., 5–6.

Table 1 (continued)

A/A	Requirement/Capability Gap	Categories of Tools Used to Meet the Requirement	FASTER Solution/Tool
6	The ability to obtain critical information remotely about the extent, perimeter, or interior of the incident	• Categories 1 (Situational awareness), 2 (Mobile and Wearable Technologies), 4 (Autonomous Vehicles) and 6 (Common Operational Picture)	• Augmented Reality (AR) for Operational Support (Category 1), • Extended Vision Technologies using Commercial Light-Weight UAVs (Category 1), • Mission management and Progress Monitoring (Category 6), • K9 Behavior Recognition (Category 2), • Wearable Gesture-based UxV (Category 2), • Robotic Platform (Category 4), • Swarm operational capabilities to allow complex tasks (Category 4), • Portable control center (Category 6), • Social media analysis (Category 6)
7	The ability to conduct on-scene operations remotely without endangering responders	• Categories 1 (Situational awareness), 2 (Mobile and Wearable Technologies), 4 (Autonomous Vehicles) and 6 (Common Operational Picture)	• Extended Vision Technologies using Commercial Light-Weight UAVs (Category 1), • Animal Wearable for Behavior Recognition (Category 2), • Wearable Gesture-based UxV (Category 2), • Robotic Platform (Category 4), • Swarm operational capabilities to allow complex tasks (Category 4), • Portable control center (Category 6)
8	The ability to monitor the physiological signs of emergency responders	• Categories 1 (Situational awareness), 2 (Mobile and Wearable Technologies) and 6 (Common Operational Picture)	• Augmented Reality (AR) for Operational Support (Category 1), • Mission management and Progress Monitoring (Category 6), • Smart wearables and textiles (Category 2), • Portable control center (Category 6)
9	The ability to create actionable intelligence based on data and information from multiple sources	• Categories 1 (Situational awareness), 2 (Mobile and Wearable Technologies), 5 (Resilient Communications Support) and 6 (Common Operational Picture)	• Augmented Reality (AR) for Operational Support (Category 1), • Mission management and Progress Monitoring (Category 6), • Sensory data fusion (Category 2), • Blockchain distributed network (Distributed Ledger Technology) (Category 5), • Portable control center (Category 6), • Social media analysis (Category 6)
10	The ability to provide appropriate and advanced personal protective equipment	• Categories 2 (Mobile and Wearable Technologies),	• Smart wearables and textiles (Category 2)

As wearables continue to populate more of the consumer space, it is reasonable to infer that the same would occur across various industries, including disaster response. Both government agencies and NGOs are attracted to this technology for its potential to aid in humanitarian and disaster relief efforts. Furthermore, the same characteristics that appeal to the general consumer have also prompted further studies of wearable technology and its potential applications for the professional agencies working in emergency disaster response.

1. Hurricanes

Hurricanes present many environmental risks that innately threaten the overall safety and personal health of emergency responders.[141] A typical Atlantic hurricane season begins on June 1 and ends November 30, with peak activity usually occurring between the middle of August and late October.[142] During this time, the climate regularly consists of extreme heat accompanied by high humidity. This is a common concern for the emergency responders expected to perform arduous physical tasks while exposed to the elements. These environmental factors make emergency responders highly susceptible to a variety of heat illnesses usually resulting in heat exhaustion and heat stroke.[143] Such heat effects can have significant impacts on the operational efficacy of an emergency response team by reducing manpower, thereby introducing further consequences such as fatigue due to longer work cycles and the increased frequency of complacency at the work site. Moreover, the compounding hazards in the aftermath of a hurricane can present a new host of difficult challenges including physical injury due to falls, slips and trips; exposure to harmful chemicals like carbon monoxide; and the potential outbreak of sickness due to biological hazards such as stagnant flood waters mixing with sewage released from non-operational treatment systems.[144] Thus, it is imperative that certain systems be in place to ensure the protection and safety of emergency responders operating in these conditions.

2. Structural Collapse

Emergency responders are trained and equipped to respond to a variety of emergency situations, perhaps none more dangerous than a collapsed structure. It is common for emergency responders to encounter such situations in various settings, whether the result of a construction accident, fire, earthquake, or weather event such as a

[141] "Guidance for Emergency Responders in USVI and Puerto Rico," Centers for Disease Control and Prevention, September 23, 2018, https://www.cdc.gov/niosh/topics/emres/pr-response.html.

