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IOT IN CRISIS MANAGEMENT

by

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June 2023

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13. ABSTRACT (maximum 200 words)

Emergency management agencies are responsible for developing processes to maintain situational awareness in emergency operations centers (EOCs) to prepare for and respond to disasters. Implementing internet of things (IoT) technologies can revolutionize emergency management and response by providing real-time data, improving communication and coordination, and leading to more efficient and effective emergency responses. IoT can provide signals intelligence to inform situational awareness in EOCs, provided the organization prepares for and uses the technology intentionally and integrates systems from daily processes. Through case studies on smart and novel cities, this thesis evaluates the possibility of using emerging IoT technologies in a crisis to guide local emergency management agencies in predicting emerging threats and maintaining situational awareness and demonstrates how IoT systems used for daily processes can generate signals intelligence. This thesis asserts that cities can use IoT systems to set baseline data readings and machine learning to detect anomalies within the community. Looking ahead, Songdo, South Korea, and NEOM in Saudi Arabia provide examples of how new cities can build a smart foundation around technology while engaging with anticipated residents to meet their needs. This research concludes that as IoT technology evolves, emergency managers must adapt and utilize these advancements to enhance operations and protect communities.

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IOT IN CRISIS MANAGEMENT

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Emergency management agencies are responsible for developing processes to maintain situational awareness in emergency operations centers (EOCs) to prepare for and respond to disasters. Implementing internet of things (IoT) technologies can revolutionize emergency management and response by providing real-time data, improving communication and coordination, and leading to more efficient and effective emergency responses. IoT can provide signals intelligence to inform situational awareness in EOCs, provided the organization prepares for and uses the technology intentionally and integrates systems from daily processes. Through case studies on smart and novel cities, this thesis evaluates the possibility of using emerging IoT technologies in a crisis to guide local emergency management agencies in predicting emerging threats and maintaining situational awareness and demonstrates how IoT systems used for daily processes can generate signals intelligence. This thesis asserts that cities can use IoT systems to set baseline data readings and machine learning to detect anomalies within the community. Looking ahead, Songdo, South Korea, and NEOM in Saudi Arabia provide examples of how new cities can build a smart foundation around technology while engaging with anticipated residents to meet their needs. This research concludes that as IoT technology evolves, emergency managers must adapt and utilize these advancements to enhance operations and protect communities.

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LIST OF ACRONYMS AND ABBREVIATIONS

AI	artificial intelligence
AoT	Array of Things
DAS	Domain Awareness System
D2D	device to device
DHS	Department of Homeland Security
DT	digital twin
EEI	essential element of information
EOC	emergency operations center
FEMA	Federal Emergency Management Agency
ICS	Industrial Control System
IFEZ	Incheon Free Economic Zone
IoT	internet of things
ITU	International Telecommunications Union
LTE	long term evolution
ML	machine learning
NIMS	National Incident Management System
NYPD	New York City Police Department
OODA	observe, orient, decide, act (loop)
SA	situational awareness
SCADA	Supervisory Control and Data Acquisition
SIGINT	signals intelligence
SNA	social network analysis

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EXECUTIVE SUMMARY

The availability of the internet of things (IoT) continues to grow exponentially, including IoT systems used by governmental agencies. The data collected by IoT systems increases with every evolution of connected systems, and emergency management should leverage appropriate data sets to gain and maintain situational awareness.[1] From consumer-grade household appliances to industrial controls and emergency response apparatuses, an increasing number of systems rely on connectivity every day.[2] As devices and systems continuously gain connectivity and consistently "talk" to one another, the emergency management industry has an opportunity to leverage the data. At the First International Workshop on the Internet of Things for Emergency Management (IoT4Emergency 2020), researchers acknowledged "determining the damage and the situation of endangered people following a natural or a humanmade disaster can be effectively handled by reliable IoT systems."[3] Although the intentional deployment of emergency response IoT devices will help response agencies, limited research has explored using consumer-grade IoT or the integration of industrial IoT devices. Internet-connected systems used by public works, utility providers, and other non-traditional responders typically remain separate from emergency operations centers (EOCs) and rely on decentralized access to the systems.[4] The future of emergency management may depend on its ability to adapt to IoT and integrate data-based decision-making to predict and maintain situational awareness during a disaster.

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[1] John Davies and Carolina Fortuna, introduction to *The Internet of Things*, ed. John Davies and Carolina Fortuna (West Sussex, UK: Wiley, 2020), 1.

[2] Emiliano Sisinni et al., "Industrial Internet of Things: Challenges, Opportunities, and Directions," *IEEE Transactions on Industrial Informatics* 14, no. 11 (November 2018): 4725, https://doi.org/10.1109/TII.2018.2852491; Davies and Fortuna, Introduction, 2.

[3] Julie Dugdale, Mahyar T. Moghaddam, and Henry Muccini, "IoT4Emergency: Internet of Things for Emergency Management," *ACM SIGSOFT Software Engineering Notes* 46, no. 1 (January 2021): 33, https://doi.org/10.1145/3437479.3437489.

[4] Jason P. Lappin, "Homeland Security Enterprise and Public Works: Improving the Relationship" (master's thesis, Naval Postgraduate School, 2015), 53, https://www.hsdl.org/?abstract&did=788522.

This thesis assesses whether IoT technologies can help local emergency management agencies predict an emerging threat or maintain comprehensive situational awareness. The first part of the thesis provides a descriptive analysis of emergency management processes and IoT's current and near-future state. This thesis offers scholarly perspectives on the types of systems used by local municipalities that provide real-time, everyday indicators of functionality. The first section closes with an analysis of signal intelligence tools in use by emergency management agencies. The second part of the thesis evaluates three IoT-based systems used by "smart" cities (one international and two American cities) and how emergency managers utilize IoT systems to predict emergencies or maintain situational awareness. This thesis provides a comparative analysis of the emergency management capabilities of each jurisdiction using smart technologies, including IoT systems as signal intelligence. The third part of this thesis compares the newly developed city of Songdo, South Korea, and NEOM, a futuristic city in development in Saudi Arabia.[5] The analysis of NEOM assesses the use of IoT technologies for emergency response in a city without the need to adapt pre-existing built infrastructure.

Implementing IoT technologies can revolutionize emergency management and response by providing real-time data, improving communication and coordination, and leading to more efficient and effective emergency responses. IoT can provide signals intelligence to inform situational awareness in EOCs, provided the organization prepares for and uses the technology intentionally and integrates systems from daily processes. The case studies presented in this thesis demonstrate how IoT systems used for daily processes can facilitate ongoing monitoring and status updates. Cities can use IoT systems to set baseline data readings and machine learning to detect anomalies within the community. The IoT systems can signal a change detected to a human intermediary or automatically initiate an emergency response. Early detection and assessment of a change in the environment can help mitigate the intensity of an emergency by sending emergency responders before the emergency worsens. Finally, IoT sensors deployed in the community

[5] Alshimaa Farag, "The Story of NEOM City: Opportunities and Challenges," in *New Cities and Community Extensions in Egypt and the Middle East: Visions and Challenges*, ed. Sahar Attia, Zeinab Shafik, and Asmaa Ibrahim (Cham, Switzerland: Springer, 2019), 41.

can similarly identify when an affected area has returned to its baseline, allowing the community to return to normal more quickly. While concerns regarding privacy and civil liberties remain prevalent, the case studies also demonstrate a roadmap to mitigate potential risks through the careful documentation of policies and procedures. Looking ahead, Songdo, South Korea, and NEOM in Saudi Arabia provide examples of how new cities can use technology to build a smart foundation while engaging with anticipated residents to meet their needs. As IoT technology evolves, emergency managers must adapt and utilize these advancements to enhance operations and protect communities.

IoT has the potential to revolutionize emergency management by providing real-time data and improving communication, coordination, and decision-making. Using consumer and industrial-grade IoT sensor networks, environmental monitoring, location tracking, and communication networks can help emergency management predict and prepare for disasters. Integrating IoT systems used by various departments within a jurisdiction may allow emergency services to respond rapidly, lessen the overall intensity of events, and provide recognition for a return to normal quickly. Using the available data from a network of IoT systems represents a possible next phase of IoT for cities and government entities. Implementing smart city technologies using IoT may improve the efficiency and effectiveness of city services, infrastructure, and quality of life for residents. IoT-enabled smart cities may provide emergency managers with real-time intelligence about traffic, energy usage, and other factors affecting emergency response, the goal of which is to flatten the intensity curve.

Emergency management maintains a central leadership role in maintaining situational awareness as the facilitators of EOCs, which maintain situational awareness by collecting, processing, and sharing data effectively among response agencies. The following recommendations provide guidance for emergency managers seeking to adopt IoT systems for their jurisdictional partners.

- Emergency management agencies should assess the IoT systems currently used by jurisdictional agencies and evaluate whether those systems serve as sources of information for essential elements of information (EEIs). During the emergency planning processes, agencies should assess EEIs for new systems as technology improves or gets implemented. Emergency management agencies should fully engage with information technology departments to remain aware of systems used daily by agencies.

- Upon cataloging the systems used daily by response agencies, emergency management agencies should integrate processes and systems into citywide emergency planning, training, exercises, and response. The Rio de Janeiro and Songdo models prove that citywide data and system integration can aid in response to an emergency. This integration solution requires frequent training opportunities and dynamic exercise events to educate staff and test the assumption that the right staff will operate the appropriate systems at emergency operation centers.

- Additionally, the emergency management agency staff must familiarize themselves with departmental systems by developing closer relationships with external departmental staff and learning the complexities of each organization better to anticipate barriers to the successful use of each system.

- Finally, training and exercise development must include heavily resourced imagination to test each departmental system in a coordinated fashion. The city departments and partner agencies must participate in training and exercises. This solution could be enhanced by identifying staff from each department as liaisons to develop training and exercises. Only internal knowledge of functions and processes can genuinely inform the development of complex and practical exercises. The city can identify problems and implement solutions with properly tested capabilities before an emergency. Properly tested systems and trained personnel are more likely to succeed during a catastrophic event.

In every case study presented in this thesis, privacy remains a significant concern regarding the type and amount of data government agencies collect. Addressing the privacy challenges requires the engagement of internal and external stakeholders with a supporting communication strategy to affirm that concerns will be met ethically and with integrity. As Chicago's Array of Things and New York's Domain Awareness System have demonstrated, proactively engaging with community members and organizations with documented policies governing IoT systems shows a necessary level of transparency. Ensuring the public remains aware of integrated public data is the first step to mitigating privacy concerns. Additionally, using and demonstrating publicly available data during exercises and special events may prove to the community that the agency will use the data only as described in the policy. In a book on governing technology, Andrew Barry describes how exercises, pilot implementations, and special events provide opportunities for governments to demonstrate the use of technology "otherwise impossible to demonstrate in public by other means."[6] The technological challenges involve the technical connection to systems, vulnerabilities to cyber threats, vulnerabilities to physical disruption, and a need for redundancy. Mitigating the technological challenges requires total organizational commitment, from leadership to the frontline staff, including budgetary and training commitment.

The implementation of IoT technologies has the potential to revolutionize emergency management and response by providing real-time data. By detecting changes in the built environment early, emergency management agencies can initiate emergency response before a situation worsens, potentially mitigating a disaster. While privacy and civil liberty concerns persist, cities can reduce risks by carefully documenting policies and procedures. Future technologies will change how residents and cities interact with their natural or built environments. As IoT technology evolves, emergency managers must adapt and take advantage of these advances to improve operations and safeguard communities.

[6] Andrew Barry, *Political Machines: Governing a Technological Society* (London: Bloomsbury Academic, 2001), 178, https://doi.org/10.5040/9781474213110; Francisca Gromme, "Provocation: Technology, Resistance and Surveillance in Public Space," *Environment and Planning D: Society and Space* 34, no. 6 (2016): 19, https://doi.org/10.1177/0263775816649183.

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I. THE INTERNET OF THINGS IN CRISIS MANAGEMENT

Ping! Your refrigerator just sent you a text. Your refrigerator's temperature is rising above 37 degrees Fahrenheit, and that ricotta cheese you planned to use tonight has reached an unsafe temperature. This is just one example of the internet of things (IoT). In 2012, the International Telecommunication Union defined IoT as "a global infrastructure for the information society, enabling advanced services by interconnecting (physical and virtual) things based on existing and evolving interoperable information and communication technologies."[1] The concept of IoT reached mainstream status more than a decade ago.[2] IoT allows physical devices to communicate with a data center or other internet-connected devices and provide consumers of the data with warnings to take action.[3] This actionable data set provides personal situational awareness but may also help emergency management agencies maintain a common operating picture in a catastrophic disaster. For emergency managers, your refrigerator's temperature or contents mean nothing, but the quantitative data set of your entire neighborhood's power and internet connections to devices could predict or provide valuable context in an emerging situation.

The data collected by IoT systems increase with every evolution of connected systems, and emergency management should leverage appropriate data sets to gain and maintain situational awareness.[4] From consumer-grade household appliances, to industrial controls, to emergency response apparatuses, an increasing number of systems rely on connectivity every day.[5] As devices and systems continuously gain connectivity and

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[1] International Telecommunications Union, *Overview of the Internet of Things*, Recommendation ITU-T Y.2060 (Geneva: International Telecommunications Union, 2012), 2, https://www.itu.int/rec/T-REC-Y.2060-201206-I.

[2] Md Kamruzzaman et al., "A Study of IoT-Based Post-Disaster Management," in *Proceedings of 2017 International Conference on Information Networking* (Piscataway, NJ: IEEE, 2017), 406, https://doi.org/10.1109/ICOIN.2017.7899468.

[3] John Davies and Carolina Fortuna, introduction to *The Internet of Things*, ed. John Davies and Carolina Fortuna (West Sussex, UK: Wiley, 2020), 3.

[4] Davies and Fortuna, 1.

[5] Emiliano Sisinni et al., "Industrial Internet of Things: Challenges, Opportunities, and Directions," *IEEE Transactions on Industrial Informatics* 14, no. 11 (November 2018): 4725, https://doi.org/10.1109/TII.2018.2852491; Davies and Fortuna, Introduction, 2.

consistently “talk” to one another, the emergency management industry has an opportunity to leverage the data. At the First International Workshop on the Internet of Things for Emergency Management (IoT4Emergency 2020), researchers acknowledged that “determining the damage and the situation of endangered people following a natural or a humanmade disaster can be effectively handled by reliable IoT systems.”[6] However, the IoT4Emergency 2020 event focused on IoT devices created specifically for emergency response.

Although the intentional deployment of emergency response IoT devices will help response agencies, limited research has explored using consumer-grade IoT or integrating industrial IoT devices. Even internet-connected systems used by public works, utilities, and parks and recreation typically remain separate from emergency operations centers and rely on decentralized access to the systems.[7] The future of emergency management may depend on its ability to adapt to IoT and integrate data-based decision-making to predict and maintain situational awareness during a disaster. In a prepared statement before the Senate Committee on Commerce, Science, and Transportation, Doug Davis, vice president of Intel’s worldwide IoT Group, provided recommendations for the future of IoT.[8] Davis described the same technologies that have enabled smart cities to inform residents of parking spots, location directions, and street lights as also providing emergency managers with data for better-informed decision-making.[9] With a fully integrated situational awareness system, a local municipality could establish a baseline rhythm of the city to better identify when an anomaly might trigger a broader emergency. Emergency managers can employ the live data feed as indicators of normalcy or anomaly, from rain gauge sensors and connected traffic lights, to a lost connection alert, to connected refrigerators.

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[6] Julie Dugdale, Mahyar T. Moghaddam, and Henry Muccini, “IoT4Emergency: Internet of Things for Emergency Management,” *ACM SIGSOFT Software Engineering Notes* 46, no. 1 (January 2021): 33, https://doi.org/10.1145/3437479.3437489.

[7] Jason P. Lappin, “Homeland Security Enterprise and Public Works: Improving the Relationship” (master’s thesis, Naval Postgraduate School, 2015), 53, https://www.hsdl.org/?abstract&did=788522.

[8] *The Connected World: Examining the Internet of Things: Hearing before the Committee on Commerce, Science, and Transportation, United States Senate*, 114th Cong., 1st sess. (2015), 11, https://www.govinfo.gov/content/pkg/CHRG-114shrg99818/pdf/CHRG-114shrg99818.pdf.

[9] S., 11.

This thesis builds on existing research and emerging technologies to guide local emergency management agencies in integrating IoT to predict emerging threats and maintain situational awareness. Through case studies on smart and novel cities, this thesis evaluates emerging IoT technologies and assesses local jurisdictions' use of IoT systems in a crisis.

A. RESEARCH QUESTION

How might IoT systems help local emergency management agencies predict an emerging threat or maintain comprehensive situational awareness during crisis management?

B. LITERATURE REVIEW

This literature review evaluates the available research on IoT in emergency response. As IoT devices evolve and the prevalence of disasters increases, researchers have postulated that IoT systems could be leveraged to predict an emerging threat and maintain comprehensive situational awareness.[10] The resulting literature often proposes software architectures, including network modeling, devices specific to acute incident response, or the adaptation of industrial IoT systems. This review addresses assessments of modeling IoT software architecture, specifically designed devices for field emergency response, and industrial IoT systems for critical infrastructure systems. This review concludes with literature on the risks of integrating IoT into the overall crisis management system.

1. Existing IoT Devices in Emergency Response

The use of connected devices in emergency response has received wide appraisal and evaluation; however, much of the existing research focuses on the theoretical identification of devices or discipline-specific devices. IoT systems generally consist of sensors or actuators deployed to collect data or detect change within a specific area or function. In a collection of research on IoT systems, Davies and Fortuna describe that the

[10] Dugdale, Moghaddam, and Muccini, "IoT4Emergency," 33; Asta Zelenkauskaite et al., "Interconnectedness of Complex Systems of Internet of Things through Social Network Analysis for Disaster Management," in *Proceedings of the Fourth International Conference on Intelligent Networking and Collaborative Systems* (Piscataway, NJ: IEEE, 2012), 504, https://doi.org/10.1109/iNCoS.2012.25.

data collection and classification from IoT systems provide for "better decisions that improve a behaviour or a process."[11] The increasing sources of data or signals with which to make decisions during emergency responses make a complicated issue challenging to manage. Davies and Fortuna advocate consistent processes to analyze and evaluate multiple IoT data feeds to address situations such as emergency responses. The uniform management and integration of data within the same jurisdiction lead to true interoperability and the existence of an IoT ecosystem.[12]

The available literature provides examples for structuring the integration of data feeds from multiple IoT systems to facilitate decision-making. The Fourth International Conference on Intelligent Networking and Collaborative Systems in 2012 featured a series of studies using social network analysis (SNA) to postulate a structure for layering IoT data systems to handle multiple data streams and integrate sources in disaster management scenarios.[13] Zelenkauskaite et al. focused on SNA to model the relationship between various smart devices and the physical environment. The research lacked evidence from actual incidents but postulated disaster management scenarios that could benefit from multiple IoT devices to inform decision-making. The benefit of an SNA approach is that it provides end users and developers with the parameters to select which systems relate to each other and the physical environment. These studies determined that SNA can assist in determining resource management in the context of hypothetical disaster response scenarios. The studies left the specific systems and device definition to future research.

While additional studies also suggest the layering of systems and devices, most of the literature has focused on specific IoT systems for emergency response designed with a defined or particular function. From building evacuation in a fire emergency to using connected devices to detect and alert for earthquakes, much of the available research

[11] Davies and Fortuna, Introduction, 1.

[12] John Davies and Mike Fisher, "Data Platforms: Interoperability and Insight," in *The Internet of Things*, ed. John Davies and Carolina Fortuna (West Sussex, UK: Wiley, 2020), 38.

[13] Asta Zelenkauskaite et al., "Disaster Management and Profile Modelling of IoT Objects: Conceptual Parameters for Interlinked Objects in Relation to Social Network Analysis," in *Proceedings of the Fourth International Conference on Intelligent Networking and Collaborative Systems* (Piscataway, NJ: IEEE, 2012), 511, https://doi.org/10.1109/iNCoS.2012.26; Zelenkauskaite et al., "Interconnectedness of Complex Systems of Internet of Things," 505.

focuses on specific use cases for emergency response.[14] In a study analyzing building evacuation, Ryu does suggest IoT devices could be integrated into a coordinated emergency response organization to increase response efficacy; however, the IoT devices are evacuation specific and would remain isolated to particular buildings.[15] Similarly, Arbib et al. describe the technical requirements for developing the software platform for an IoT-based building evacuation tool.[16] The findings focus on a single emergency response function in an isolated physical environment. The research remains limited in assessing a comprehensive IoT-based platform that integrates multiple devices and systems to provide situational awareness across a jurisdiction in an emergency. Additionally, the literature does not review the use of IoT systems to predict or anticipate emerging incidents by jurisdictional emergency management authorities.