[142] "Hurricanes," Florida Climate Center, accessed December 7, 2022, https://climatecenter.fsu.edu/topics/hurricanes.

[143] Centers for Disease Control and Prevention, "Guidance for Emergency Responders."

[144] Centers for Disease Control and Prevention.

hurricane.[145] Nevertheless, these types of incidents present many challenges, which are similar to the risks mentioned in the previous section. However, some challenges are unique. OSHA's *Structural Collapse Guide* outlines the expectations of emergency responders in these settings: "assisting survivors, extinguishing fires, shutting off utilities, assessing structural instabilities, shoring up safe paths into the structure and assessing other hazards, such as airborne contaminants."[146] A structural collapse often presents hazards that pose immediate dangers to emergency responders, often creating difficulties in effectively managing and ensuring the safety of emergency response teams operating on the scene. Consequently, out of necessity, it is imperative that systems be implemented to efficiently monitor both personnel and resources to ensure safe and effective worksite practices.

3. Wildfires

Wildfires pose a significant threat in many regions of the United States and are responsible for many firefighter fatalities.[147] Wildland firefighting was at one point considered the most hazardous occupation involving natural disasters.[148] As a result, researchers and practitioners have made a concerted effort to ensure the safety of wildland firefighters. One solution incorporates the use of wearables to closely monitor the location and activity of firefighters operating in hazardous environments. These emergency responders encounter similar hazards as those in response to hurricanes and structural collapses, but where these incidents largely differ is in the duration of the emergency responder's exposure to specific hazards like carbon monoxide.[149] McQuerry asserts that "wildland firefighters are continually exposed to smoke while on the job for long durations

[145] "Structural Collapse Guide," Occupational Safety and Health Administration, accessed December 7, 2022, https://www.osha.gov/emergency-preparedness/guides/structural-collapse.

[146] Occupational Safety and Health Administration.

[147] Meredith McQuerry, "Wildland Firefighting and Wearable Technology: A Review," *Journal of Textile Engineering and Fashion Technology* 2, no. 1 (February 2020), https://www.researchgate.net/publication/339447946_Wildland_Firefighting_and_Wearable_Technology_A_Review.

[148] Gregory M. Fayard, "Fatal Work Injuries Involving Natural Disasters, 1992–2006," *Disaster Medicine and Public Health Preparedness* 3, no. 4 (December 2009): 201–9, https://doi.org/10.1097/DMP.0b013e3181b65895.

[149] McQuerry, "Wildland Firefighting and Wearable."

and periods of time."[150] McQuerry's research advocates the integration of wearables to improve current systems for monitoring a firefighter's exposure to carbon monoxide as well as other harmful inhalation hazards like formaldehyde.[151] Moreover, wearables can provide a more convenient means for tracking the location of personnel to improve situational awareness. McQuerry claims that when a firefighter is in need of emergency assistance, wearables can immediately initiate an emergency alert that both locate and direct a rapid response to prevent injury or death.[152]

C. CONCLUSION

Throughout this chapter important details regarding the emergence of IoWT have been highlighted to substantiate evidence that wearables can be beneficial in disaster response, from the perspective of both the consumer and the emergency responders responsible for mitigating the most challenging disasters in the United States today. By examining how this technology can be incorporated in various settings, this author hopes to improve the safety of emergency responders as well as potentially save more lives through better preparation and response.

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[150] McQuerry, 3.

[151] McQuerry.

[152] McQuerry.

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V. CONCLUSION

Wearables are part of a new generation of technology that is transforming business practices and changing lifestyles by accelerating the growth of information and curating new forms of communication. The emergence of wearable technology has appealed to the interests of several major industries, making it one of the fastest-growing technologies to date. Industries like construction, manufacturing, and distribution, the DOD, and public safety have all found meaningful ways to implement this technology and experiment with innovations that are driving this technology forward. This thesis explored how this technology can be applied to improve the existing network architecture of disaster management and emergency response. Wearables are a versatile means for aggregating abundant fields of data from various domains, which makes them a logical solution for improving the conventional methods of disaster response.

Wearable technology has enormous potential in disaster response, but some concerns remain. It is an enticing way to improve measures that safeguard the public through better ways of communicating emergency alerts and enhancing strategies and tactics to optimize the efficacy of emergency responders. Nevertheless, issues such as security and privacy are raising concerns and creating friction among the public regarding the implementation of this new technology. The following sections address these discoveries in more detail and provide an overview of how this novel technology can be applied to improve vital elements of disaster response.

A. FINDINGS

This section discusses the findings of this thesis in four distinct elements: strengths, weaknesses, opportunities, and threats.

1. Strengths of Wearable Technology

Wearables are an intriguing solution for some of the more considerable challenges inhibiting effective disaster response. The same qualities that have had a positive influence in several other industries can be applied likewise to improve ordinary practices in disaster response. A prominent feature distinguishing wearables from the previous generations of IoT is their relation to the end-user. In this context, the user is connected to a physical device that acquires specific information about the subject, such as physiological status and geographical location. Currently, wearables achieve this function primarily through a fixed external accessory, such as a smartwatch or fitness tracker.

The DOD is taking the concept of wearables one step further with the development of a new iteration of wearable technology, referred to as the internet of battlefield things (IoBT) or the internet of military things (IoMT). IoBT or IoMT is creating wearable technology that incorporates various sensors embedded in textiles. As mentioned in Chapter II, using more sensors in different positions on the human body provides better analytics for enhancing human physical performance on the battlefield, improving tracking methods of field activity using edge computing, and refining systems for health monitoring.

The foremost strength of wearables is that they are uniquely capable of maintaining a constant connection with the user, which is vital in disaster response. There are commonalities between what the DOD is trying to achieve in developing IoBT or IoMT and what researchers are advocating with the advancement of wearables in disaster response. Furthering the integration of wearables in disaster response will allow practitioners to have continuous access to more diverse forms of information that will enhance strategic decision-making in myriad ways, thereby improving operational efficacy. One way is by improving the methods of locating and determining patient counts and viability to allocate critical resources properly. Another is enhancing systems for monitoring the physical status of both bystanders and emergency response personnel. Last, such integration provides a better means of tracking the activity of emergency responders to improve situational awareness and observe real-time metrics for refining operational objectives.

2. Weaknesses of Wearable Technology

Contrary to the strengths of wearables, certain limitations persist on account of their relatively novel applications. The following is a list of three prominent issues that have garnered significant attention from scholars and researchers.

a. Limited Battery Life

One of the most significant concerns regarding the limitations of wearables is the inadequacies with battery life. Wearables are designed to be small and unintrusive to entice a user to wear any variation or combination of wearable devices. As a result of their small scale, these wearable devices currently lack a sustainable power source. Typically, a user is required to recharge the device on a regular basis. Charging cycles may fluctuate depending on the frequency of use or the number of applications used simultaneously. In both instances, the duration of battery life can be drastically reduced. Researchers and developers have devised ways to extend battery life by equipping wearable devices with either more power-efficient operating systems or auxiliary power sources, like solar power. However, these problems persist, despite attempts to extend the longevity of battery life.

b. Issues with Sustaining Network Connectivity

Another issue raising concerns about wearables is network connectivity. Wearable technology relies on the access and availability of a network for the transfer of data. The connection is typically established in a single format through Bluetooth, Wi-Fi, or a cellular broadcast service. Such connections present significant concerns, especially in disaster response applications, due to the likely disruption in services by the damage inflicted on critical infrastructure from a hurricane, earthquake, or wildfire, for example. In this scenario, wearable technology is rendered ineffective until services can be restored.

c. Inaccurate Analytics

Despite the recent advancements in wearable technology, there still is a need to refine the accuracy of its analytical capabilities. The wearable devices currently available to the general population typically use a one-dimensional method for acquiring information. A good example is a fitness tracker, which uses the rudimentary measurement of steps as a means for tracking the physical output of an individual, usually calculated in calories. This non-discretionary measurement does not account for external variables like an individual’s exposure to climate or the supplementation of load-bearing activities that can drastically influence variations with measurements.

As previously mentioned, major industries like the DOD are developing ways to address these analytic deficiencies by incorporating mechanisms that use multiple sensors. However, it will be some time before that technology is made available for general use and, more importantly, affordable for the average consumer.

3. Opportunities for Use in Disaster Response

One area where wearables could have the most impact relates to the challenges affecting the transfer of information amid all three levels of inter- and intra-agency coordination. With conventional methods of disaster data analysis ill-equipped to handle the vast collection of information acquired through new technology, such as wearables, a better platform is needed to facilitate an open yet secure exchange of information during multi-agency responses to disasters.

Incorporating wearable technology with cloud computing in the disaster response setting would create more opportunities for agencies acting at the micro, intermediate, and macro levels to have secure access to a shared source of information. This information-sharing would provide the transparency needed to perform essential strategic and operational functions such as adequately managing the allocation of critical and often limited resources, providing the most up-to-date information to safeguard the public, monitoring and directing real-time efforts of emergency responders to optimize effective response strategies, and obtaining immediate feedback for adapting strategies to meet the demands of an evolving incident.