2. Industrial IoT Systems for Critical Infrastructure

Increasingly, research has identified information sharing between infrastructure agencies and the homeland security enterprise as essential to maintaining situational awareness.[17] The Department of Homeland Security (DHS) describes the Supervisory Control and Data Acquisition (SCADA) system and the Industrial Control System (ICS) as critical tools in information sharing and situational awareness for jurisdictions.[18] This shift has resulted in public and private entities modernizing and connecting their systems to improve access to ICS in real time and create new industrial IoT systems.[19] The

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[14] Chang-Su Ryu, "IoT-Based Intelligent for Fire Emergency Response Systems," *International Journal of Smart Home* 9, no. 3 (2015): 161–68, https://doi.org/10.14257/ijsh.2015.9.3.15; Claudio Arbib et al., "Real-Time Emergency Response through Performant IoT Architectures" (paper presented at the International Conference on Information Systems for Crisis Response and Management, Valencia, Spain, 2019), https://hal.archives-ouvertes.fr/hal-02091586; Richard M. Allen, Qingkai Kong, and Robert Martin-Short, "The MyShake Platform: A Global Vision for Earthquake Early Warning," *Pure and Applied Geophysics* 177, no. 4 (April 2020): 1699–1712, https://doi.org/10.1007/s00024-019-02337-7.

[15] Ryu, "IoT-Based Intelligent for Fire Emergency Response Systems," 161.

[16] Arbib et al., "Real-Time Emergency Response through Performant IoT Architectures," 15.

[17] Lappin, "Homeland Security Enterprise and Public Works," 72–73.

[18] Cybersecurity and Infrastructure Security Agency, *Recommended Practice: Improving Industrial Control System Cybersecurity with Defense-in-Depth Strategies* (Washington, DC: Department of Homeland Security, 2016), 1, https://www.cisa.gov/uscert/sites/default/files/recommended_practices/NCCIC_ICS-CERT_Defense_in_Depth_2016_S508C.pdf.

[19] Cybersecurity and Infrastructure Security Agency, 1.

improved automated IoT technologies for ICS can reduce overhead costs from upkeep and in recognizing failure.[20] Dugdale, Moghaddam, and Muccini describe how "a gas pipeline that reaches a dangerously high pressure can be equipped with an IoT device that detects the problem and informs a remote-control system to address the situation before it reaches the point of an explosion."[21] As the critical infrastructure of industrial IoT systems has improved, the technology has spawned a series of increasingly isolated device systems. The available research acknowledges the limitations of legacy ICS remaining isolated. Sisinni et al. evaluate the challenges and opportunities with industrial IoT and advise industry to "avoid isolated systems based on proprietary solutions and enable data sharing and interoperability among these closed subsystems . . . and the yet-to-come applications."[22] Additionally, Lappin describes the multi-jurisdictional ownership of nationwide infrastructure as an impediment to modernization and progress.[23] Industrial IoT must refrain from adopting closed network systems and remain open to future developments while anticipating the potential security risks to such systems.

3. Risks to Integrating IoT into Crisis Management

The available literature consistently discusses two limitations in integrating IoT into crisis management: processing IoT data and cybersecurity standards. The data-layering concept, as proposed by Zelenkauskaite et al., echoes throughout the available literature.[24] Dugdale, Moghaddam, and Muccini discuss the challenge of "satisfying the real-time requirement" during disaster response.[25] This challenge impacts both performance during the response and the extent to which emergency responders will trust

[20] Hermann Kopetz, *Real-Time Systems* (Boston: Springer, 2011), 311, https://doi.org/10.1007/978-1-4419-8237-7.

[21] Dugdale, Moghaddam, and Muccini, "IoT4Emergency," 34.

[22] Sisinni et al., "Industrial Internet of Things," 4727.

[23] Lappin, "Homeland Security Enterprise and Public Works," 70.

[24] Zelenkauskaite et al., "Interconnectedness of Complex Systems of Internet of Things."

[25] Dugdale, Moghaddam, and Muccini, "IoT4Emergency," 36.

that the system will work when needed. Much of the research in processing data is technical, focusing on computer science, data analytics, and algorithms.[26]

As the use of IoT devices expands in the consumer, industrial, and governmental sectors, concerns over security and privacy have increased. In a 2018 study on the evolution of IoT security, Vorakulpipat et al. describe three generations. The study suggests IoT developers have evolved from fractured and incompatible security to the current processes driven by cloud computing protocols. Vorakulpipat et al. suggest that blockchain and artificial intelligence will drive third and future generations for increased speed and security.[27] The research applies only to device-specific development, and the organizational implementation of IoT devices requires additional research.

In 2014, President Obama's National Security Telecommunications Advisory Committee issued a report on IoT adoption.[28] As a result, DHS deployed "Four Lines of Effort" in its *Strategic Principles for Securing the Internet of Things*. In particular, DHS detailed the following:

- Coordinate across federal departments and agencies to engage with IoT stakeholders and jointly explore ways to mitigate the risks posed by IoT.
- Build awareness of risks associated with IoT across stakeholders.
- Identify and advance incentives for incorporating IoT security.
- Contribute to international standards development processes for IoT.[29]

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[26] Zelenkauskaite et al., "Disaster Management and Profile Modelling of IoT Objects"; Zelenkauskaite et al., "Interconnectedness of Complex Systems of Internet of Things"; Javed Asad et al., "IoTEF: A Federated Edge-Cloud Architecture for Fault-Tolerant IoT Applications," *Journal of Grid Computing* 18, no. 1 (March 2020): 57–80, http://dx.doi.org/10.1007/s10723-019-09498-8; Kamruzzaman et al., "A Study of IoT-Based Post-Disaster Management."

[27] Chalee Vorakulpipat et al., "Recent Challenges, Trends, and Concerns Related to IoT Security: An Evolutionary Study," in *Proceedings of the 20th International Conference on Advanced Communication Technology* (Piscataway, NJ: IEEE, 2018): 406–8, https://doi.org/10.23919/ICACT.2018.8323774.

[28] David Barron, "The President's National Security Telecommunications Advisory Committee," in *Proceedings of the 2006 IEEE Military Communications Conference* (Piscataway, NJ: IEEE, 2006), 1–5, https://doi.org/10.1109/MILCOM.2006.302481.

[29] Department of Homeland Security, *Strategic Principles for Securing the Internet of Things (IoT)*, version 1.0 (Washington, DC: Department of Homeland Security, 2016), 13, https://www.dhs.gov/sites/default/files/publications/Strategic_Principles_for_Securing_the_Internet_of_Things-2016-1115-FINAL_v2-dg11.pdf.

4. Gaps in the Literature: Integrating a Wider Collection of IoT Systems into Emergency Management

The existing literature assesses and evaluates the uses of specific IoT devices in emergency response, highlighting the benefits for the end user receiving or processing the information. Much of the research identifies models to build or develop new IoT devices by layering or stacking data sets for improved information processing. In doing so, the research has largely missed the opportunity to assess the value of diversified IoT systems in the consumer and industrial arenas for broader emergency management. Specific research needs to investigate the use of diversified IoT systems by jurisdictions to manage and maintain situational awareness. Privacy issues and the potential for anticipating impacts on communities deserve special consideration.

C. RESEARCH DESIGN

This thesis assesses whether IoT technologies can help local emergency management agencies predict an emerging threat or maintain comprehensive situational awareness. The first part of the thesis provides a descriptive analysis of emergency management processes and IoT's current and near-future state, including scholarly perspectives on the types of systems used by local municipalities that provide real-time, everyday indicators of functionality. The first section closes with an analysis of signal intelligence tools in use by emergency management agencies.

The second part of the thesis evaluates three IoT-based systems used by "smart" cities (one international and two American cities) and how emergency managers utilize IoT systems to predict emergencies or maintain situational awareness. This thesis provides a comparative analysis of the emergency management capabilities of each jurisdiction using smart technologies, including IoT systems as signal intelligence. A smart city is broadly defined as jurisdictions or communities that utilize information and communication technologies to collect and analyze data from a pre-existing built urban environment to inform decision-making and improve the quality of life.[30] In recent years, many organizations have taken to ranking smart cities. While this thesis does not evaluate smart cities in general, it utilizes a smart city index to select cities for evaluation. The Institute for Management Development and Singapore University for Technology and Design released the *2021 Smart City Index* to analyze 118 cities and "assess the perceptions of residents on issues related to structures and technology applications available."[31] Each city was assigned a rating based on the perceptions of 120 residents in each city. This thesis examines two cities in the United States and one international city from the 2021 *Smart City Index*. These selections took the following metrics into account: 1) overall ranking on the 2021 *Smart City Index* and 2) demonstrated use of a consolidated platform integrating IoT systems.

The third part of this thesis compares the newly developed city, Songdo, South Korea, and NEOM, a futuristic city in development in Saudi Arabia.[32] The analysis of NEOM assesses the use of IoT technologies for emergency response in a city without the need to adapt pre-existing built infrastructure. This thesis results in a comparative analysis of the emergency management capabilities of each jurisdiction using smart technologies, including IoT systems as signals intelligence. The case studies assess the viability of using IoT systems to predict emergencies and maintain situational awareness for emergency management. The case studies identify best practices used by smart cities and NEOM to utilize and sustain IoT systems in emergency response and coordination.

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[30] Jonathan Woetzel et al., *Smart Cities: Digital Solutions for a More Livable Future* (New York: McKinsey Global Institute, 2018), 22, https://www.mckinsey.com/business-functions/operations/our-insights/smart-cities-digital-solutions-for-a-more-livable-future; Emile Mardacany, "Smart Cities Characteristics: Importance of Built Environments Components," in *Proceedings of IET Conference on Future Intelligent Cities* (Piscataway, NJ: IEEE, 2014), 2, https://doi.org/10.1049/ic.2014.0045; Eden Strategy Institute, *Top 50 Smart City Governments* (Singapore: Eden Strategy Institute and ONG & ONG, 2018), 15, https://www.smartcitygovt.com/202021-publication.

[31] Institute for Management Development, *Smart City Index 2021: A Tool for Action—An Instrument for Better Lives for All Citizens* (Lausanne, Switzerland: Institute for Management Development, 2021), 13, https://www.imd.org/smart-city-observatory/home/.

[32] Alshimaa Farag, "The Story of NEOM City: Opportunities and Challenges," in *New Cities and Community Extensions in Egypt and the Middle East: Visions and Challenges*, ed. Sahar Attia, Zeinab Shafik, and Asmaa Ibrahim (Cham, Switzerland: Springer, 2019), 41.

D. CHAPTER OVERVIEW

Following this introduction, Chapter II examines the discipline of emergency management and its role in coordinating a crisis response. The chapter assesses the collection of information to maintain situational awareness in emergency operations centers. Chapter III introduces the rapidly evolving field of IoT. Through an examination of IoT engineering, network connectivity, and machine learning, the chapter evaluates IoT as a source of signals intelligence and a resource for emergency operations centers to maintain situational awareness. Chapter IV presents three case studies on existing cities employing smart technologies to enhance daily operations. The case studies assess the application of IoT systems to emergency and disaster response. The smart systems include Chicago's Array of Things, New York City's Domain Awareness System, and Rio de Janeiro's Center of Operations. Chapter V introduces two additional case studies of novel cities, Songdo, South Korea, and NEOM, Saudi Arabia. The case studies evaluate the application of technologies without the perceived burden of a built environment. Chapter VI provides a summary of findings, recommendations for emergency management agencies, and areas for future research.

II. USE THE FORCE: EMERGENCY AND CRISIS MANAGEMENT

> In a dark place, we find ourselves, and a little more knowledge lights our way.
>
> —Yoda, *Star Wars Episode III: Revenge of the Sith*

The United States faces a consistent threat of disaster, with the nation's emergency responders fighting battles from climate change to civil unrest and from earthquakes to hurricanes. Public safety agencies must remain agile and adaptive to new threats while maintaining the ability to respond to everyday emergencies. In particular, the broad discipline of emergency management has the potential to lead the way in using innovative methods to collect "a little more knowledge to light the way" while responding to emergencies. As a relatively new public safety discipline, emergency management continues to carve out a more relevant role among traditional agencies such as law enforcement and fire suppression by preparing for all hazards, coordinating responses, and facilitating recovery.[33] Instead of tactical units such as police cruisers and fire engines, emergency management leads a comprehensive response representing all jurisdictional agencies and partners.

In most cases, the practical operations of emergency management agencies occur in "agency operations centers, department operations centers, emergency coordination centers, emergency operations centers, joint information centers, joint operations centers, and multi-agency coordination centers."[34] Above all, the emergency operations center (EOC) most commonly serves as the central coordination point for a jurisdictional response to a disaster. The role of emergency management allows for traditional public safety departments to focus on their specialty rather than broader community issues. During an

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[33] Thomas D. Phelan, *Emergency Management and Tactical Response Operations: Bridging the Gap* (Oxford: Elsevier Science & Technology, 2008), 7, ProQuest Ebook Central.

[34] Erik Rau, "Reading from the Same Map: Towards a New Situational Awareness Model for Emergency Management" (master's thesis, Naval Postgraduate School, 2020), 32, https://www.hsdl.org/?abstract&did=839422.

emergency response or a "dark place," the EOC is the coordination point of "knowledge to light the way."

EOCs throughout the United States serve as the central coordination point and management of services during and after an emergency. Although EOC structures and specific procedures may vary, every EOC provides a system for "collecting, analyzing, and sharing information."[35] The EOC system supports decision-making by maintaining comprehensive situational awareness with access to real-time information from systems used by the jurisdiction's departments and partner agencies. In the aftermath of COVID-19, the Federal Emergency Management Agency released an *Emergency Operations Center How-to Quick Reference Guide* that for the first time referenced virtual and hybrid options for EOCs.[36] The guide recommended teleconferencing, computer systems, and interconnectivity as improved situational awareness tools and methods. This guidance provides an opportunity to develop interoperability before, during, and after a crisis by integrating IoT systems in use by various agencies.

A. SCALE AND SCOPE

This section first describes the scale and scope of emergency management with a discussion of the role of emergency management among today's public safety disciplines. This discussion is followed by an explanation of two guiding frameworks: the *National Preparedness Goal* and the National Incident Management System.

1. Role of Emergency Management

In general, the management of emergencies has occurred naturally throughout history, but the concept of a distinct public safety discipline of emergency management developed recently. Although traditional public safety disciplines such as firefighting and law enforcement can trace their histories back to ancient times, emergency management

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35 Federal Emergency Management Agency, *National Incident Management System: Emergency Operations Center How-to Quick Reference Guide* (Washington, DC: Federal Emergency Management Agency, 2022), 3, https://www.fema.gov/sites/default/files/documents/fema_eoc-quick-reference_guide.pdf.

36 Federal Emergency Management Agency, *How-to Quick Reference Guide*.

has no extended lineage. The formation of distinct organizations to manage and coordinate public safety across disciplines in the United States arose from the Cold War and civil defense era in the 1950s.[37] Over the following decades, emergency management responsibility rose from the local and state levels to the federal level. In 1979, Executive Order 12127 officially established the Federal Emergency Management Agency (FEMA). The establishment of FEMA heralded the beginning of a federally coordinated emergency management structure, yet as in doctrine, all emergencies are inherently local. According to the *National Response Framework*, "Incident management begins and ends locally, and most jurisdictions are managed or executed at the closest possible geographical, organizational, and jurisdictional levels."[38] Local and state governments plan for all hazards and manage emergencies. Following *National Incident Management System* (NIMS) guidance, emergency planning, and response requires a comprehensive approach to "all incidents, from traffic accidents to major disasters."[39] The broad spectrum of response areas continues to grow. Like law enforcement and fire response, emergency management agencies continually engage in diverse situations, including planned special events and homelessness. As Haddow, Bullock, and Coppola state in their *Introduction to Emergency Management*, "This supports the premise that emergency management is integral to the security of everyone's daily lives and should be integrated into daily decisions and not just called upon during times of disaster."[40] Engaging emergency management in daily city functions could lead to better, faster responses and mitigate minor incidents from turning into larger emergencies.

[37] George D. Haddow, Jane A. Bullock, and Damon P. Coppola, *Introduction to Emergency Management*, 6th ed. (Amsterdam: Butterworth-Heinemann, 2017), 3.

[38] Department of Homeland Security, *National Response Framework*, 4th ed. (Washington, DC: Department of Homeland Security, 2019), 15, https://www.hsdl.org/?abstract&did=830753.

[39] Federal Emergency Management Agency, *National Incident Management System*, 3rd ed. (Washington, DC: Federal Emergency Management Agency, 2017), 1, https://www.hsdl.org/?abstract&did=804929.

[40] Haddow, Bullock, and Coppola, *Introduction to Emergency Management*, 2.

2. National Preparedness Goal

DHS and FEMA provide guidance, best practices, and leadership to the overall emergency management infrastructure. Primarily, the *National Preparedness Goal* establishes the foundational elements on which most emergency management systems build capabilities. In a broad statement, "the National Preparedness Goal is . . . [a] secure and resilient Nation with the capabilities required across the whole community to prevent, protect against, mitigate, respond to, and recover from the threats and hazards that pose the greatest risk."[41] The goal serves as the aspirational end state and acknowledges the continual development of capabilities. FEMA breaks down the *National Preparedness Goal* into five mission areas: prevention, protection, mitigation, response, and recovery. Within each mission area, core capabilities outline the necessary elements for success. The capabilities do not reflect the entirety of any single agency's responsibilities but rather detail the "combined efforts of the whole community."[42] Although the *National Preparedness Goal* details five mission areas, this thesis focuses on the mission areas of protection and response (see Figure 1).

Figure 1. The National Preparedness Goal.[43]

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[41] Department of Homeland Security, *National Preparedness Goal*, 2nd ed. (Washington, DC: Department of Homeland Security, 2015), 1.

[42] Department of Homeland Security, 3.

[43] Adapted from "National Preparedness Goal: Capabilities and Mission Areas," Federal Emergency Management Agency, accessed January 19, 2023, https://emilms.fema.gov/is_0552/groups/10.html.

The mission area of *protection* aims to provide a base level of preparedness among emergency response agencies. As referenced in the *National Preparedness Goal*, "Protection includes the capabilities to safeguard the homeland against acts of terrorism and manmade or natural disasters. It focuses on actions to protect our people, our vital interests, and our way of life."[44] The associated core capabilities include operational coordination and intelligence and information sharing. To improve and maintain operational coordination, response agencies, including law enforcement, fire rescue, public works, public health, parks and recreation, and other non-traditional responders, must cooperate and collaborate with one another. Operational coordination requires the agencies involved in the protection mission area to "maintain partnership structures among protection elements to support networking, planning, and coordination" to respond to all hazards.[45] Emergency management serves that purpose by assessing the jurisdiction's specific needs and supporting departments and agencies before an incident. Successful operational coordination facilitates the core capability of intelligence and information sharing. By networking all jurisdictional agencies, including non-traditional responders, in the planning and coordination process, emergency management has the knowledge and understanding of the needs and capabilities of each partner agency. Emergency management can "exchange intelligence, information, data, or knowledge among government or private sector entities" by establishing relationships and facilitating connections. Traditionally, emergency management uses the EOC to convene partner agencies for planning and pre-event coordination, yet the EOC relies on personnel rather than pre-established connections to respond to the facility.

While first responders, such as law enforcement and fire, serve as the most visible response to emergencies, the EOC serves as the venue for the complete jurisdiction to respond. Emergency management has a unique capability and responsibility of facilitating operational coordination through the EOC. The mission area of *response* directly indicates the need to "save lives, protect property and the environment, and meet basic human needs

[44] Department of Homeland Security, *National Preparedness Goal*, 8.

[45] Department of Homeland Security, 9.

after an incident."[46] To facilitate response, the core capability of situational assessment provides the required data to make informed decisions. The *National Preparedness Goal* states explicitly that situational assessment must "deliver enhanced information to reinforce ongoing lifesaving and life-sustaining activities" by "engaging governmental, private, and civic sector [s]."[47] Every agency in the EOC has information to inform the situational assessment. Establishing an optimal organizational structure for sharing information and enabling complex decision-making sets the foundation for emergency response.

3. The National Incident Management System

Response systems have developed into standard practices from NIMS, which provides guidance "to prevent, protect, mitigate, respond to, and recover from all hazards."[48] Policies and procedures detail step-by-step processes to help ensure an adequate response. Figure 2 describes the NIMS model for federal support to disasters.[49] When determining the scale and scope of an incident, among other things, NIMS requires data collection and processing. The third edition of NIMS from FEMA states, "Personnel should collect data in a manner that observes standard data collection techniques and definitions, analyze the data, and share it through the appropriate channels."[50] All processes rely on a person to share the correct information with the right partner at the right moment. During an emergency response to everyday or disaster events, having the right person might prove impossible or not happen right away; however, integrating systems and processes into the EOC before an event may improve the speed and quality of information available to decision-makers.

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46 Department of Homeland Security, 12.