4. Threats of Wearable Technology

Wearables are capable of providing ample, valuable information that, if used correctly, can help decision-makers overcome some of the most difficult challenges encountered in disaster response, but like many new things, wearables lack regulatory oversight, specifically regarding security and privacy. As a result, there are significant concerns over threats affecting consumer privacy with implications for consumer consent and issues with maintaining the integrity of operational security in disaster response.

a. Consumer Privacy

Consumer privacy is one facet of wearable technology that warrants serious consideration from researchers and scholars. Most consumers who possess and routinely use wearable devices are typically unaware of the information collected and its potential use for nefarious purposes. The personal data collected from these devices can range from personal financial information to personal medical information, which—not to diverge—could arguably infringe on federal laws like the Health Insurance Portability and Accountability Act. Nevertheless, the issues involving consumer privacy are significant, and considerable action should be taken to protect the consumer while simultaneously achieving a means to make willfully and lawfully available the information needed to aid the appropriate agencies responsible for providing the various functions of disaster response.

b. Operational Security

Operational security is another major issue concerning wearables and their perceived threats to privacy and security. Wearables are intended to operate as an always-on device and, in doing so, have been attributed to inadvertently collecting sensitive information through their passive capabilities. The DOD has encountered this issue in recent years. For example, in 2018, a popular fitness-tracking web-based application, Strava, produced a report illustrating the daily activities of service members using wearables on various military installations.[153] Military officials, alarmed by this discovery, were fearful of the threats that might compromise the safety of their service members as well as the security of military bases. Consequently, the DOD restricted wearables on military installations until proper security protocols could be implemented.[154] Similar issues apply to disaster response. Emergency responders operating in the vicinity of a disaster, with wearables over an unsecured network, are vulnerable to the same threats as the DOD. Emergency responders are often expected to work in areas where preserving

[153] Jim Garamone, "DoD Studying Implications of Wearable Devices Giving Too Much Info," Department of Defense, January 29, 2018, https://www.defense.gov/News/News-Stories/Article/Article/1426579/dod-studying-implications-of-wearable-devices-giving-too-much-info/.

[154] Garamone.

sensitive information is necessary—not only to minimize the interruptions affecting the continuity of operations but, most importantly, to protect the unintentional disclosure of the victim's identities involved in an event. In July 2022, the National Institute of Standards and Technology's Computer Security Resource Center published a comprehensive report that provides security guidance for the use of wearables by emergency responders. In the report, the authors assert "that mobile devices have advanced greatly over the years and are capable of meeting most of the public safety security objectives . . . [but] wearable devices struggle to meet some of the public safety security objectives."[155]

B. RECOMMENDATIONS

This section puts forth recommendations derived from the research of this thesis to address specific issues outlined in the previous chapters and advocate advancing the application of wearables in disaster response. The following recommendations address the needs of both the general consumer and practitioners working in disaster response to ultimately enhance emergency communications with the public and optimize the safety and operational efficacy of emergency responders.

1. Consumer Wearables as a Supplemental Layer of Emergency Communications

Wearables are a convenient and uniquely effective tool for keeping users informed, thus making them an ideal option for use as a supplemental alerting device in emergency situations. Wearables can be an added layer to existing forms of emergency communication when the ability to notify populations has been reduced or is limited due to uncertain circumstances, as in a hurricane or no-notice situation such as a structural collapse. Either way, wearables, by virtue of their design, are a better means of providing last-minute emergency alerting that is two-fold. First, it can directly assist subjects by guiding them away from a threat by recommending the best route for emergency evacuation or the closest area of safe refuge using geolocation. Second, disaster management can monitor the

[155] Kevin Brady et al., *Security Guidance for First Responder Mobile and Wearable Devices*, NIST IR 8235 (Gaithersburg, MD: National Institute for Standards and Technology, July 2022), 21, https://nvlpubs.nist.gov/nistpubs/ir/2022/NIST.IR.8235.pdf.

response of many populations for better insight to redirect or disburse activity that may overwhelm segments of infrastructure during a mass evacuation. Moreover, wearables can be used in the recovery phase of incidents to help locate and reunite individuals who may have been separated during the course of an event.