47 Department of Homeland Security, 17.

48 Federal Emergency Management Agency, *National Incident Management System*, 1.

49 Federal Emergency Management Agency, 48.

50 Federal Emergency Management Agency, 54.

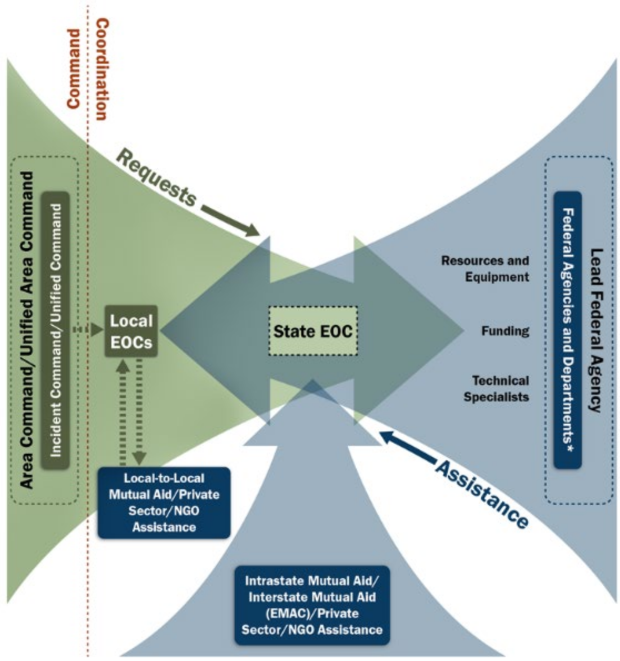

Figure 2. NIMS Model for Federal Support.[51]

B. SITUATIONAL AWARENESS GATHERING

NIMS highlights the importance of gathering timely and relevant incident information because accurate information leads to better situational awareness (SA). Endsley and Jones describe SA as "the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future."[52] In emergency management, the EOC maintains SA by effectively collecting and processing data. Note that SA includes the proper collection of data and the sharing of information among response agencies. FEMA states, "Data collection and processing include the following standard elements: initial size up/rapid assessment, data collection plans, validation, analysis, dissemination, and updating."[53] In EOCs, the data predefined for collection are typically considered essential elements of

[51] Source: Federal Emergency Management Agency, 48.

[52] Mica R. Endsley and Debra G. Jones, *Designing for Situation Awareness: An Approach to User-Centered Design*, 2nd ed. (Boca Raton: CRC Press, 2012), 13, https://doi.org/10.1201/b11371.

[53] Federal Emergency Management Agency, *National Incident Management System*, 55.

information (EEIs). For every organization, EEIs establish the minimum necessary information to assess how well the organization functions.

Generally, emergency management agencies assess EEIs during planning for hazards. One essential feature is that the data collection plan needs to detail the processes responders would take to collect the data after an incident. According to NIMS, "Personnel accomplish data gathering using a wide variety of methods."[54] The data collection in an EOC generally involves using traditional emergency response systems, such as emergency radios, field reports, consulting specialists, and data, including computer-aided dispatch systems, geospatial systems, and crisis information systems. This collection process can prove effective when trained personnel respond to the incident; however, redundant processes should account for the inevitability that trained personnel become scarce resources.

EEIs provide the minimum baseline of information to maintain SA and make informed decisions. For example, in Figure 3, Kruse et al. propose EEIs and potential sources and datasets of information for an earthquake in Monterey, California. Kruse et al. demonstrate that the experts in response and recovery could define the required information to maintain SA (i.e., EEIs) after an earthquake, and multiple remote sensing technologies could effectively inform those requirements.[55] EOC staff use "validated data to determine its implications for incident management and to turn raw data into information that is useful for decision making."[56] EEIs and the predefined data collection processes facilitate the development of SA and ensure the validity of the data. Sources such as the National Weather Service may inform weather forecasts with validity whereas social media reports of inclement weather need verification.

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[54] Federal Emergency Management Agency, 56.

[55] F. Kruse et al., "Multispectral, Hyperspectral, and LiDAR Remote Sensing and Geographic Information Fusion for Improved Earthquake Response," in *Proceedings of SPIE Algorithms and Technologies for Multispectral, Hyperspectral, and Ultraspectral Imagery*, vol. 9088, ed. Miguel Velez-Reyes and Fred A. Kruse (Bellingham, WA: SPIE, 2014), 0K-3, https://doi.org/10.1117/12.2049725.

[56] Federal Emergency Management Agency, *National Incident Management System*, 56.

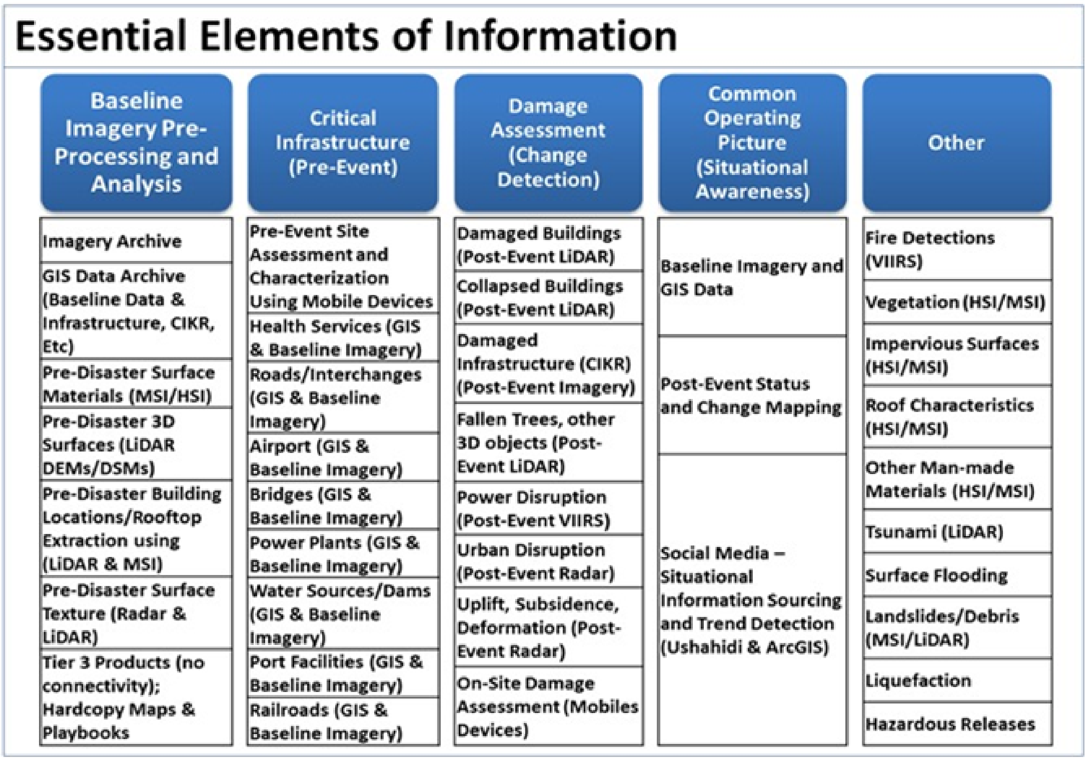

Figure 3. Example EEIs.[57]

By predefining EEIs, an organization can secure the information or data directly from the database or system generating the data. Effective data collection of EEIs establishes an understanding of the evolving situation and provides organizational SA.

C. DECISION-MAKING

In EOCs, decision-making in complex situations remains a difficult task. Maintaining SA through collecting and disseminating essential information demonstrates one of the primary missions of emergency management. As the facilitators of decision-making during crises, emergency management practitioners must continually assess the essential elements of information and determine the appropriate sources. As stated in NIMS, "Standardized sampling and data collection [enable] reliable analysis and [improve]

57 Source: Kruse et al., "Multispectral, Hyperspectral, and LiDAR Remote Sensing," 2.

assessment quality."[58] Effective implementation of the NIMS doctrine creates shared SA. More simply, SA absorbs relevant information at the right time to make decisions.

Scholars employ decision-making models to describe and improve decision-making processes in emergency management. Its study has been the subject of many papers and models.[59] John Boyd's observe, orient, decide, act (OODA) loop presents a well-accepted one for decision-makers, developed from the perspective of a fighter pilot.[60] Figure 4 describes the ongoing OODA loop.[61] In particular, the observe and orient processes relate to the role of the EOC in facilitating the decide and act phases. As described by Révay and Líška, "Observe is the process of acquiring information about the environment by interacting with it, sensing it, or receiving information about it."[62] In EOC processes, the observation phase represents how emergency management personnel collect EEIs. Azuma, Daily, and Furmanski describe orientation as "making judgments of the situation to understand what it means."[63] The orientation phase relates to EOC processes as the sensemaking from the many signals and sources of information. In the *Journal of Emergency Management*, Tanui proposes that OODA implementation not only applies but would "improve emergency response."[64] Tanui emphasizes that "gaining knowledge and intelligence of the operating environment . . . [directly] intersects with Boyd's O-observe and O-orient phases of the OODA loop."[65] Therefore, emergency management must seek ways to enhance the ability to collect information and intelligence to maintain SA and inform effective decision-making.

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58 Federal Emergency Management Agency, *National Incident Management System*, 54.

59 R. Azuma, M. Daily, and C. Furmanski, "A Review of Time Critical Decision Making Models and Human Cognitive Processes," in *Proceedings of the 2006 IEEE Aerospace Conference* (Piscataway, NJ: IEEE, 2006), 1, https://doi.org/10.1109/AERO.2006.1656041.

60 Martin Révay and Miroslav Líška, "OODA Loop in Command & Control Systems," in *Proceedings of the 2017 Communication and Information Technologies* (Piscataway, NJ: IEEE, 2017), 2, https://doi.org/10.23919/KIT.2017.8109463.

61 Révay and Líška, 2.

62 Révay and Líška, 3.

63 Azuma, Daily, and Furmanski, "A Review of Time Critical Decision Making Models," 2.

64 David J. Tanui, "Application of Boyd's OODA Loop to Emergency Response," *Journal of Emergency Management* 19, no. 5 (2021): 461, https://doi.org/10.5055/jem.0564.

65 Tanui, 462.

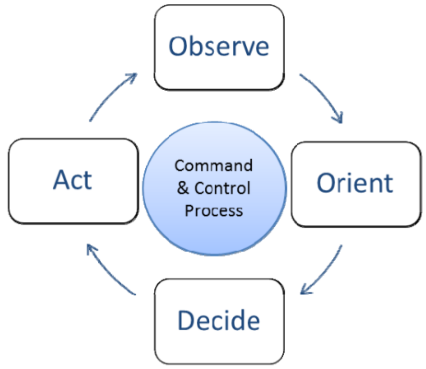

Figure 4. John Boyd's OODA Loop.[66]

D. CONCLUSION

Adhering to NIMS guidance to meet the *National Preparedness Goal*, agencies active in response, including non-traditional responders, follow processes for SA that require specialized access and skill sets; however, interconnected systems provide real-time monitoring and status to departments daily. In many jurisdictions, the gap in maintaining SA to facilitate executive decision-making lies with the availability of personnel to interpret departmental systems and disseminate the information. By automating access to the information or data and establishing processes to analyze the information quickly, emergency management may bridge the gap and improve decision-making in the EOC. As shown in Figure 5, the simulated response bell curve is established through the collection of EEIs. When the community signals an emergency through methods such as 9-1-1 calls, public safety agencies respond accordingly. As mitigation and response efforts intensify, the emergency or disaster reaches its peak and eventually subsides, allowing the jurisdiction to return to its normal state. Emergency management may find a solution by exploring a technology category available to communities nationwide—IoT.

[66] Source: Révay and Líška, "OODA Loop in Command & Control Systems," 2.

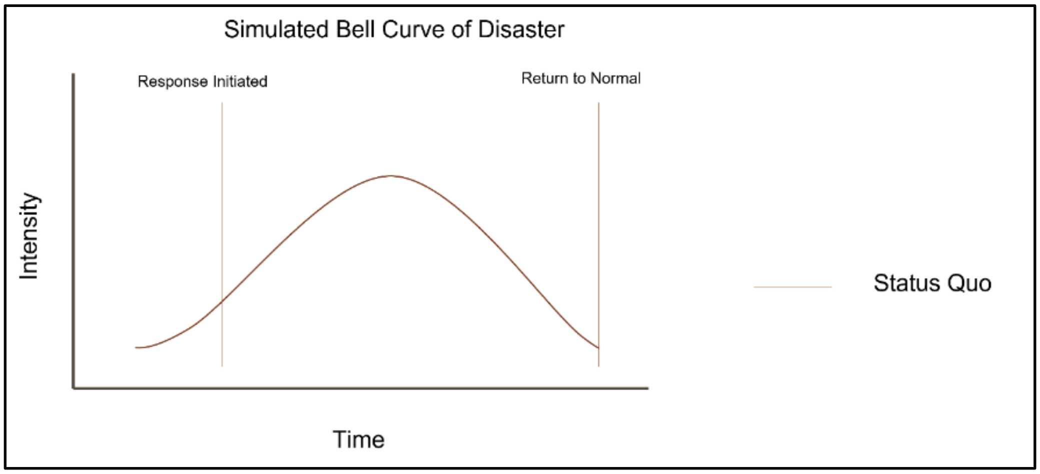

Figure 5. A Simulated Bell Curve of a Disaster.[67]

[67] Adapted from Department of Homeland Security, *National Disaster Recovery Framework*, 2nd ed. (Washington, DC: Department of Homeland Security, 2016), 5, https://www.fema.gov/sites/default/files/2020-06/national_disaster_recovery_framework_2nd.pdf, with help from data analyst Cristian Ramirez at the Center for Homeland Defense and Security's Strategic Communications.

III. A NEW HOPE: THE INTERNET OF THINGS

> This is the weapon of a Jedi Knight. Not as clumsy or random as a blaster; an elegant weapon for a more civilized age.
>
> —Obi-Wan Kenobi, *Star Wars Episode IV: A New Hope*

Emergency management has the national and local mandate to maintain SA to support first responders but lacks automated integration into data and information processes. In this context, this chapter demonstrates the promise of IoT in providing real-time data and improving SA. IoT represents a tool or "weapon" emergency managers can use to improve and maintain SA in EOCs. With the variety of environments and applications of IoT, the possibilities extend to potentially endless situations for emergency management to utilize a ubiquitous technology to improve and maintain SA.

This chapter examines the world of IoT and its possible application to emergency management. This chapter categorizes IoT devices by describing consumer and industrial-grade IoT technologies and examines the networking possibilities, including available and emerging networks. The chapter analyzes IoT as signals intelligence and its applications to emergency management. Finally, the chapter examines advanced IoT technologies, including machine learning and edge computing.

A. EMERGING TECHNOLOGY

The world has become a more connected and integrated series of systems. From social media to virtual personal assistants, streetlights to refrigerators, potentially everything connects to the internet. Sensors monitored by cloud computing services turn on and manipulate other devices and switches embedded in the physical world. Since 2012, the International Telecommunications Union (ITU) has defined IoT as "a global infrastructure for the information society, enabling advanced services by interconnecting (physical and virtual) things based on existing and evolving interoperable information and communication technologies."[68] That broad definition of IoT leads to a similarly broad

[68] International Telecommunications Union, *Overview of the Internet of Things*, 2.

inclusion of devices and systems; however, most researchers agree that IoT will change how people interact with their physical environments.[69] Similarly, emergency management can modernize EOCs by utilizing IoT to improve and maintain SA.

Seemingly every day, new IoT devices and systems come online and connect. In the past, humanity needed to take action, but IoT has changed how people experience the world and receive information through a diverse ecosystem of interconnected devices. In an oft-cited figure, Bradley, Barbier, and Handler estimated in 2013 that 10 billion IoT devices were available on the consumer market, with approximately 50 billion expected by 2020.[70] The staggering expansion of data sources will likely continue through new IoT technologies and integration development. Manyika et al. found that combining IoT devices and systems provide enhanced benefits to organizations: "Interoperability would significantly improve performance by combining sensor data from different machines and systems to provide decision-makers with an integrated view of performance."[71] As the availability of IoT devices and systems expands, the availability of usable information and data will increase. As Davies and Fortuna describe, "Richer information can be collected and used by automated systems to provide actionable insight and to respond to changing contexts with appropriate intelligent actions."[72] The range of IoT devices and the data collected vary widely, and many industries have already seen the impact of connected systems.[73] Manyika et al. describe nine "environments such as homes, offices, factories, worksites (mining, oil and gas, and construction), retail environments, cities, vehicles, and the outdoors."

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[69] James Manyika et al., *The Internet of Things: Mapping the Value beyond the Hype* (San Francisco: McKinsey Global Institute, 2015), 1; Luigi Atzori, Antonio Iera, and Giacomo Morabito, "Understanding the Internet of Things: Definition, Potentials, and Societal Role of a Fast Evolving Paradigm," *Ad Hoc Networks* 56 (2017): 122, https://doi.org/10.1016/j.adhoc.2016.12.004; Shin Dong-Hee and Yong Jin Park, "Understanding the Internet of Things Ecosystem: Multi-Level Analysis of Users, Society, and Ecology," *Digital Policy, Regulation and Governance* 19, no. 1 (2017): 77, https://doi.org/10.1108/DPRG-07-2016-0035; Mohsen Attaran, "The Internet of Things: Limitless Opportunities for Business and Society," *Journal of Strategic Innovation and Sustainability* 12, no. 1 (March 2017): 18.

[70] Joseph Bradley, Joel Barbier, and Doug Handler, *Embracing the Internet of Everything to Capture Your Share of $14.4 Trillion* (San Jose: Cisco, 2013), 2.

[71] Manyika et al., *Mapping the Value beyond the Hype*, 24.

[72] Davies and Fortuna, Introduction, 1.

[73] Attaran, "The Internet of Things," 13.

As the availability of IoT devices has expanded in recent years, the number of consumer-grade IoT devices has grown significantly. Consumer-grade IoT refers to using IoT technology in everyday devices and appliances that individuals use in their homes and workplaces and on the go.[74] These devices include smart speakers, thermostats, security cameras, and fitness trackers. The consumer-grade IoT device provides information to a user with the intention of the user taking action. For example, a smart thermostat may signal to a homeowner via a smartphone app that the temperature has reached a predefined threshold. From anywhere, the homeowner can then raise or lower the temperature accordingly. The smart thermostat can learn the user's temperature preferences over time, automatically adjusting the temperature to one's liking. Conversely, if returning home from vacation, the homeowner could signal the thermostat and set a temperature for arrival, providing convenience and saving energy costs.[75] Consumer-grade IoT devices empower individuals to monitor sensing devices and make adjustments remotely.

1. Consumer Grade

Advancements in interconnected systems enable consumers to control devices at home and work remotely. In general, the consumer-grade IoT device senses a change in the environment and sends a signal to a user, a process known as device-to-user.[76] Users primarily control consumer-grade IoT devices through smartphones or web portals, such as smart home devices, wearables, and other connected devices. Consumer-grade IoT devices provide convenience, energy savings, and valuable perceptions in users' daily lives. Davies and Fortuna have observed that "IoT has a unique potential for automating and improving human-made systems and behaviours by enabling unprecedented understanding and insight."[77] As the technology continues to evolve, consumers can expect to see even more consumer-grade IoT devices on the market, offering even more ways to make their lives easier and more connected. Consumer-grade IoT represents single

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[74] Manyika et al., *Mapping the Value beyond the Hype*, 18.

[75] Manyika et al., 53.

[76] Sisinni et al., "Industrial Internet of Things," 4725.

[77] Davies and Fortuna, Introduction, 1.

devices or systems that provide information to the end user whereas industrial IoT refers to device-to-machine and control systems or machine-to-machine interfaces, which significantly expand the network of interconnected devices.[78]

2. Industrial Grade

Industrial-grade IoT refers to using IoT technology in industrial settings, wherein the devices and sensors often connect to an ICS and monitor and control industrial processes. For example, in a manufacturing plant, sensors can monitor the temperature and humidity of the production environment, and cameras track the movement of products on the assembly line.[79] This information can optimize production, improve efficiency, and reduce downtime. IoT can make a significant impact on safety in the workplace. By connecting sensors and cameras to industrial control systems, businesses and organizations can monitor a facility and detect potential hazards such as flooding, gas leaks, or fires to improve safety and reduce the risk of accidents. Likewise, industrial IoT can facilitate management at an emergency scene. Equipping industrial equipment and vehicles with GPS trackers and radio frequency identification tags makes it possible to track the location and condition of these assets in real time.[80] In a post-disaster scenario, the real-time tracking of vehicles and equipment could signal passable roadways and the location of staff in potentially hazardous pathways. This information can optimize logistics, improve the efficiency of the production process, and reduce the risk of equipment being lost or stolen.

Industrial-grade IoT may improve industrial processes by providing real-time data and improving efficiency and safety. By enabling direct connections between devices and sensors with control systems, industrial-grade IoT can monitor and adjust processes as necessary. With asset tracking and safety monitoring, industrial-grade IoT can help reduce downtime, improve the efficiency of the production process, and ultimately save resources. In contrast to consumer-grade IoT, which primarily focuses on user-device interaction, industrial-grade IoT expands the sensing device network, thus increasing the volume of

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[78] Sisinni et al., "Industrial Internet of Things," 4725.

[79] Sisinni et al., 4725.

[80] Atzori, Iera, and Morabito, "Understanding the Internet of Things," 9.

available data. Emergency management could utilize these sources of information provided the IoT systems remain connected via networks.

B. IOT NETWORK CONNECTIVITY

Consumer- and industrial-grade IoT systems rely on networking to communicate, transmit data, and interact with other devices. IoT networking refers to the various methods and technologies used to connect IoT devices to the internet and other devices.[81] The connectivity options available for IoT devices are diverse, and the choice of which one to use depends on the application's requirements and the device. The ITU expanded its definition of IoT in 2014 by issuing a recommendation with standard requirements for IoT systems but stopped short of requiring networking specifications.[82] The lack of definition may have served IoT's evolution by enabling more independent development and increasing network connections. As noted by Putland, "A range of technology and networking options are available to meet particular requirements" for the continuously growing IoT solutions, and "each option has different characteristics with respect to cost, quality, reliability, power, range, and the volume of data for which it is designed."[83] As Militano et al. point out, "IoT is populated by highly heterogeneous objects, each one providing specific functions accessible through its own dialect and network."[84] With a diverse set of devices and an equally diverse methodology to connect them, many may express concern over the availability of technologies to connect IoT devices. Fortunately, the availability of network connections alleviates the concern to an extent. Figure 6 depicts common network pathways available in cities, illustrating how communication networks, from cellular networks to Wi-Fi signals, have become ubiquitous.

[81] Sisinni et al., "Industrial Internet of Things," 4725.

[82] International Telecommunications Union, *Common Requirements of the Internet of Things*, Recommendation ITU-T Y.2066 (Geneva: International Telecommunications Union, 2014), 9, https://www.itu.int/rec/T-REC-Y.2066-201406-I/en.

[83] Paul Putland, "Connecting Devices: Access Networks," in *The Internet of Things*, ed. John Davies and Carolina Fortuna (West Sussex, UK: Wiley, 2020), 9, 18.

[84] Leonardo Militano et al., "Device-to-Device Communications for 5G Internet of Things," *EAI Endorsed Transactions on Internet of Things* 1, no. 1 (2015): 5, https://doi.org/10.4108/eai.26-10-2015.150598.

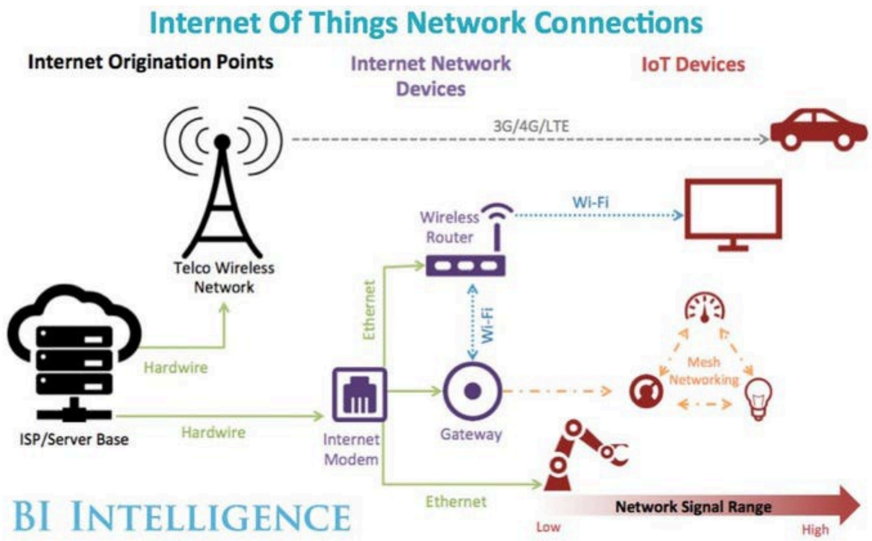

Figure 6. Common IoT Network Connections.[85]

Several networking systems operate universally in most metropolitan areas among the existing technologies. Bluetooth or cabled ethernet networks meet IoT device needs over short distances.[86] Devices such as smartwatches and personal assistants use these "short range networks with a radius of a few meters."[87] Bluetooth-connected devices usually require low-power, high-bandwidth data transfer capabilities that control smart home devices or send simple commands between devices. Wi-Fi-connected devices require high-bandwidth data transfer over longer distances, for streaming video or sending large amounts of data, for example.[88] Cellular networks, including the ubiquitous long term evolution (LTE) and the new 5G, provide the best networking connection to accommodate data transmission over longer distances in remote or mobile instances.[89] Using the

[85] Source: Jonathan Camhi, "How Different Networking Standards Are Competing to Connect the Internet of Things," Business Insider, March 1, 2015, https://www.businessinsider.com/iot-networks-report-2015-11.

[86] Militano et al., "Device-to-Device Communications for 5G Internet of Things," 3–4.

[87] Atzori, Iera, and Morabito, "Understanding the Internet of Things," 132.

[88] Neeraj Kumar and Aisha Makkar, *Machine Learning in Cognitive IoT* (Boca Raton: CRC Press, 2020), 18, https://doi.org/10.1201/9780429342615.

[89] Putland, "Connecting Devices: Access Networks," 10.

emerging 5G network, IoT enters the next generation enabling more device-to-device (D2D) communications. As Militano et al. describe, "D2D communications refers to the paradigm where devices communicate directly with each other without routing the data paths through a network infrastructure."[90] The advancement of D2D in 5G environments can meet the demands of IoT ecosystems, addressing the cost, quality, reliability, power, range, and volume of data.

The literature describes IoT architecture with layers corresponding to different functionalities and responsibilities. In simplified terms, the layers include the device, connectivity, data management, and application.[91] Each layer has its specific function; the device layer is responsible for collecting the data, the network layer for communication, the data management layer for data storage and processing, and the application layer for the user interface and the applications. The example in Figure 7 features a layered IoT structure. By organizing the devices into these layers, the system can scale more efficiently since each layer can operate independently without affecting the functioning of other layers. For example, adding a new sensor to the device layer does not impact the networking or application layers' functioning as long as the sensor correctly processes and transmits the data. This distributed architecture also keeps data processing and analysis close to its source, reducing latency and improving response times.[92] This hierarchical structure allows for a modular approach to developing and deploying IoT systems, which can help improve scalability, security, and efficiency.

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[90] Militano et al., "Device-to-Device Communications for 5G Internet of Things," 2.

[91] Davies and Fortuna, Introduction, 3–4; Akil Ramesh, S. Rajkumar, and L. M. Jenila Livingston, "Disaster Management in Smart Cities Using IoT and Big Data," *Journal of Physics: Conference Series* 1716, no. 1 (December 2020): 2, https://doi.org/10.1088/1742-6596/1716/1/012060; International Telecommunications Union, *Overview of the Internet of Things*, 7.

[92] Davies and Fortuna, Introduction, 5.

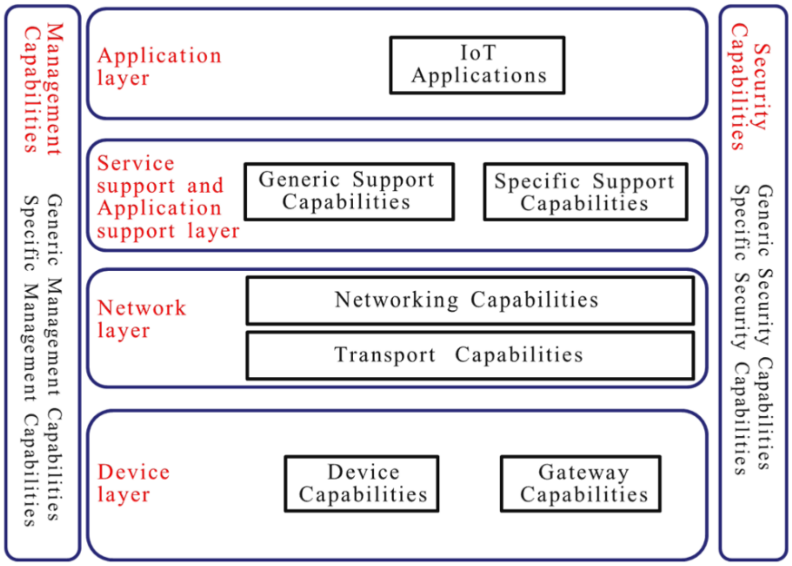

Figure 7. Example IoT Layered Architecture.[93]

C. IOT IN EMERGENCY RESPONSE

The following section examines possible use cases of IoT in emergency response. Although references to specific devices are helpful, this section focuses on the broader perspective of IoT uses for large organizations such as cities. As discussed in Chapter II, SA represents a primary emergency management function as prescribed by the *National Preparedness Goal* and *National Incident Management System*. The following subsections examine frameworks and concepts that formulate SA and how IoT fits within each, including the OODA loop and signals intelligence.[94]

1. OODA Loop

The OODA loop decision-making framework relies on the collection of pertinent data. IoT aids SA by providing real-time data to feed into the OODA loop through connected remote devices and sensors. The wealth of data gathered by IoT devices and systems applies to the OODA loop's decision-making process in the observe and orient

93 Source: International Telecommunications Union, *Overview of the Internet of Things*, 7.

94 John Boyd's OODA loop for decision making is described in Chapter II.

phases. Crane and Peeke extol the potential benefits of IoT devices as a source of signals intelligence for military units.[95] Specifically, knowing "the location and patterns of life . . . increase [s] the protection of the Warfighter, as well as reduce [s] the risk of civilian casualties."[96] While addressing the use of IoT by military personnel in dense urban environments, Crane and Peeke's argument parallels the domestic first responder's and emergency management's crisis response roles. Ray, Mukherjee, and Shu substantiate the possible role of IoT and discuss a series of disaster scenarios, including the most likely architectures needed to provide effective SA.[97] Advancing through the OODA loop, the collection of increasing amounts of data provides opportunities in the decide and act phases. Applying machine learning and artificial intelligence could improve the decide and act phases "to filter and make sense of all the data."[98] By quickly analyzing data, machine learning could provide alerts to changing conditions and possibly adapt to the activation of other devices according to user parameters. Throughout the OODA loop, the available IoT infrastructure in cities has a principal role in gaining and maintaining SA before, during, and after an emergency.

IoT influences SA during each of the OODA loop stages. In the observe stage, IoT devices can collect data from the environment in real time by monitoring critical infrastructure, weather conditions, and the movements of people and vehicles, providing emergency managers with a complete picture of the area.[99] In particular, monitoring weather conditions, air and water quality, and other environmental factors can affect emergency response by predicting natural disasters like hurricanes and floods. In the orient stage, data analytics platforms and technologies—such as machine learning and artificial

[95] Alfred C. Crane and Richard Peeke, "Using the Internet of Things to Gain and Maintain Situational Awareness in Dense Urban Environments and Megacities," *Military Intelligence Professional Bulletin* 42, no. 3 (2016): 42.

[96] Crane and Peeke, 42.

[97] Partha Pratim Ray, Mithun Mukherjee, and Lei Shu, "Internet of Things for Disaster Management: State-of-the-Art and Prospects," *IEEE Access* 5 (2017): 18824, https://doi.org/10.1109/ACCESS.2017.2752174.

[98] Crane and Peeke, "Using the Internet of Things to Gain and Maintain Situational Awareness," 42.

[99] L. Yang, S. H. Yang, and L. Plotnick, "How the Internet of Things Technology Enhances Emergency Response Operations," *Technological Forecasting & Social Change* 80, no. 9 (2013): 33, https://doi.org/10.1016/j.techfore.2012.07.011.

intelligence—can identify patterns, trends, and relationships in the data that may be relevant, providing emergency managers with better SA, including anomaly detection and alerts.[100] In the decide stage, IoT data can predict the likelihood of a natural disaster and determine the best course of action to minimize the disaster's impact. Ray, Mukherjee, and Shu offer IoT systems and structures for potential earthquake prediction and alerting, whereby a measurement that exceeds the defined threshold triggers the system to alert people in the area to the danger.[101] In the act stage, IoT systems can trigger devices remotely. Everyday IoT systems control traffic lights, change the temperature in buildings, or adjust the valves in SCADA systems based on signals from other sensors. The automation of basic operations and the confirmation of change alleviate human operators and allow for the reprioritization of tasks, especially during an emergency with limited resources.

IoT replicates the OODA loop in providing real-time data and improving communication, coordination, and response times. By connecting devices and sensors to the EOC via internet connections, IoT can provide signals intelligence and automation to improve the decision-making process of the OODA loop. Emergency managers can use IoT as signals intelligence to move through the loop, gaining an advantage by responding more quickly and effectively to environmental changes.

2. IoT AS SIGNALS INTELLIGENCE

Signals intelligence (SIGINT) traditionally refers to gathering and analyzing electronic signals, such as communications and radar emissions, to assemble information and intelligence.[102] Although the conventional definition of SIGINT conveys a covert collection of data on foreign adversaries' capabilities, intentions, and activities to support military operations, IoT represents an emerging opportunity to consider cyber-physical

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[100] Ray, Mukherjee, and Shu, "Internet of Things for Disaster Management," 18832.

[101] Ray, Mukherjee, and Shu, 18828.

[102] "Signals Intelligence (SIGINT) Overview," National Security Agency, accessed January 16, 2023, https://www.nsa.gov/Signals-Intelligence/Overview/.

systems as a source of domestic SIGINT to protect the homeland. In Executive Order 14086, President Biden details the purpose of SIGINT:

> The United States collects signals intelligence so that its national security decisionmakers have access to the timely, accurate, and insightful information necessary to advance the national security interests of the United States and to protect its citizens and the citizens of its allies and partners from harm. Signals intelligence capabilities are a major reason we have been able to adapt to a dynamic and challenging security environment, and the United States must preserve and continue to develop robust and technologically advanced signals intelligence capabilities to protect our security and that of our allies and partners.[103]

In the same way the Intelligence Community analyzes foreign SIGINT, emergency management analysts can process and analyze the data to extract valuable information from IoT devices and systems distributed throughout local communities. The analysis includes filtering, decoding, and decrypting the signals and using various analytical tools and techniques, such as signal processing, data mining, and machine learning. In considering IoT systems as SIGINT, the executive order outlines specific "legitimate objectives" and "privacy and civil liberties safeguards" to guide the Intelligence Community and domestic emergency management.[104] The resulting data provide opportunities to identify threats and maintain SA to protect residents. SIGINT sources could come from every IoT-based sensor in the community including devices in use by jurisdictions.

D. ADVANCED IOT

Although IoT has reached ubiquity with an estimated 50 million devices, advancements in supporting technologies continue to progress. The following section examines a few supporting technologies that enable IoT ecosystems as a remote sensing source of SIGINT, including machine learning and edge computing.

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[103] Exec. Order No. 14086, 87 FR 62283 (2022), § 1, https://www.govinfo.gov/content/pkg/FR-2022-10-14/pdf/2022-22531.pdf.

[104] Exec. Order No. 14086, § 2.

1. Machine Learning

The history of machine learning began well before the dawn of IoT and interconnected devices. From the Turing test in 1950 to developing related algorithms in the 1970s, researchers agree that machine learning represents a subset of artificial intelligence (AI) that uses data to conduct analysis and adapt to the intelligence.[105] Based on models and data analysis, machine learning finds patterns in data that can make predictions or decisions without human intervention. The predominant machine learning models use supervised and unsupervised algorithms.[106]

2. Supervised Learning

In supervised learning, an algorithm uses labeled data, meaning the data have indicators that direct the machine to the correct output or answer. The algorithm then uses these labeled data to learn and determine outcomes on new unlabeled data.[107] Brand, Koch, and Xu describe supervised learning as "training data that contains both inputs (also called independent variables, covariates, and features) and labeled outcomes (also called targets, dependent variables, outcomes, and responses)."[108] Supervised learning provides patterns to which the machine can compare input data. Generally, supervised learning establishes two processes: classification and regression. Kumar and Makkar describe *classification* as "the decision to be taken between two alternatives."[109] In other words, the machine analyzes specific characteristics to identify or categorize data using specific parameters. Kumar and Makkar define *regression* as "the supervised learning used for predicting real point values."[110] The machine analyzes specific data in regression to quantify values, such as probability. A simplified infographic from Booz

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105 Jennie E. Brand, Bernard Koch, and Jiahui Xu, "Machine Learning," in *SAGE Research Methods Foundations*, ed. Paul Atkinson et al., (London: SAGE Publications, 2020), 3, https://doi.org/10.4135/9781526421036883644; Panos Louridas and Christof Ebert, "Machine Learning," *IEEE Software* 33, no. 5 (September 2016): 1, https://doi.org/10.1109/MS.2016.114.

106 Brand, Koch, and Xu, "Machine Learning," 3.

107 Louridas and Ebert, "Machine Learning," 110.

108 Brand, Koch, and Xu, "Machine Learning," 3.

109 Kumar and Makkar, *Machine Learning in Cognitive IoT*, 129.

110 Kumar and Makkar, 131.

Allen Hamilton depicts the process of supervised learning whereby a machine learns from category labels and tests them against unlabeled items (see Figure 8).

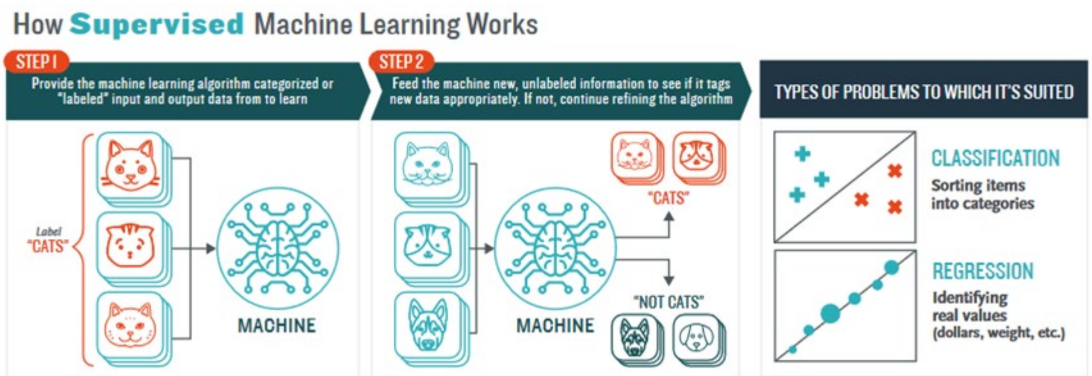

Figure 8. How Supervised Machine Learning Works.[111]

3. Unsupervised Learning

In unsupervised learning, the algorithm does not have labeled data and must find patterns and structures in the data independently. The machine must analyze the data inputs to identify characteristics or data as similar or distinct to create categories.[112] Brand, Koch, and Xu describe unsupervised learning as "models with data only on the features, without labels on the outcomes."[113] Unsupervised learning relies on the machine to detect patterns in the data without a model with which to compare. The predominant methods of unsupervised learning come from clustering or anomaly detection. Specifically, the clustering method identifies previously unknown patterns in a given dataset while anomaly detection identifies deviations from a discernible pattern.[114] The clustering and anomaly detection methods provide a dynamic learning model for decision-making.

[111] Source: "How Do Machines Learn?," Booz Allen Hamilton, accessed January 27, 2023, https://www.boozallen.com/s/insight/blog/how-do-machines-learn.html.

[112] Louridas and Ebert, "Machine Learning," 113.

[113] Brand, Koch, and Xu, "Machine Learning," 3.

[114] Brand, Koch, and Xu, "Machine Learning," 23; Ethem Alpaydin, *Machine Learning: The New AI* (Cambridge, MA: MIT Press, 2021), 89, 150, IEEE Explore; Kumar and Makkar, *Machine Learning in Cognitive IoT*, 79.

A common form of the clustering method comes from the retail industry, where loyalty programs track members' purchases and make recommendations for future purchases based on the buying patterns of similar customers. A 2012 article by Hill in *Forbes* describes how Target stores developed a capability to send specific ads to pregnant customers based solely on purchasing histories.[115] Target's use demonstrated how the clustering method could identify groups and predict behaviors. Anomaly detection finds exclusions to those groups and can trigger alerting or actuation of other machines. In a study to detect crypto-ransomware in IoT networks, Azmoodeh et al. validated using "the unique local fingerprint of ransomware's energy consumption to distinguish ransomware from non-malicious applications."[116] By first clustering the known power consumption of inert programs, Azmoodeh et al. identified the outliers or anomaly clusters and triggered a response. Booz Allen Hamilton has simplified the clustering and anomaly detection processes in an infographic: Step 1 presents unlabeled inputs to the machine, and in Step 2, the machine groups like elements. The third panel shows how an anomaly stands out (see Figure 9).