2. Wearables for the Emergency Responder

Wearables are a great way to keep emergency responders safe and protect them from the hazards they often encounter in disaster response. These devices can be applied in a manner that facilitates a heightened level of awareness for an individual through continuous physiological monitoring. With wearables, such as smartwatches, emergency responders can be remotely monitored in environments where their physical activity is reaching dangerously high thresholds. Indicators like body temperature and heart rate help to determine more appropriate work cycles to reduce significant injury due to extreme physical fatigue or work site complacency.

Wearables can also improve the safety of emergency responders subjected to unknown hazards. Environments can sometimes present hazards that are undetectable by human senses, such as carbon monoxide—an invisible, odorless, and tasteless gas commonly found in hazardous areas where emergency responders are required to work and, without early detection, can have lethal consequences.[156] Wearables equipped with physiological sensors can detect oxygen saturation levels in the bloodstream and alert individuals when they encounter an oxygen-deficient environment.

Just as the DOD has developed IoBT utilizing a multi-sensor configuration, a similar format would benefit the individual emergency responder to enhance personal safety and protection.

3. Wearables for Multi-agency Collaboration in Disaster Response

Wearables can also be extremely helpful with real-time tracking of emergency responders for improving multi-agency collaboration in disaster response. Providing

[156] "Carbon Monoxide Poisoning: General Information," Centers for Disease Control and Prevention, July 1, 2021, https://www.cdc.gov/co/faqs.htm.

emergency responders with wearables equipped in a configuration using geolocation will provide real-time analytics that can track the location and progress of various agencies attempting to work in unison. In this author's experience as an emergency responder, agencies may intentionally or unintentionally duplicate the efforts of another, thereby creating significant problems with the misappropriation of limited resources or the improper allocation of manpower during time-sensitive events. Having a more transparent means of resource oversight would help alleviate the recurrence of these issues. Wearables offer one way of doing that.

Equipping emergency responders with a configuration of sensors similar to IoBT and assimilating these data in a universal platform accessible to qualified agencies would help deter redundant operations and streamline the unified multi-agency disaster response.

C. FUTURE RESEARCH

During the research for this thesis, the following items stood out as prudent concerns for advancing wearable technology and, thus, should be considered for future research.

1. Hybrid Network for Enhanced Connectivity

Modern wearable technology relies chiefly on a single platform for connectivity. As previously mentioned, wearables require constant connectivity to facilitate the continuous transfer of data. Even under normal circumstances and in fair environmental conditions, this single platform can lose connectivity, thereby rendering the wearable device ineffective. This matter is exacerbated in a disaster when some services are completely unavailable due to environmental factors or damage to infrastructure systems. Moreover, during the recovery phase of a disaster, services are being restored and are typically intermittent and unreliable for prolonged periods following an incident. Nevertheless, relying on a single platform for constant connectivity is problematic and a concerted effort should be made to explore the use of a hybrid network system that encompasses different types of networks with redundancies to ensure constant connectivity.

2. Concerns for Information Security and Personal Privacy

The most significant issues regarding wearables are the concerns over security and personal privacy. As previously discussed, wearables are uniquely equipped to passively capture a wide variety of information that can be used to improve various aspects of people's lives. However, this technology also presents some significant challenges with how information is collected from these devices and then used after it has been aggregated. Some serious questions were beyond the scope of this thesis but are worth exploring in future research:

- How should this information be protected?
- Who should have oversight?
- What should be considered justifiable for allowing access to personal data collected from wearable technology?

3. Dealing with Big Data

Wearables accumulate massive amounts of information that can be used in various ways. This thesis proposed ways it can be applied to aid in disaster management and response. However, one issue that was briefly mentioned in Chapter I and should be considered for further research is the role of big data in wearable technology. The abundance of information captured from wearable technology, termed big data, has created significant challenges with processing information and determining what is useful and what should be disregarded as either incorrect or irrelevant. When considering the role of wearable technology in disaster response and management, the following question should be considered: How can big data be utilized to efficiently and effectively inform decision-based strategies in disaster response?

D. CONCLUSION

This thesis has discussed the emergence of wearable technology and how it can be used to improve essential practices in disaster response. The culmination of this painstaking research has provided good reason for advancing the study and integration of wearable technology as a solution for some of the most difficult challenges encountered in disaster management and response. Moreover, its intent was to attract the interests of practitioners who seek the latest innovations in technology as a way to reform current practices to meet the evolving complexities of today's disasters and achieve the overarching goal of improving the capabilities of our nation's agencies to preserve property and save lives.

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