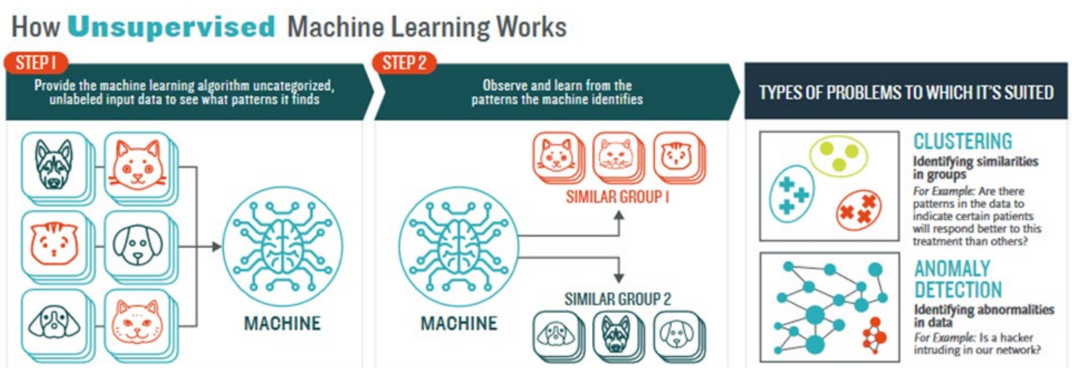

Figure 9. How Unsupervised Machine Learning Works.[117]

[115] Kashmir Hill, "How Target Figured Out a Teen Girl Was Pregnant before Her Father Did," *Forbes*, February 16, 2012, https://www.forbes.com/sites/kashmirhill/2012/02/16/how-target-figured-out-a-teen-girl-was-pregnant-before-her-father-did/.

[116] Amin Azmoodeh et al., "Detecting Crypto-Ransomware in IoT Networks Based on Energy Consumption Footprint," *Journal of Ambient Intelligence and Humanized Computing* 9, no. 4 (2018): 1150, https://doi.org/10.1007/s12652-017-0558-5.

[117] Source: Booz Allen Hamilton, "How Do Machines Learn?"

In the context of IoT and smart cities, machine learning can play a critical role in collecting, analyzing, and interpreting data generated by IoT devices and sensors. Machine learning algorithms can help make sense of these data, providing insights that can inform urban planning, infrastructure management, and emergency response decisions. As machine learning brings IoT devices closer together, creating a data visualization from the overwhelming stream of information could prove challenging. One potential solution, digital twins, follows.

4. Digital Twin

An integrated IoT ecosystem in a municipal environment would produce a vast amount of data and require a methodology to view the data in a digestible format. One method of data visualization using integrated data systems has been termed the digital twin (DT), which the Digital Twin Consortium has defined as "a virtual representation of real-world entities and processes, synchronized at a specified frequency and fidelity."[118] In other words, a DT provides a digital version of a physical object or system created and maintained using sensors and data feeds. The Centre for Digital Built Britain states that DT requires "a relationship between the digital and physical world."[119] A successful DT integrates an ongoing data collection process to ensure accurate, real-time visualization of the object or system.[120] DT visualizations assist users in making sense of complex systems and aggregate a vast amount of data from physical items or environments.

Using data from sensors, cameras, and other sources to create a detailed 3D representation, DTs simulate the object or system's behavior, performance, and interactions under different conditions, such as temperature, pressure, or load changes. As a complex system, cities could benefit from implementing DTs to visualize and manage

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118 Anto Budiardjo et al., *Assuring Trustworthiness in Dynamic Systems* (Boston: Digital Twin Consortium, 2022), 5.

119 "Describing Digital Twins: Anatomy and Taxonomy for Digital Twins," National Digital Twin Programme and Centre for Digital Built Britain, accessed January 16, 2023, https://digital-twins.kumu.io/describing-digital-twins.

120 K. N. Abdrakhmanova et al., "Review of Modern Software Complexes and Digital Twin Concept for Forecasting Emergency Situations in Oil and Gas Industry," *IOP Conference Series: Materials Science and Engineering* 862 (May 2020): 3, https://doi.org/10.1088/1757-899X/862/3/032078.

the integration of IoT systems. This information can optimize city systems' design, operation, and maintenance and help identify and mitigate potential problems. According to Crane and Peeke, "Building a comprehensive, living model of a city or even a city block would enhance situational awareness and provide the necessary data for leaders to make rapid decisions and increase the protection of the combat element in an [operating environment]."[121] Using the virtual environments provided by DTs, users can interact with the digital replica and provide real-time intelligence to emergency responders in the field.

A DT provides a virtual representation of a physical object or system, such as a machine, building, or city, that can simulate and analyze its behavior, performance, and interactions. As a replica of a real-world object or system, DT technology helps to predict behavior, performance, and interactions. Emergency management can use digital twins to optimize the city's IoT ecosystem design, operation, and maintenance to identify and mitigate potential problems.

E. IOT RISKS

Implementing IoT technologies in cities presents a range of risks that significantly affect the functioning of cities and the well-being of residents. These risks include cybersecurity threats, privacy concerns, interoperability, reliability, and scalability.[122] Cities must develop comprehensive policies and procedures to mitigate risks and ensure IoT technologies' safe and secure use.

Interconnected devices and systems have inherent risks caused by connectivity to devices and users. IoT devices connected to the internet represent a vulnerability to cyber-attacks while collecting and transmitting large amounts of data, including potentially

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121 Crane and Peeke, "Using the Internet of Things to Gain and Maintain Situational Awareness," 42.

122 Davies and Fortuna, Introduction, 6; Interagency International Cybersecurity Standardization Working Group, *Interagency Report on the Status of International Cybersecurity Standardization for the Internet of Things (IoT)*, NISTIR 8200, ed. Michael Hogan and Ben Piccarreta (Gaithersburg, MD: National Institute of Standards and Technology, 2018), 35, https://doi.org/10.6028/NIST.IR.8200.

sensitive information about individuals (e.g., their location).[123] Some recommended best practices by the Cybersecurity and Infrastructure Security Agency include implementing strong data encryption, devising strict privacy policies, and regularly reviewing and auditing the collected and stored data.[124] An IoT ecosystem will generate a vast data set from diverse systems and devices. The sheer quantity of data lacks a unifying standard to ensure system compatibility.[125] Cities should take steps to address the lack of interoperability, such as implementing standards for IoT devices and promoting the use of open-source technologies.[126] As IoT devices depend on the internet and are subject to network outages or other issues, cities should implement redundancy and failover mechanisms, including regularly testing and maintaining the devices. Additionally, IoT devices generate large volumes of data, which can be challenging to manage and analyze. Cities should address scalability by implementing data analytics platforms and machine learning and regularly reviewing and auditing the collected and stored data.[127] By properly applying best practices for cybersecurity and implementing data analytics, cities can mitigate some risks of IoT systems to users and devices.

In sum, cities must acknowledge the potential risks associated with IoT, including cybersecurity, privacy, interoperability, reliability, and scalability. Then, they should address these risks by implementing security and privacy measures, redundancy, and failover mechanisms and by regularly reviewing and auditing the collected and stored data.

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[123] Manyika et al., *Mapping the Value beyond the Hype*, 105; Hossein Mohammadi Rouzbahani et al., "Anomaly Detection in Cyber-Physical Systems Using Machine Learning," in *Handbook of Big Data Privacy*, ed. Kim-Kwang Raymond Choo and Ali Dehghantanha (Cham: Springer, 2020), 219, https://doi.org/10.1007/978-3-030-38557-6_10.

[124] "Securing the Internet of Things," *Cybersecurity and Infrastructure Security Agency* (blog), February 1, 2021, https://www.cisa.gov/news-events/news/securing-internet-things-iot; Department of Homeland Security, *Strategic Principles for Securing the Internet of Things*, 9.

[125] Attaran, "The Internet of Things," 18.

[126] Badis Hammi et al., "IoT Technologies for Smart Cities," *IET Networks* 7, no. 1 (2018): 10, https://doi.org/10.1049/iet-net.2017.0163.

[127] Ray, Mukherjee, and Shu, "Internet of Things for Disaster Management," 18833.

F. CONCLUSION

IoT provides “a new hope” to emergency management by providing real-time data and improving communication, coordination, and response times. Established IoT sensor networks, environmental monitoring, location tracking, and communication networks can help predict and prepare communities for natural disasters. Integrating IoT systems in use by various departments within a jurisdiction might allow emergency services to respond more quickly, lessen the overall intensity of events, and begin recovery from an emergency. Using the available data from a network of IoT systems represents a possible next phase of IoT for cities and government entities. IoT-enabled smart cities can provide emergency managers with real-time intelligence about traffic, energy usage, and other factors affecting emergency response. The next chapter presents a series of case studies on smart cities using IoT technology to strike back at the complexities and challenges of modern urban society by gathering and using the vast amounts of data produced by information systems to help advance environmental security and public safety.

IV. EMPIRES STRIKE BACK: SMART CITIES MODEL

Luminous beings are we, not this crude matter.

—Yoda, *Star Wars Episode V: The Empire Strikes Back*

The concept of smart cities has captivated city managers and mayors in recent years as cities worldwide have sought to improve the efficiency and effectiveness of their services and infrastructure and enhance the quality of life for residents. By intentionally using technology and data synthesis, cities can develop capabilities to serve their residents now and into the future.[128] IoT provides one of the central technologies to enable older cities (empires) to strike back against the burdens of existing built infrastructures and achieve their smart city goals. As discussed in Chapter III, IoT technologies collect and analyze data on various factors, such as traffic flow, air quality, and energy consumption, for consumer and industrial purposes. In cities, the generated data inform policy and urban design decisions and improve the efficiency and effectiveness of city services. The intentional daily use of data helps to establish a baseline of city operations to detect anomalies more quickly. Smart cities that use deployed IoT technologies can improve emergency response and coordination by integrating deployed technologies into EOCs.

This chapter presents a series of case studies examining how smart cities use available data generated by IoT systems and devices distributed throughout the jurisdiction. It reviews IoT-based systems from three case studies in the 2021 *Smart City Index*—Chicago, New York, and Rio de Janeiro—of cities adopting smart technologies in established built environments.[129] These cities have used embedded IoT technologies to overcome the perceived limitations of their built environments, illuminating data and trends through sensors and machine learning. Additionally, each system has demonstrated uses in public safety or emergency response. The chapter closes by analyzing

128 Woetzel et al., *Smart Cities*, 22.

129 Institute for Management Development, *Smart City Index 2021*, 9–10.

how the existing IoT technologies can maintain and improve SA before, during, and after an emergency.

A. CASE STUDY: CHICAGO'S ARRAY OF THINGS

In seeking a better way to assess and monitor microclimates throughout the urban landscape, the City of Chicago developed the Array of Things (AoT). In 2016, in partnership with the University of Chicago and Argonne National Laboratory, the city deployed the AoT project utilizing a single node to collect and analyze environmental data, such as air quality, temperature, and traffic flow.[130] Providing environmental data and real-time SIGINT, AoT informs a piece of Chicago's WindyGrid data visualization platform to improve government services, including emergency response.[131] In a collaborative process with the community at large and the scientific community, Catlett et al. developed AoT as a distributed project "emphasizing new measurements that could be supported with edge computing, in turn requiring . . . [AI] and Machine Learning (ML) support."[132] With an expected 500 devices deployed among municipal infrastructure throughout Chicago, AoT could provide an opportunity to study integrated IoT technologies and community benefits (see Figure 10).[133] AoT has supported multiple research areas, including data analysis, edge computing, and embedded hardware systems.

[130] Mark Potosnak et al., "Array of Things: Characterizing Low-Cost Air Quality Sensors for a City-Wide Instrument," Authorea, December 13, 2018, https://doi.org/10.1002/essoar.10500209.1.

[131] Rob Mitchum, "Chicago Becomes First City to Launch Array of Things," Computation Institute, August 29, 2016, https://voices.uchicago.edu/compinst/press-releases/chicago-becomes-first-city-launch-array-things/; Sean Thornton, "Chicago Launches OpenGrid to Democratize Open Data," Data-Smart City Solutions, January 20, 2016, https://datasmart.hks.harvard.edu/news/article/chicago-launches-opengrid-to-democratize-open-data-778.

[132] Charlie Catlett et al., "Measuring Cities with Software-Defined Sensors," *Journal of Social Computing* 1, no. 1 (September 2020): 15, https://doi.org/10.23919/JSC.2020.0003.

[133] Pete Beckman et al., "Waggle: An Open Sensor Platform for Edge Computing," in *Proceedings of 2016 IEEE SENSORS* (Piscataway, NJ: IEEE, 2016), 1, https://doi.org/10.1109/ICSENS.2016.7808975.

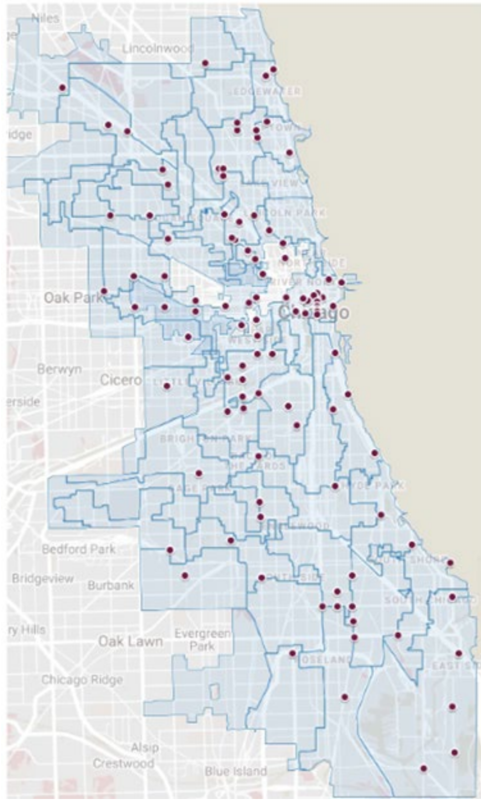

Figure 10. Distribution Map of AoT in Chicago.[134]

1. Integrated IoT Data Systems

In the development of AoT, Catlett et al. acknowledged the need to create a device with the technical capability and scientific specificity to provide and analyze data applicable to the scientific community. AoT aims to collect sufficient data with accuracy to allow the people of Chicago and city departments to respond to changing elements in the environment.[135] Catlett et al. proposed that "AoT will provide high spatial and temporal resolution sensor data from an active urban environment for analysis and

[134] Source: Charlie Catlett et al., "Hands-on Computer Science: The Array of Things Experimental Urban Instrument," *Computing in Science Engineering* 24, no. 1 (January 2022): 59, https://doi.org/10.1109/MCSE.2021.3139405. The red dots on the distribution map of Chicago represent the AoT devices installed.

[135] "What Is Array of Things?," Array of Things, accessed February 10, 2023, https://arrayofthings.github.io/faq.html.

integration into scientific workflows, mobile applications, or other services."[136] In short, the sensors embedded in AoT devices need to provide precise measurements so that scientists and city officials can effectively use the data. For example, in monitoring the rate of rainfall in microclimates throughout the city, AoT can identify potential flooding based on the capacity of drainage in the area and improve the city's response.[137] Additionally, the traditional dispersion of air quality sensors provides varying degrees of accuracy in urban environments due to the complexities of city life and lack of specificity.[138] In response to the needs of climatologists and energy efficiency scientists, AoT developers installed "an upward-facing camera and light, UV, and [infrared] sensors" to the existing model.[139] Adding to the environmental sensors, additional AoT capabilities allow for lifestyle assessments in the city. The AoT devices measure a range of environmental data, from weather to air quality, while ensuring emerging technologies integrate into the device (see Figure 11).[140] The modular nature of the design and the openness to integrate new appropriate technologies make AoT a model for future development; however, with different sensor technologies, the developers needed to relegate computing power to the lowest level—within the device itself—using edge computing.

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[136] Charles E. Catlett et al., "Array of Things: A Scientific Research Instrument in the Public Way: Platform Design and Early Lessons Learned," in *Proceedings of the 2nd International Workshop on Science of Smart City Operations and Platforms Engineering* (New York: ACM Press, 2017), 2, https://doi.org/10.1145/3063386.3063771.

[137] Array of Things, "What Is Array of Things?"

[138] Yu Zheng, Furui Liu, and Hsun-Ping Hsieh, "U-Air: When Urban Air Quality Inference Meets Big Data," in *Proceedings of the 19th ACM SIGKDD International Conference on Knowledge Discovery and Data Mining* (New York: ACM Press, 2013), 1443–44, https://doi.org/10.1145/2487575.2488188.

[139] Catlett et al., "Array of Things," 2.

[140] "Current AoT Node Architecture," Array of Things, accessed February 10, 2023, https://arrayofthings.github.io/node.html.

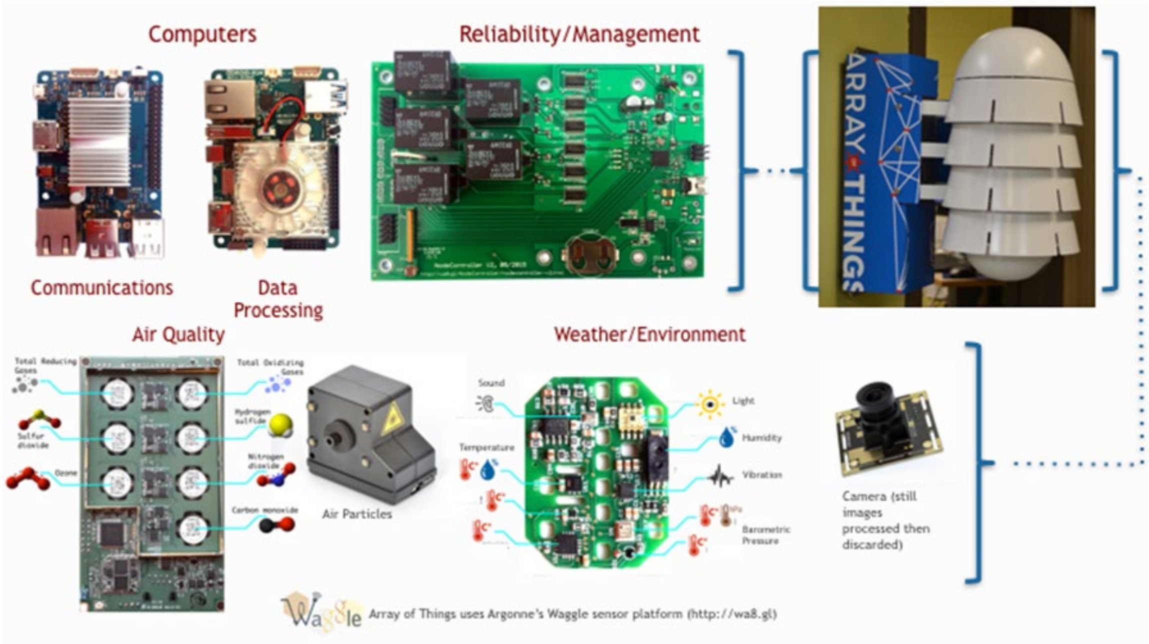

Figure 11. AoT Design and Technology Integration.[141]

AoT nodes use edge computing to process information collected at each posting location, maximizing the data-sharing resources. Edge computing advances the processing of data as close to the collecting device as possible and limits the amount of data necessary for transmission. As defined by Shi, Pallis, and Xu, "Edge computing is a new paradigm in which the resources of an edge server are placed at the edge of the Internet, in close proximity to mobile devices, sensors, end users, and the emerging IoT."[142] The integration of edge computing allows AoT to reduce energy costs and minimizes the required bandwidth for transmitting data. According to Catlett et al., in 2017, AoT nodes used "in-situ processing of sensor data to develop new and/or integrated data products, such as the use of machine learning techniques to extract features from imagery or sound."[143] The edge-computing capability allows the devices to analyze the data collected without transmitting potentially sensitive data sets such as video or audio to a central compilation.

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[141] Source: Array of Things.

[142] Weisong Shi, George Pallis, and Zhiwei Xu, "Edge Computing," *Proceedings of the IEEE* 107, no. 8 (August 2019): 1475, https://doi.org/10.1109/JPROC.2019.2928287.

[143] Beckman et al., "Waggle," 3.

The processing power allows the node to contribute to a data set that counts individuals or vehicles through an area and discards images with any personally identifiable information.[144] The power of edge computing and the design of AoT allow for the future expansion of sensors integrated into the platform to expand urban assessment.

The modular design of AoT anticipates new technologies and advancements in capability, increasing the likelihood of continued operation and adaptability in the future. Using an open-source platform, AoT enables new technologies to ensure data and hardware integration. Catlett et al. anticipated "AoT as a platform for testing new sensors, communication devices, computational devices, or other hardware embedded in a major urban area."[145] As the scientific community requested additional technologies, the community also demanded new capabilities, such as automated hazard identification and the density of transactional populations such as vehicles and people. In response, Beckman et al. have described AoT adaptations, among which "two cameras and . . . [a] microphone will use the edge-computing capabilities to explore how smart city technologies can improve the energy efficiency and quality of life for city residents."[146] Although the future of IoT will come quickly, AoT can adapt to emerging technologies.

As a designed modular sensor system, AoT demonstrates the expanding impact of IoT technologies. As discussed in Chapter III, most of the data collected by existing IoT technologies remain underutilized, and more data remain to be collected. English et al. concluded that "recent advances in sensing and computing technologies exemplified by the AoT have the potential to inform the study of any behavioral or social phenomena where environmental context matters."[147] Using the information that AoT collects could provide the details to help decision-makers navigate complex emergencies, especially concerning the environment or weather. The expansion of available technologies may also herald the

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[144] Beckman et al., "Waggle," 1.

[145] Catlett et al., "Array of Things," 2.

[146] Beckman et al., "Waggle," 3.

[147] Ned English et al., "Making Sense of Sensor Data: How Local Environmental Conditions Add Value to Social Science Research," *Social Science Computer Review* 40, no. 1 (February 2022): 11, https://doi.org/10.1177/0894439320920601.

heightened impact of AoT. Indeed, as English et al. explain, the implications for systems like AoT may "reach far beyond studying the impact of neighborhood air quality."[148] Future additions to the AoT platform could have similar effects, such as adding cameras with edge-computing capability. Acknowledging the potential concerns of the community, the AoT project has proactively addressed privacy and defined limitations on the technology through policy.

2. Challenges and Limitations

Even though the AoT project's intended mission has sought to measure and analyze environmental data, privacy concerns, such as those discussed in Chapter III, have caused challenges and presented limitations to the wider use of the system. As a sensing tool, AoT has raised concerns about civil liberties pertaining to data collection, storage, and use. The technology's potential use for "surveillance" and the risk of "hacked" devices alarmed community members.[149] The project proactively drafted privacy and use policies and socialized the drafts with "experts from academia, industry and government privacy law, and privacy advocacy groups including the Electronic Frontier Foundation . . . and American Civil Liberties Union . . . to review and improve the policies."[150] The anticipatory work may have mitigated some concerns despite the images being captured on public streets with no reasonable expectation of privacy. Additionally, an AoT Executive Oversight Council maintains and assures adherence to privacy policies.[151] By proactively acknowledging the perception and reality of risk to the privacy of residents, the project developers likely mitigated a more adverse response from the public.

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148 English et al., 10.

149 Catlett et al., "Hands-on Computer Science," 4; Catlett et al., "Measuring Cities with Software-Defined Sensors," 17.

150 Catlett et al., "Measuring Cities with Software-Defined Sensors," 17.

151 Charles Noel Schilke, "Raising the IQ of Smart Cities: Chicago's 'Array of Things' Urban Data Device," *Real Estate Issues*, Spring 2017, 72.

3. Analysis

Chicago's long-standing history and built environment have not impeded its growth into a smart city and the development of integrated technologies. Chicago's AoT project has successfully provided valuable data on the city's environment and infrastructure, informing policy and urban design decisions. For example, the data collected on air quality have identified areas of the city with high levels of pollution and developed strategies to reduce them.[152] The data collection of environmental impacts represents potential SA gathering from non-traditional sources. The environmental measurements of rainfall, relative humidity, and temperature become SIGINT during weather emergencies. The signals may inform the rate of impact a weather event will have on an area of the city, with rainfall indicating potential flooding and temperature and humidity indicating a rising heat index. Similarly, the automated analysis of pedestrian and traffic flow could provide valuable SA for additional threats both environmentally and during potential terrorist events.

AoT has also expanded the initial portfolio of sensors to accommodate requests from the scientific community and residents. Expanding sensor capabilities and incorporating new technology demonstrate opportunities for previously unconventional use cases, such as for public safety departments. Just as Chicago has expanded the use of environmentally focused AoT, other smart cities could further develop their IoT systems—such is the case with New York City's Domain Awareness System.

B. CASE STUDY: NEW YORK CITY'S DOMAIN AWARENESS SYSTEM

New York City's Domain Awareness System (DAS) demonstrates one example of IoT integration by a public safety agency to enhance smart city initiatives. The New York City Police Department (NYPD) has a long history of using data to guide proactive policing, first using CompStat in 1994.[153] DAS enhances the data through an integrated

[152] Potosnak et al., "Array of Things."

[153] Mark C. Molinari, "Implementing CompStat Principles into Critical Infrastructure Protection and Improvement" (master's thesis, Naval Postgraduate School, 2016), 73. CompStat, short for comparative statistics, is a police management and accountability tool that originated with the NYPD in 1994.

network of cameras, license plate readers, and other sensors.[154] As a public–private partnership between New York City and Microsoft, DAS enables the collection and analysis of data from multiple sources, providing a more comprehensive view of safety and security by employing real-time analytics and alerting. This case study examines improved emergency response coordination made possible by IoT technologies integrated into DAS by the NYPD.

1. Integrated IoT Data Systems

DAS uses various IoT technologies to collect data to improve responses to public safety issues and threats. The initial iteration of DAS began with access to private security cameras but quickly expanded to license plate readers, radiation detectors, active and historical 9-1-1 call data, and other sensors. As a single source of SA, DAS provides the NYPD with access to unprecedented information at all levels of the organization. The NYPD quickly realized the overwhelming volume of data available to its officers and developed an alerting mechanism to prioritize the incoming information feed. The alerting mechanism comprises three phases: "automated alerting, adjudication, and action."[155] The integrated IoT systems initiate an alert based on predefined algorithms. Then, a sworn NYPD officer reviews the flagged image or 9-1-1 call for accuracy. The adjudication phase exists primarily to "determine whether it is a true or false positive."[156] Figure 12 describes the alerting process conducted by DAS, including the sources of information (known as inputs) and the algorithmic analysis provided to each input. According to Levine et al., alerts from DAS "resulted in improved police responses, additional evidence collected, and more violent criminals being arrested and charged."[157] Moreover, DAS's analytical capability proved invaluable, allowing officers to focus primarily on information that directly benefited their tactical or strategic decisions.

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[154] E. S. Levine et al., "The New York City Police Department's Domain Awareness System," *Interfaces* 47, no. 1 (February 2017): 70–71, https://doi.org/10.1287/inte.2016.0860.

[155] E. S. Levine and J. S. Tisch, "Analytics in Action at the New York City Police Department's Counterterrorism Bureau," *Military Operations Research* 19, no. 4 (2014): 5.

[156] Levine and Tisch, 9.

[157] Levine et al., "The New York City Police Department's Domain Awareness System," 80.

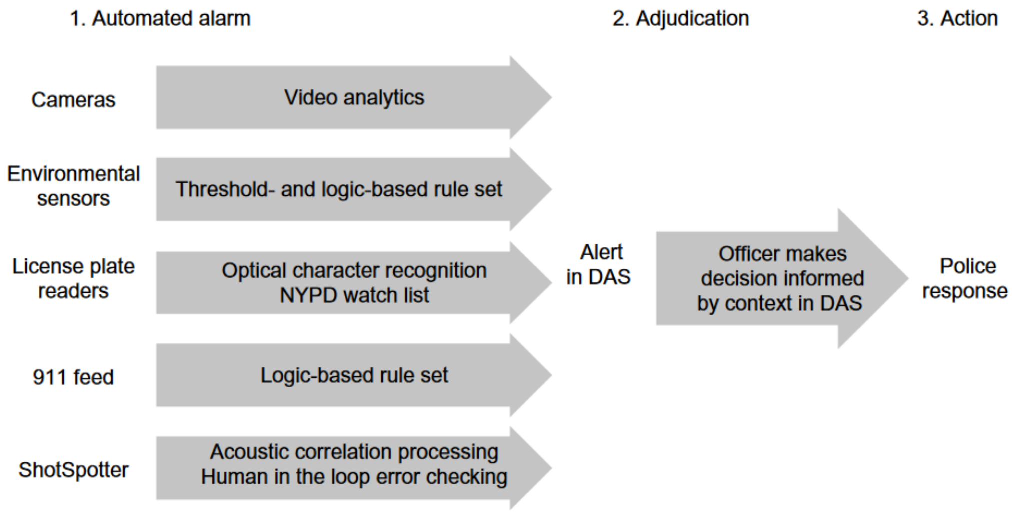

Figure 12. The NYPD's DAS Alerting Process.[158]

The centrally integrated technology in DAS provides several benefits for the city and its residents. Integrating these technologies into a single system enables the centralized analysis of data to inform real-time response and after-the-fact deployment decisions. According to the NYPD's 2021 *Domain Awareness System: Impact and Use Policy*, "NYPD personnel use [DAS] to make strategic and tactical decisions."[159] A strategic decision could involve, for example, the delivery of real-time metrics for increases in burglaries, enabling a unit commander to redeploy NYPD officers dynamically. Moreover, DAS "delivers tailored information and analytics to mobile devices and precinct desktops," and "all officers' smartphones, and on the tablets in all police vehicles."[160] The immediate dissemination of data, directly and indirectly, impacts how the NYPD deploys personnel and uses data. A tactical decision could involve tracking a carjacking suspect when a license plate reader identifies the vehicle and alerting nearby NYPD units in the vicinity.[161]

[158] Source: Levine et al., 74.

[159] New York City Police Department, *Domain Awareness System: Impact and Use Policy* (New York: New York City Police Department, 2021), 3, https://www1.nyc.gov/assets/nypd/downloads/pdf/public_information/post-final/domain-awareness-system-das-nypd-impact-and-use-policy_4.9.21_final.pdf.

[160] Levine et al., "The New York City Police Department's Domain Awareness System," 71.

[161] Levine et al., 71–72.

DAS has improved information sharing and allowed the NYPD to make dynamic, data-driven decisions.

By centralizing data analysis, the NYPD can employ ML to analyze data and provide more actionable intelligence to patrol officers for immediate use and investigations. Before the implementation of DAS and integrated systems, investigations required officers to search multiple databases. As Levine and Tisch describe, "The independent interfaces [made] it more difficult for investigators to identify connections across the data sources."[162] Maintaining the three-phased approach of automation, adjudication, and action, integrated databases have streamlined the investigator's evaluation of the data. With multiple data sources, investigators need an interface to view the data, so DAS provides visualization tools, including photos, previous crime reports, and a calendar of incidents overlaid on a map.[163] The overlay of data provides a sort of DT of the area that assists investigators. DAS requires human adjudication of data, but it can also assist with pattern recognition.

The automation of data analysis through DAS has enhanced the NYPD's service delivery. DAS conducts pattern recognition using adjudicated data and then recognizes license plates on the NYPD's watch list.[164] Once an officer confirms an image from an automated license plate reader, the pattern recognition results in two outputs: time-place and routing patterns. According to Levine et al., time-place patterns result "when a vehicle passes the same [license plate reader] on multiple occasions on a particular day of the week and at a particular time."[165] Time-place pattern recognition allows officers to anticipate when a suspect will return to a specific location or at a specific time and place to conduct a stop. DAS routing pattern recognition does not consider the "when" as a factor but rather the time between waypoints. If a suspect once crossed a license plate reader and 20 minutes later crossed another, officers can anticipate a 20-minute window to conduct a stop.[166] ML

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[162] Levine and Tisch, "Analytics in Action," 9.

[163] Levine and Tisch, 9–10.

[164] Levine and Tisch, 7.

[165] Levine et al., "The New York City Police Department's Domain Awareness System," 75.

[166] Levine and Tisch, "Analytics in Action," 5.

enhancement, including pattern recognition, continues to provide more actionable insights for the NYPD. Though DAS's implementation and subsequent iterations have improved law enforcement response and coordination, the NYPD has faced a few challenges and limitations.

2. Challenges and Limitations

Despite the benefits of integrated technology in DAS, the NYPD needed to address specific challenges and limitations associated with its use, including technology acceptance and privacy. As identified in Chapter III, the data collected by any IoT system, including DAS, raise concerns about privacy and data security. As Erik Dahl states, "Little research has been done to examine the benefits of local domain awareness systems, and more work is needed to balance gains from increased security against any impact on civil liberties."[167] At the outset of DAS, the NYPD faced concerns over privacy and the potential infringement of civil liberties.[168] In 2009, the NYPD wrote a privacy and use policy outlining specific limitations for users of DAS and protections of the data. In particular, the policy restricted access to authorized users for proper law enforcement action and prescribed the nature of stored data: "NYPD personnel may only [use] DAS for legitimate law enforcement purposes."[169] The policy development included public outreach and engagement to solicit feedback and define revisions.[170] With only the NYPD using DAS, integrating new technologies and systems may face renewed privacy concerns. Limiting and ensuring access and use of DAS may serve New York in purely law enforcement situations, but rarely do emergencies remain discipline specific.

The strength of the DAS system as a law enforcement tool in combating crime and countering terrorism may also represent a significant limitation. As discussed in Chapter

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167 Erik J. Dahl, "The Localization of Intelligence: A New Direction for American Federalism," *International Journal of Intelligence and CounterIntelligence* 34, no. 1 (2021): 17, https://doi.org/10.1080/08850607.2020.1716563.

168 Stephenie Slahor, "NYPD and Microsoft's DAS . . . Coordinated Surveillance and Crime Data," *Law and Order* 60, no. 11 (November 2012): 17.

169 New York City Police Department, *Domain Awareness System*, 4.

170 Levine and Tisch, "Analytics in Action," 12; Levine et al., "The New York City Police Department's Domain Awareness System," 78.

III and represented by Chicago's AoT, many connected IoT devices and systems collect signals from around the jurisdiction. The NYPD describes DAS as a "law enforcement technology solution that aggregates and analyzes public safety data in real-time, providing NYPD investigators and analysts with a comprehensive view of potential threats and criminal activity."[171] DAS remains isolated in the law enforcement domain with access specific to law enforcement sources and only for the NYPD. This structural limitation could prevent comprehensive SA within the city. In 2015, the NYPD released a strategic information technology document stating the intention "to integrate more data from . . . other city agencies (e.g., Administration for Children's Services, Department of Health and Mental Hygiene, and Department of Education), and social media."[172] While restricting access to law enforcement–sensitive material such as criminal histories meets some privacy concerns, other city agencies may benefit from receiving similar alerts or warnings. For example, after an available license plate adjudication, DAS could alert all NYPD officers and field crews from the Department of Public Works or Sewer and Maintenance. In that case, non–law enforcement agencies could report seeing the vehicle to the network. Alternatively, representatives from the Departments of Children's Services, Health and Mental Hygiene, and Education could benefit from automated reporting if they encountered a known suspect through clinical services. However, a concern would emerge over how a social service–oriented agency would respond to such an alert. Though the data could be used in a non-investigatory capacity, the risk to civil liberties would likely limit the expansion of a system primarily owned and operated by a law enforcement agency.

3. Analysis

New York City's DAS demonstrates how integrating technology in smart cities can improve the safety and security of an urban center. The NYPD uses IoT and ML to collect and analyze data from multiple sources, providing the city's law enforcement and counter-

[171] "New York City Police Department and Microsoft Partner to Bring Real-Time Crime Prevention and Counterterrorism Technology Solution to Global Law Enforcement Agencies," PR Newswire, August 8, 2012, 1, ProQuest.

[172] New York City Police Department, *Developing the NYPD's Information Technology* (New York: New York City Police Department, 2015), 4, https://www.hsdl.org/c/abstract/.

terrorism teams with SA. DAS provides real-time information to law enforcement and emergency response teams using ML from cameras, license plate readers, and radiological sensors. DAS maintains a human element by requiring a sworn officer to adjudicate the images and data prior to an action by the system. The system aggregates the data to identify suspicious behavior or potential threats and could, with centralized data collection and systematic analysis, predict incidents before emergencies, allowing for the redeployment of personnel beforehand. Through automated alerts and ML, IoT systems effectively serve as SIGINT; however, direct access to the benefits of DAS remains limited to law enforcement. Though privacy concerns limit the system's expansion to an extent, the city's top-down data integration may improve utilization and help mitigate the privacy concerns.

C. CASE STUDY: RIO DE JANEIRO'S CENTER OF OPERATIONS

The summer of 2010 will be remembered as a tipping point for the City of Rio de Janeiro (Rio). Summer storms devastated the city's poorest areas, known as favelas. Landslides, flash floods, and missing and dead people signaled a needed change.[173] With hundreds dead and thousands homeless, the local government committed to reforms, especially for the favelas. The city's systems had failed to perform during the response to the storm, using inadequate means of anticipating impacts on city infrastructure, maintaining SA, and coordinating a response to the incident.[174] With the impending 2014 World Cup and 2016 Olympic Games, Rio's inability to mitigate the effects of disasters received the focus of the city's executive leadership, including the mayor. Rio recognized the need for an improved communication and coordination center that emphasized real-time access to SIGINT regarding the city's status. The Center of Operations' objectives include the "aim of anticipating solutions and minimizing occurrences of great impact on the city, such as heavy rain, landslides and traffic accidents with repercussions on urban

[173] "Rio de Janeiro's Centre of Operations: COR," Centre for Public Impact, March 25, 2016, https://www.centreforpublicimpact.org/case-study/ioe-based-rio-operations-center; Natasha Singer, "Mission Control, Built for Cities," *New York Times*, March 4, 2012, ProQuest; Volker Buscher and Lean Doody, *Global Innovators: International Case Studies on Smart Cities Smart* (London: United Kingdom Department for Business, Innovation and Skills, 2013), 15.

[174] Christopher Frey, "World Cup 2014: Inside Rio's Bond-Villain Mission Control," *Guardian*, May 23, 2014, https://www.theguardian.com/cities/2014/may/23/world-cup-inside-rio-bond-villain-mission-control.

mobility."[175] The creation of the Rio Center of Operations represented a significant advance in embracing technology and providing a service to the people of Rio every day. This case study examines the centralization of Rio's department operations, including IoT systems and processes, into a single operations center.

1. Integrated IoT Data Systems

Before creating the Center of Operations, Rio's disparate agencies and departments managed their day-to-day operations individually, with each entity managing its piece of the operation. Rio's agencies and departments functioned out of offices dispersed throughout the city, reinforcing the operational divide. As Alexandre Cardeman, executive director for technology at the Rio Center of Operations, describes, "There was information about different events scattered in different offices. There was the metro system, businesses, the railway, all the concessions that provide public service in Rio. But they were all isolated from each other."[176] Rio's decentralized response system built on historic infrastructure caused confusion and impeded the government's ability to coordinate a response effectively. The city needed a system combining a significant amount of data from multiple agencies, facilitating better coordination, and providing information to the public. Figure 13 demonstrates the centralization of data and processes in Rio's Center of Operations. Integrating data systems from Rio's 50 city agencies into the Center of Operations generated more efficiency in day-to-day functions and emergency response.[177] Rio adapted to a data-driven model of managing municipal services for the everyday resident and visitors to the city.

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[175] "Perguntas Frequentes" [Common Questions], Prefeitura da Cidade do Rio de Janeiro [City Hall of Rio de Janeiro], accessed August 12, 2022, https://cor.rio/faq/.

[176] Cisco, *IoE-Based Rio Operations Center Improves Safety, Traffic Flow, Emergency Response Capabilities* (San Jose, CA: Cisco, 2014), 3, https://www.cisco.com/c/dam/m/en_us/ioe/public_sector/pdfs/jurisdictions/Rio_Jurisdiction_Profile__051214REV.pdf.

[177] Cisco, 5.

Figure 13. Rio de Janeiro's Integrated Data System at the Center of Operations.[178]

Rio's smart city evolution continues to evolve and adapt to the needs of its residents by developing and improving the built environment to integrate data collection. The Rio Center of Operations represents the city's largest and most ambitious smart city project.[179] According to Kitchin, at the Center of Operations, "algorithms and a team of analysts process, visualize, analyze and monitor a vast amount of live service data, alongside data aggregated over time and huge volumes of administration data."[180] The collection and integration of sensors began with environmental data collection and expanded to emergency services, employee reports, and the public. Rain gauges, water flow monitors, and radar feed data into a risk profile that helps inform the likely impact on communities. Based on that information, the Center of Operations uses ML to determine when to send alerts, open or close roadways, divert public transit, or deploy mitigation teams from public

[178] Source: Cisco, 5.

[179] Singer, "Mission Control, Built for Cities."

[180] Rob Kitchin, "The Real-Time City? Big Data and Smart Urbanism," *GeoJournal* 79, no. 1 (2014): 6, https://doi.org/10.1007/s10708-013-9516-8.

works.[181] According to Bittencourt et al., "The system notifies city officials and emergency responders when changes occur in flood and landslide forecast for the city and [sends] mobile communications, including automated email messages and instant messaging to emergency personnel and citizens."[182] Automating notifications to staff and the public helps eliminate points of failure in a string process. Halegoua describes the Center of Operations as "credited with improving Rio's disaster and emergency response systems."[183] Integrating non-traditional response systems extended the reach of the Center of Operations into daily operations. Other integrated systems include electrical grid status, hundreds of cameras, and public vehicle tracking, such as garbage trucks, buses, and taxis.[184] The regular everyday integration of data into the Center of Operations has enabled and accelerated the center's positive impact on the people and the municipality of Rio de Janeiro.

Rio established a system of change to start and ensure the success of the Center of Operations. The integration of data systems from a multitude of agencies requires a thorough design process to ensure coordination. Reorienting agencies from operating in traditional locations with antiquated technologies required "an up-front agreement about duties and how agencies [would] perform."[185] In addition to the agreement, change has occurred over time with the support of executive leadership during the transition. Rio moved to formalize creating and integrating the Center of Operations through a series of executive decrees and resolutions. Among the executive actions, Rio formalized the integration of the Center of Operations into the Mayor's Office and ensured its

[181] Cisco, *IoE-Based Rio Operations Center Improves Safety*, 4; Centre For Public Impact, "Rio de Janeiro's Centre of Operations."

[182] Bernardo K. Bittencourt et al., "Evaluating Preparedness and Resilience Initiatives for Distressed Populations Vulnerable to Disasters in Rio De Janeiro, Brazil," in *Proceedings of the 2013 IEEE Systems and Information Engineering Design Symposium* (Piscataway, NJ: IEEE, 2013), 58, https://doi.org/10.1109/SIEDS.2013.6549494.

[183] Germaine R. Halegoua, *Smart Cities*, (Cambridge, MA: MIT Press, 2020), 14.

[184] Cisco, *IoE-Based Rio Operations Center Improves Safety*, 4; Buscher and Doody, *Global Innovators*, 15.

[185] Cisco, *IoE-Based Rio Operations Center Improves Safety*, 6.

organizational structure through the Civil House (legislature).[186] These actions established the center's legitimacy while codifying agencies' requirements to prioritize their new roles. The codification of the Center of Operations also helped to sustain its capabilities.

2. Challenges and Limitations

Overhauling the infrastructure and daily operations of a built environment like Rio did not come without challenges and limitations. This section outlines a few issues while noting actions taken by the municipality to address them.

The Center of Operations mitigated some delays in response from the previous reactive model, but system integration and co-locating representatives from Rio's major departments caused additional challenges. The technical integration came through a public–private partnership, which included developing a state-of-the-art central control center.[187] The practical implementation of the software did not appear to meet the needs of Rio immediately. Gaffney and Robertson have said the city's technical team "took selected items out of the IBM toolbox, wrote their own software, and ended the formal relationship with IBM."[188] The city's relationship with IBM deteriorated, as it had become impossible to sustain, and ended before the Center of Operations had been fully established. Furthermore, the integration of data systems, implementation of ML, and use of automation did not reduce the staff members needed to monitor the city. Frey observed in 2014 that "about 70 [center] staff, clad in crisp white jumpsuits, [sat] before banks of desktop screens."[189] As shown in Figure 14, an overhead view of the center reinforces Frey's observation of a large complement of staff monitoring a wall of video monitors. The Center of Operations created a new management layer over a system of integration. Although this

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[186] Decreto Rio No. 46881, de 25 de Novembro de 2019, Diário Oficial do Município do Rio de Janeiro [D.O.E.R.J.] 26.11.2019 (Braz.); Resolução "P" No. 1399, de 29 de Março de 2019, Diário Oficial do Município do Rio de Janeiro [D.O.E.R.J.] 01.04.2019 (Braz.).

[187] Buscher and Doody, *Global Innovators*, 15.

[188] Christopher Gaffney and Cerianne Robertson, "Smarter than Smart: Rio de Janeiro's Flawed Emergence as a Smart City," *Journal of Urban Technology* 25, no. 3 (2018): 11, https://doi.org/10.1080/10630732.2015.1102423.

[189] Frey, "World Cup 2014," 3.

model seemed to meet the needs of Rio, smaller jurisdictions might not have the capability of staffing and maintaining a new layer of management, even in the name of public safety.

Figure 14. Overhead View of the Center of Operations in Rio de Janeiro.[190]

Though the Center of Operations was designed to centralize the data and resources for maintaining SA of the city, some old habits have remained, including privatizing services and prioritizing the wealthy. Rio has a variety of privately owned infrastructure in the transportation sector, including buses, bridges, and rail systems. As detailed by Gaffney and Robertson, "Most of Rio's transportation systems are privatized and the city must reach an agreement with the concessionaries to deliver video feeds."[191] The gap in data acquisition has limited the ability of the Center of Operations to coordinate transportation issues. In a related issue, absent agreements with private transportation providers, the metropolitan areas remain uncovered by cameras, and the extended deployment of cameras and other IoT devices appears to be limited to the city's wealthier areas.[192] The limited deployment of sensors and cameras among denser populations hampers the Center of Operations' ability to mitigate incidents and respond quickly.

[190] Source: Bittencourt et al., "Evaluating Preparedness and Resilience Initiatives," 59.

[191] Gaffney and Robertson, "Smarter than Smart," 10.

[192] Gaffney and Robertson, 11.

Centralized operations and the integrated technology can only support the city response based on available data and SIGINT.

3. Analysis

With Rio de Janeiro as a case study, the emphasis on data integration provided an opportunity to benefit the community. The creation of the Rio Center of Operations represented a significant step in embracing technology and providing a service to the people of Rio. Rio adapted to a data-driven model of managing municipal services for everyday residents and city visitors. The codification of Rio's Center of Operations and the requirement for agencies to participate in the initiative set a foundation for continued improvement. By centralizing the full complement of city services into a single platform, Rio established a modern approach to city management. The expressed intention of rapidly detecting and responding to incidents would pull the role of emergency management into daily operations management. Such a role suits emergency management as a foundational element of city management rather than an after-the-fact response agency. Even with all the advancement and available technology, the built environment and the cultures of staff and residents played a significant role in developing this smart city. Inevitably, the technology must still meet the needs of the community served. Rio's case illustrates how a well-working system still needs continuous improvement to address the needs of an entire community.

D. SUMMARY

Implementing smart city technologies using IoT may improve the efficiency and effectiveness of city services, infrastructure, and the quality of life for residents. Chicago's AoT, New York City's DAS, and Rio de Janeiro's Center of Operations have shown that although smart city technologies can bring many benefits, they also come with challenges and limitations.

The case studies presented in this chapter demonstrate the potential benefits of smart city technologies in responding to emergencies. These technologies can provide real-time data, improve coordination and communication among different agencies, and ultimately lead to more efficient and effective emergency responses. Chicago's AoT has successfully provided valuable data on the city's environment and infrastructure, informing policy and urban design decisions. Using edge computing, AoT has provided efficient collection and analysis of data by extending the computation to the node. Computing at the edge helps to mitigate privacy and data security challenges to AoT by limiting data transmission and eliminating images after data extraction. Similarly, New York City's DAS has proven successful in providing valuable information to law enforcement officials by streamlining data collection and dissemination using ML and pattern recognition. In particular, DAS automatically alerts officers of potential threats in their area of responsibility for adjudication and subsequent action. Last, Rio de Janeiro has demonstrated a successful implementation of centralized IoT integrating all city systems and departments into the Center of Operations. Through a careful change management and planning process, an entire jurisdiction can adjust old habits and overcome artificial barriers through the intentional use of technology such as IoT.

Potential privacy violations and infringement on civil liberties remain a concern; however, through the careful documentation of policies and procedures, the case studies demonstrate a roadmap to mitigate potential risks. The similar approaches by Chicago and New York City to proactively document the authorized uses of AoT and DAS—sharing the drafts with constituents and interested parties and integrating feedback—have been proven viable solutions. As the systems innovate and add data sources, including potentially private, consumer-grade IoT, the privacy policies should also evolve and adapt to ensure citizen protection.

In summary, the case studies presented in this chapter demonstrate the potential benefits of smart city technologies in responding to emergencies. These technologies can provide real-time data, improve coordination and communication among different agencies, and ultimately lead to more efficient and effective emergency responses. The enhanced data collection, analysis, and applications allow Chicago, New York, and Rio de Janeiro to strike back against the notions of old cities and infrastructures. In the next chapter, additional case studies of Songdo, South Korea, and NEOM serve as exemplars of novel cities with foundational smart technologies embedded throughout urban centers, thus representing a new hope for cities.

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V. RETURN OF THE JEDI: THE NOVEL CITY APPROACH

> The Force is strong in my family. My father has it. I have it. My sister has it. [My city has it.]
>
> —Luke Skywalker, *Star Wars Episode VI: The Return of the Jedi*

While smart cities utilize information and communications technologies, including IoT, to improve data gathering and analysis for built environments, the novel city concept uses a technology foundation to build a new environment. Chapter IV discussed the smart city approach of adapting an existing city to integrated technologies, providing more data and insight into public services. Novel cities, or as Halegoua describes them, "smart-from-the-start cities," use integrated technologies and data analytics to build the resident experience.[193] This relative blank slate demonstrates a unique opportunity to provide enhanced services without the limitations of the built environment. These novel cities design services around technology, analogous to using "the Force." The following case studies review Songdo, South Korea, and NEOM, Saudi Arabia, as exemplars of novel cities with foundational smart technologies embedded throughout. While construction continues in Songdo, residents and businesses now call the area home. In contrast, NEOM remains under construction, with residents limited to staff. These reviews evaluate the integrated technologies and their use in emergency or disaster response. Each case study examines the respective city's design, explores the IoT technologies in use, and discusses the model's challenges.

A. SONGDO, SOUTH KOREA

Heralded as a future city, Songdo, South Korea, provides a novel approach to urban design due to the integration of technology as a priority. Designed and developed to be a smart city, Songdo utilizes emerging technologies, such as IoT and ML, to create a sustainable, livable, and efficient urban environment.[194] As one of the first novel cities to

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[193] Halegoua, *Smart Cities*, 44.

[194] Myung-Hee Kim, "Study on the Case of Songdo Smart City Based on the Citizen Participation Approach," *Webology* 19, no. 1 (2022): 4683, https://doi.org/10.14704/WEB/V19I1/WEB19312.

be driven by technological development, Songdo's current design and development encourage innovation in a whole city design lab.[195] Though initially proposed in 1988 to provide millions of housing units, according to Peyrard and Gelézeau, the Songdo project transitioned in 1994 "to become one of the most important nodes in the world economy network, like Hong Kong or Singapore."[196] Songdo represented an initiative for the South Korean government to bring cities into the future.

1. The Design

The South Korean government initially facilitated the development of Songdo and other similar projects, first dubbed "ubiquitous cities" in the early 2000s and then smart cities more recently.[197] Figure 15 depicts the South Korean government's strategic initiatives related to ubiquitous cities followed by smart cities. The policies provided a framework to develop long-term strategies and initiatives rather than isolated projects. In particular, according to the Ministry of Land, Infrastructure and Transport, South Korea provides "active policy support, such as expanding fiscal investment and drastic deregulation, for the successful development and expansion of smart cities."[198] Municipalities responded by establishing local structures to advance smart initiatives. In Songdo, a public–private partnership governs the city's development and design, leading to ambitious technological goals using various sensing technologies.[199] In particular, J. P. Morgan, Cisco Systems, and Gale International have provided significant investment and

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[195] "Songdo Provides the Spark for the Iot," Smart Cities World, October 21, 2016, https://www.smartcitiesworld.net/news/news/songdo-provides-the-spark-for-the-iot-1038.

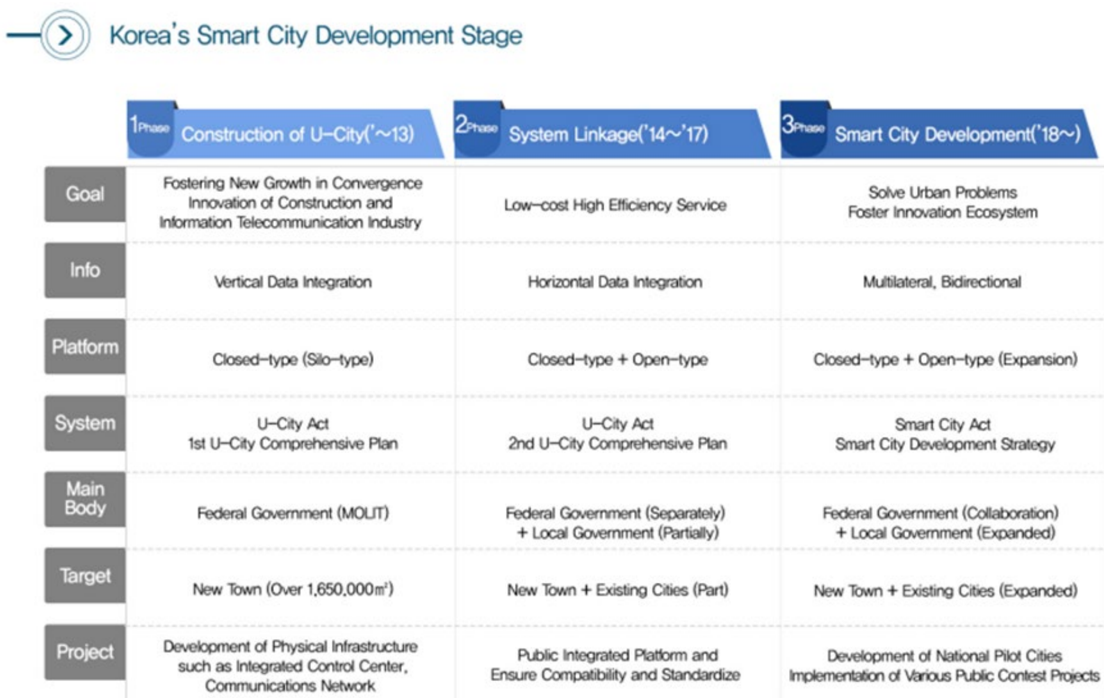
[196] Suzanne Peyrard and Valérie Gelézeau, "Smart City Songdo? A Digital Turn on Urban Fabric," *Seoul Journal of Korean Studies* 33, no. 2 (2020): 5, https://doi.org/10.1353/seo.2020.0019; Y. Kovalev et al., "Political Models of Smart Cities and the Role of Network Actors in Their Implementation (the Case of Vienna, Lyon, and New Songdo in Seoul)," *AIP Conference Proceedings* 2442, no. 1 (2021): 3, https://doi.org/10.1063/5.0075638.

[197] South Korean Ministry of Land, Infrastructure and Transport, *Korea's Smart City* (Sejong City: South Korean Ministry of Land, Infrastructure and Transport, 2023), https://smartcity.go.kr/wp-content/uploads/2022/09/2023-Smart-city-brochure.pdf.

[198] South Korean Ministry of Land, Infrastructure and Transport, *Korean Smart Cities* (Sejong City: South Korean Ministry of Land, Infrastructure and Transport, 2019), 6, https://smartcity.go.kr/wp-content/uploads/2019/08/Smart-city-broschureENGLISH.pdf.

[199] Anna Verena Eireiner, "Promises of Urbanism: New Songdo City and the Power of Infrastructure," *Space and Culture* (2021): 6, https://doi.org/10.1177/12063312211038716.

development in Songdo.[200] To achieve its goals, Songdo utilizes an interconnected system of IoT devices and ML to analyze collected data.



Korea's Smart City Development Stage

	1 Phase Construction of U-City('~13)	2 Phase System Linkage('14~'17)	3 Phase Smart City Development('18~)
Goal	Fostering New Growth in Convergence Innovation of Construction and Information Telecommunication Industry	Low-cost High Efficiency Service	Solve Urban Problems Foster Innovation Ecosystem
Info	Vertical Data Integration	Horizontal Data Integration	Multilateral, Bidirectional
Platform	Closed-type (Silo-type)	Closed-type + Open-type	Closed-type + Open-type (Expansion)
System	U-City Act 1st U-City Comprehensive Plan	U-City Act 2nd U-City Comprehensive Plan	Smart City Act Smart City Development Strategy
Main Body	Federal Government (MOLIT)	Federal Government (Separately) + Local Government (Partially)	Federal Government (Collaboration) + Local Government (Expanded)
Target	New Town (Over 1,650,000m²)	New Town + Existing Cities (Part)	New Town + Existing Cities (Expanded)
Project	Development of Physical Infrastructure such as Integrated Control Center, Communications Network	Public Integrated Platform and Ensure Compatibility and Standardize	Development of National Pilot Cities Implementation of Various Public Contest Projects

Figure 15. South Korean Smart City Strategic Initiatives.[201]

Songdo represents one of the most ambitious smart city projects in South Korea from the perspective of design, investment, and integrated technologies. According to Martin, Songdo "is one of the largest real estate development projects in history, with an estimated combined public and private input of US$35 billion in its central International Business District . . . alone."[202] The area selected for the development of Songdo used approximately 53 square kilometers of reclaimed wetlands, an area slightly smaller than

200 Glen David Kuecker and Kris Hartley, "How Smart Cities Became the Urban Norm: Power and Knowledge in New Songdo City," *Annals of the American Association of Geographers* 110, no. 2 (March 2020): 519, https://doi.org/10.1080/24694452.2019.1617102.

201 Source: South Korean Ministry of Land, Infrastructure and Transport, *Korean Smart Cities*, 7.

202 Bridget Martin, "Selectively Connected: New Songdo and the Production of Global Space," in *Asian Cities: Colonial to Global*, ed. Gregory Bracken (Amsterdam: Amsterdam University Press, 2015), 242, ProQuest Ebook Central.

the island of Manhattan in New York City.[203] Incorporated into the Incheon Free Economic Zone (IFEZ), Songdo benefits from a location close to South Korea's capital, Seoul, and adjacent to Incheon International Airport. The proximity to the economic drivers of the South Korean economy suggests an international prioritization.[204] From a pure design perspective, Songdo provides a reasonable alternative to Seoul for worldwide markets.[205] Martin describes Songdo as a "playground for planners, developers, and architects who snapped up the opportunity to pursue bold, mega-grained projects before the 2008 recession hit."[206] The design of Songdo demonstrates the ambitious hopes of attracting international residents and businesses with ample office and retail space and integrated technologies. In addition to the IFEZ financial incentives, including reduced taxes and regulations, the design of Songdo offers ample office, retail, and residential spaces.[207] Figure 16 provides a conceptual layout of Songdo by designers from KPF.[208] As Martin describes, the "emphasis on technology is integral to New Songdo's development and also reflects how South Korea is repositioning itself on the international stage through government programmes."[209] Connecting and integrating systems are expected to attract future residents and businesses, making Songdo a financial and technological world market.

[203] Sofia T. Shwayri, "A Model Korean Ubiquitous Eco-City? The Politics of Making Songdo," *Journal of Urban Technology* 20, no. 1 (January 2013): 44, https://doi.org/10.1080/10630732.2012.735409; Martin, "Selectively Connected," 246.

[204] Eireiner, "Promises of Urbanism," 5.

[205] Kaley Overstreet, "Building a City from Scratch: The Story of Songdo, Korea," Arch Daily, June 11, 2021, https://www.archdaily.com/962924/building-a-city-from-scratch-the-story-of-songdo-korea.

[206] Martin, "Selectively Connected," 247.

[207] Eireiner, "Promises of Urbanism," 6.

[208] "New Songdo City: Songdo International Business District," KPF, accessed February 4, 2023, https://www.kpf.com/project/new-songdo-city.

[209] Martin, "Selectively Connected," 250.

Figure 16. Songdo, South Korea, Area Map.[210]

2. INTEGRATED TECHNOLOGIES

Novel cities like Songdo, South Korea, use IoT sensors and devices throughout the urban center to monitor and control various systems and services. Technology prioritization sets a foundation for infrastructure design and development using ML algorithms to optimize system performance and improve the city's overall quality of life.[211] As Mohammadian and Rezaie observe, "Fundamentally, every aspect of public life in Songdo . . . founded on technology, ranging from an integrated public transport system

[210] Source: KPF, "New Songdo City: Songdo International Business District."

[211] Kim, "Study on the Case of Songdo Smart City," 4683.

to the government's emergency warning system," enhances the smart city's image.[212] In Songdo, sensors permeate the city in new ways, measuring everything. As Kovalev et al. further detail, "Electronic sensors and measuring devices are integrated in residential and office buildings, in the communication system, electricity, heat and water supply, transportation of goods, [and] garbage."[213] The placement and design of sensors throughout the city facilitate system performance assessments and help to improve public service delivery from transportation to waste management. Data from distributed sensors flow into central management systems whereby staff and city leadership make operational decisions.[214] The network of systems allows constant data monitoring and anomaly detection to address issues before incidents occur.

Songdo's IoT systems employ a coordinated command and control process to integrate the vast amount of data collected and make real-time decisions. While some systems utilize edge computing to make determinations remotely, every system centralizes data in a command and control center for automated analysis and optimization.[215] Songdo's Integrated Operations Center provides the physical location for staff to monitor city services and maintain operational control. The Integrated Operations Center incorporates services for crime prevention, disaster prevention, traffic management, environment, facility management, and citizen engagement (see Figure 17).[216] As Lee et al. describe, "The collected data is stored at the data base through the integrated platform and analyzed by application services and big data analysis to provide citizens with useful services."[217] The software employs ML algorithms to analyze signal data, images, and

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212 Hamid Doost Mohammadian and Fatemeh Rezaie, "Blue-Green Smart Mobility Technologies as Readiness for Facing Tomorrow's Urban Shock toward the World as a Better Place for Living (Case Studies: Songdo and Copenhagen)," *Technologies* 8, no. 3 (September 2020): 12, https://doi.org/10.3390/technologies8030039.

213 Kovalev et al., "Political Models of Smart Cities," 4.

214 Katie Huge and Justin Pau, "Songdo: The World's Smartest City?," UNC Institute for the Environment, June 8, 2019, https://ie.unc.edu/clean-tech-post/songdo-the-worlds-smartest-city/.

215 Martin, "Selectively Connected," 250; Huge and Pau, "Songdo," 2; Kovalev et al., "Political Models of Smart Cities," 4.

216 Sang Keon Lee et al., *International Case Studies of Smart Cities: Songdo, Republic of Korea* (New York: Inter-American Development Bank, 2016), 23, https://publications.iadb.org/en/node/12491.

217 Lee et al., 6.

audio and applies recommendations to specific platforms. Additionally, the Integrated Operations Center communicates with agencies beyond the boundaries of Songdo, including, as Lee et al. describe, "the Incheon City Traffic Information Center, Institute of Health and Environment, Korea Meteorological Administration, [and] Police Agency."[218] The Integrated Operations Center provides the daily management and emergency operations functions using an integrated system of systems to improve the experience of people living and working in Songdo.

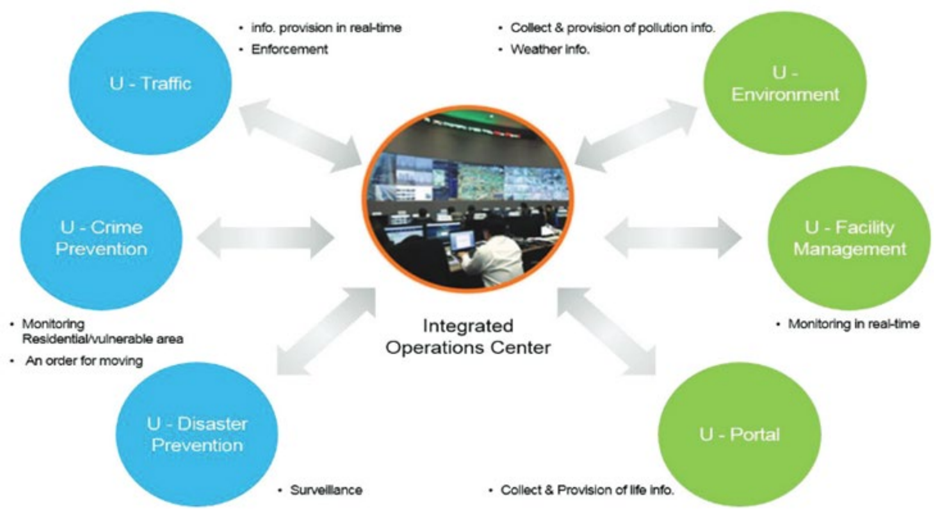

Figure 17. Functions of the Songdo Integrated Operations Center.[219]

The crime prevention system utilizes sensors, video, and audio to monitor Songdo for criminal activity proactively. The extensive network of cameras in particular forms an exponential resource for the Integrated Operations Center. Though the presence of cameras or CCTV in Korean cities does not stand out as unusual, the concentration of cameras in Songdo does.[220] Kovalev et al. observe, "Thousands of installed video cameras continuously monitor the situation on the streets, recreation areas, [and] playgrounds."[221]

[218] Lee et al., 16.

[219] Source: Lee et al., 14.

[220] Peyrard and Gelézeau, "Smart City Songdo?," 14.

[221] Kovalev et al., "Political Models of Smart Cities," 4.

The crime prevention system benefits from the availability of sensors in detecting vehicles and focusing attention on emerging incidents. The integrated technologies and processes present similarly to those of New York City's DAS.[222] As Lee et al. detail, "Based on the information collected from cameras and sound detectors, video images and on-site sounds are analyzed according to patterns."[223] As with DAS, anomaly detection alerts staff who evaluate (adjudicate) the information and then share it with appropriate personnel. In another example, Lee et al. describe the Integrated Operations Center's using the traffic management system to manipulate lights at "left turn lanes to allow the continuous traffic flow of emergency vehicles."[224] The crime prevention system provides a unique everyday resource to Songdo combined with additional systems.

The environment system includes a network of IoT devices that monitor environmental and weather impacts on the city. The Integrated Operations Center uses the collected data to improve the efficiency and sustainability of the city's systems and services.[225] The Integrated Operations Center conducts air quality monitoring for pollutants and other hazardous substances. Lee et al. describe a vast network of sensors—"wind velocity sensors, temperature and humidity sensors, insolation amount measuring sensors, UV ray sensors, sunshine sensors, rainfall sensors, air pressure sensors, yellow dust measurement sensors, road surface sensors, visibility sensors, and visibility cameras"—used to inform the environment management system.[226] In turn, the Integrated Operations Center uses the environmental data as SIGINT for other city services such as transportation management and disaster prevention.[227] In deploying IoT technologies like Chicago's AoT, the environmental management system collects data to inform the Integrated Operations Center of specific microclimates throughout the city. The Integrated

[222] The New York City Police Department's Domain Awareness System integrates IoT technologies to collect data to improve response to public safety issues and threats. A case study on DAS appears in Chapter IV.

[223] Lee et al., *International Case Studies of Smart Cities*, 22.

[224] Lee et al., 8.

[225] Shwayri, "A Model Korean Ubiquitous Eco-City?," 52.

[226] Lee et al., *International Case Studies of Smart Cities*, 26.

[227] Eireiner, "Promises of Urbanism," 7.

Operations Center utilizes the data to inform all other services, including facility management, disaster prevention, and traffic management.

Songdo's facility management system includes a network of sensors, cameras, and other IoT devices that monitor various aspects of the city's facilities and infrastructure. The collected data improve the daily efficiency and sustainability of facilities and systems operating within the city. One example of networked sensors comes from Songdo's waste management system, which leverages IoT to improve efficiency and sustainability. Outwardly, the system features the absence of garbage trucks in the city.[228] Inwardly, the Songdo waste management system operates as a network of sensors that monitor and control the flow of waste throughout the city, including within the homes and apartments of residents. Sensors control access to waste bins, detect proper containers, and assess the residents' compliance with sorting requirements.[229] As Eireiner describes, "If the resident acts in accordance to the rule set by the system, the trash gets sucked through underground pipes into the 'Third Zone Automated Waste Collection Plant,' where 76% of waste is recycled and the rest is burned to produce energy."[230] The pneumatic waste collection system provides automated service to residential units and public waste receptacles, eliminating the need for traditional garbage and recycling trucks on the street (see Figure 18).[231] The required sorting and automated collection system increases the recycling rate in the city, reduces the amount of waste that goes to landfills, and decreases infrastructure traffic on the road. Songdo's smart waste management system has improved the efficiency and sustainability of the city's waste management efforts. By leveraging IoT technology, the city monitors and controls the flow of waste more effectively for everyday use, reducing its impact on the environment and improving the quality of life for its residents.

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[228] Shwayri, "A Model Korean Ubiquitous Eco-City?," 47; Christoph Neidhart, "Müllschlucker mit Augen" [Garbage Chute with Eyes], *Süddeutsche Zeitung* [South German Newspaper], July 18, 2017, https://www.sueddeutsche.de/wirtschaft/sz-serie-smart-cities-muellschlucker-mit-augen-1.3592814.

[229] Eireiner, "Promises of Urbanism," 4; Neidhart, "Müllschlucker mit Augen."

[230] Eireiner, "Promises of Urbanism," 4; Ross Arbes and Charles Bethea, "Songdo, South Korea: City of the Future?," *Atlantic*, September 27, 2014, https://www.theatlantic.com/international/archive/2014/09/songdo-south-korea-the-city-of-the-future/380849/.

[231] KPF, "New Songdo City."

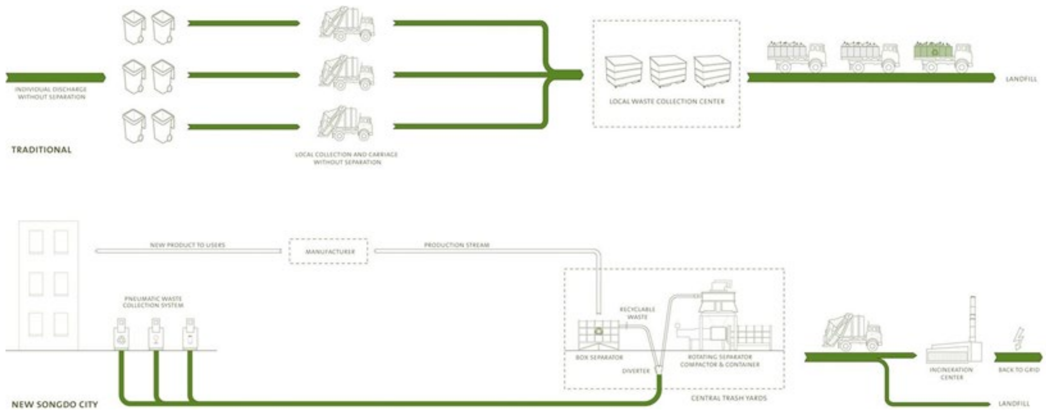

Figure 18. Design of Songdo's Integrated Waste Management System.[232]

The Integrated Operations Center provides the physical location to manage the system of systems combining disaster response with day-to-day operations. Songdo's disaster prevention system utilizes a combination of crime prevention, traffic, environment, and facility management systems to analyze, predict, and respond to potential disasters.[233] Given Songdo's foundation on reclaimed land, the Integrated Operations Center utilizes deployed sensors to evaluate and share "information when disaster occurs, monitoring for land subsidence, flooding, and . . . fires."[234] In addition to its monitoring capabilities, the disaster prevention system also includes a public warning system that can quickly notify residents and visitors of potential dangers, allowing them to take appropriate action.[235] This system can be activated through various methods, including alarms, text messages, and mobile apps, ensuring rapid and wide dissemination of information.[236] The disaster prevention system in Songdo is similar to the traditional emergency management roles in the United States. In contrast, Songdo's disaster prevention system has integrated access to other city services and utilizes data and ML to predict and respond to emergencies. By

[232] Source: KPF.

[233] Lee et al., *International Case Studies of Smart Cities*, 24.

[234] Lee et al., 32.

[235] Lee et al., 24.

[236] Seungho Yoo, "Songdo: The Hype and Decline of World's First Smart City," in *Sustainable Cities in Asia*, ed. Federico Caprotti and Li Yu (London: Routledge, 2018), 11; Lee et al., *International Case Studies of Smart Cities*, 24.

leveraging the role of the Integrated Operations Center, the city predicts, monitors, and responds to potential disasters and emergencies in real time, improving the safety and well-being of its residents and visitors.

3. CHALLENGES AND LIMITATIONS

Developing the novel Songdo city has come with challenges and limitations even without the burden of existing built infrastructure. This section outlines a few issues while noting actions taken by the municipality to address them.

Despite Songdo's intended design and development to attract a global residency and business district, the city remains a vastly unpopulated space with underutilized technology. In most literature discussing Songdo's governance or technology, researchers note the absence of people in the city, or at least well below the expected population.[237] As Eireiner notes, "Songdo City is perfectly laid out to facilitate the production, distribution, and consumption of goods and services, [yet] it is vastly unattractive to [Koreans] and foreigners [alike]."[238] While considerable effort and planning have gone into the designed layout, infrastructure, and services, the city lacks an element that draws in residents. Shwayri points to the 30 years of volatility in the development of Songdo "shaped by government policy with periods of support and indifference."[239] Disjointed leadership, intermixed with multiple recessions, led to gaps in public policy development.[240] The novel city had the advantage of building new infrastructure, but the developers seemingly failed to consider the people who would live there. As Martin describes, the "residents of the city are not involved in the processes of discussing the

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237 Eireiner, "Promises of Urbanism," 3; Mohammadian and Rezaie, "Blue-Green Smart Mobility Technologies," 11; Aylin Ilhan, Rena Moehlmann, and Wolfgang Stock, "Citizens' Acceptance of U-Life Services in the Ubiquitous City Songdo," in *Citizen's Right to the Digital City: Urban Interfaces, Activism, and Placemaking*, ed. M. Foth, M. Brynskov, and T. Ojala (Singapore: Springer, 2015), 219, https://doi.org/10.1007/978-981-287-919-6_12.

238 Eireiner, "Promises of Urbanism," 9.

239 Shwayri, "A Model Korean Ubiquitous Eco-City?," 53.

240 Peyrard and Gelézeau, "Smart City Songdo?," 5; Shwayri, "A Model Korean Ubiquitous Eco-City?," 42.

future development."[241] The lack of citizen engagement thus limits the ability of developers to formulate a viable value proposition for the residents.[242] Songdo has been marketed as a futuristic city with embedded sensor technologies, but the residents do not utilize the technology or do not have access to the expected systems. Simply providing technology and embedded sensors in services does not necessarily mean the residents will use the features.

In Songdo, the residents challenged the expectation of city leaders and developers that the residents would use the technologies. Of the available technologies, residents have used only the systems that provide the most direct service application. Peyrard and Gelézeau observe that residents "create their own smart life by 'poaching' fragments of the things around them in ways that may not exactly reflect the smart life originally planned for them."[243] Though the technologies appear to provide usefulness when residents first move to Songdo, demand wavers as the practical use of technologies declines.[244] Martin states that the "emphasis on technology can be linked to disaster preparedness and energy efficiency as well as to a regime of surveillance and increasing personal responsibilization."[245] In short, while the technologies can serve the community, the constant data collection and monitoring seem to burden the individual residents with complying with rules and regulations. For example, the waste management system requires residents to sort waste into separate bags bought from specialty retailers to avoid warnings and fines.[246] The requirements of using the perceived helpful technology could create barriers for the end user or resident. In sum, a divide remains between the available technology and the residents who use it.

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241 Kovalev et al., "Political Models of Smart Cities," 4.

242 David J. Bland and Alexander Osterwalder, *Testing Business Ideas* (Hoboken, NJ: Wiley, 2020), 22.

243 Peyrard and Gelézeau, "Smart City Songdo?," 15.

244 Yoo, "The Hype and Decline of World's First Smart City," 4.

245 Martin, "Selectively Connected," 250.

246 Eireiner, "Promises of Urbanism," 4; Neidhart, "Müllschlucker mit Augen."

4. ANALYSIS

Building a city from scratch has advantages, and Songdo, South Korea, has benefited by developing new infrastructure and integrated smart technologies. The emphasis on technology has led to integrating daily city functions such as street light management, garbage disposal, and public safety into a cohesive system. The Integrated Operations Center provides city leaders with a central location to assess the city's status and make dynamic decisions toward preventing or resolving issues more quickly every day. The disaster prevention system utilizes traffic, environment, and facility management data to maintain SA by analyzing IoT technologies as SIGINT. Building the city from the ground up facilitated the move to a technologically focused system without the need to overcome built environments or limitations; however, the city's development lacked necessary engagement with the anticipated residents. Any future city should consider involving the expected populations in the development and requirements of any technological system.

Songdo, South Korea, demonstrates how a novel city can build its infrastructure around the use of technology without the concerns and limitations of an existing built environment. In particular, Songdo's Integrated Operations Center uses the SIGINT generated by IoT-based systems operated daily to maintain a disaster prevention system. While Songdo faces challenges in attracting residents and businesses, the city's infrastructure stands ready for population growth. In contrast, the region of NEOM in Saudi Arabia began construction in 2017 and anticipates complete integration with IoT-based technologies.[247] The following section examines the proposed region of NEOM and the basis of technological development for the next novel city.

B. NEOM, SAUDI ARABIA

The NEOM project represents the cutting edge of possibilities in city development, focusing on technology. In October 2017, Prince Mohammed bin Salman announced the

[247] Rahma M. Doheim, Alshimaa A. Farag, and Samaa Badawi, "Smart City Vision and Practices across the Kingdom of Saudi Arabia," in *Smart Cities: Issues and Challenges*, ed. Anna Visvizi and Miltiadis D. Lytras (Amsterdam: Elsevier, 2019), 313, https://doi.org/10.1016/B978-0-12-816639-0.00017-X.

planned development of NEOM in previously undeveloped Northwestern Saudi Arabia.[248] As Doheim, Farag, and Badawi describe, "The point of building in a very new land is to avoid the common features of conventional cities that everything is new: fresh investments, young people, robotic population, new technology, and new regulations."[249] The grand project serves as a policy change from reliance on fossil fuels to technology.[250] Aligning with Saudi Vision 2030, NEOM aims to lead Saudi Arabia into the future, prioritizing technology integration into the fabric of the design.[251] Ashehri details that Saudi Arabia "has decided to adopt Digitization and AI as the key enablers of its new era."[252] Announced with an initial project investment of $500 billion, the design of NEOM represents the world's most ambitious smart city project.[253] Farag describes the aim of this significant investment: "to create the city that is most efficient, happiest, safest, and healthiest place to work and live in, and to lead the world to the future."[254] Though primarily theoretical while under construction, the design and technology integrations provide a unique case study of using IoT systems to develop smart infrastructure.

1. The Design

The NEOM project provides a rare design opportunity to usher in a transformative era for Saudi Arabia. The NEOM project includes individual city developments, such as The Line (a linear city), Oxagon (an industrial city), Sindalah (a luxury vacation island),

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[248] Farag, "The Story of NEOM City," 37; Doheim, Farag, and Badawi, "Smart City Vision and Practices," 313.

[249] Doheim, Farag, and Badawi, "Smart City Vision and Practices," 313.

[250] Elizabeth Dickinson, "Saudi Arabia Is Betting Its Future on a Desert Megacity," *Foreign Policy*, November 3, 2017, https://foreignpolicy.com/2017/11/03/saudi-arabia-is-betting-its-future-on-a-desert-megacity-neom-qaddiya-vision-2030/.

[251] Nadia Yusuf and Dareen Abdulmohsen, "Saudi Arabia's NEOM Project as a Testing Ground for Economically Feasible Planned Cities: Case Study," *Sustainability* 15, no. 1 (January 2023): 2, https://doi.org/10.3390/su15010608.

[252] Rana Ashehri, "Governance of Artificial Intelligence in KSA (NEOM as a Model)," *International Journal of Advanced Studies* 9, no. 1 (2019): 73, https://doi.org/10.12731/2227-930X-2019-1-64-81.

[253] Ashehri, "Governance of Artificial Intelligence in KSA," 77; Farag, "The Story of NEOM City," 37; Benjamin Grab, Wiebke Geldmacher, and Razvan Ionescu, "Managing the Risks Associated with the Cyber City Project—Case Study of the NEOM Project" (paper presented at Innovation Management and Education Excellence through Vision 2020, Milan, Italy, April 2018), 2.

[254] Farag, "The Story of NEOM City," 36.

and Trojena (a mountainous resort), and occupies multiple locations in an undeveloped Saudi Arabian region.[255] Ashehri describes the region as the "north-west of Saudi Arabia in Tabuk, including a marine land located within the Egyptian and Jordanian borders of a total area of 26,500 km^2 extending 460 km on the coast of [the] Read Sea."[256] The location provides NEOM access to trade routes between Egypt and Jordan and accessible land, air, and sea transit.[257] Additionally, the site offers the projected opportunity for sustainable city development. As Doheim, Farag, and Badawi describe, the "NEOM location is blessed by the richness of mineral resources, oil, and gas, in addition to . . . natural resources such as . . . perennial solar resources (20 MJ/m^2) and . . . wind speed (an average of 10.3 m/s)."[258] The area allocated to the NEOM project facilitates the development of infrastructure dependent on renewable energy using solar and wind resources.[259] The Line is the prototype city within the larger NEOM project and provides the testing ground for technology integration and future development.

When evaluating the projects within NEOM, The Line is the focal point for technological development and urban living. While urban planners have considered linear city designs since the 19th century, The Line in NEOM presents a modern, technologically focused model.[260] According to the formal announcement from the NEOM project, the

255 "About Page," NEOM, accessed February 21, 2023, https://www.neom.com/en-us/about.

256 Ashehri, "Governance of Artificial Intelligence in KSA," 76.

257 Farag, "The Story of NEOM City," 37.

258 Doheim, Farag, and Badawi, "Smart City Vision and Practices," 313.

259 Jefferson A. Riera et al., "Simulated Co-optimization of Renewable Energy and Desalination Systems in NEOM, Saudi Arabia," *Nature Communications* 13, no. 1 (2022): 3, https://doi.org/10.1038/s41467-022-31233-3; Hegazy Rezk, Mohammed Alghassab, and Hamdy A. Ziedan, "An Optimal Sizing of Stand-Alone Hybrid PV-Fuel Cell-Battery to Desalinate Seawater at Saudi NEOM City," *Processes* 8, no. 4 (April 2020): 2, https://doi.org/10.3390/pr8040382; "HRH Crown Prince Mohammed bin Salman Announces Designs for the Line, the City of the Future in NEOM," NEOM, July 25, 2022, https://www.neom.com/en-us/newsroom/hrh-announces-theline-designs.

260 Natalia E. Paszkowska-Kaczmarek, "The Line—The Saudi-Arabian Linear City Concept as the Prototype of Future Cities," *Architecturae et Artibus* 13, no. 2 (2021): 34, https://doi.org/10.24427/aea-2021-vol13-no2-03.

design of The Line includes a structure "only 200 meters wide, 170 kilometers long and 500 meters above sea level."[261] Figure 19 depicts a rendering of the anticipated structure of The Line.[262] The Line concept expects to condense the footprint of an estimated nine million residents to preserve nature and maximize service resources.[263] Sections within The Line create the equivalent of neighborhoods in traditional cities. As Paszkowska-Kaczmarek describes, "The Line will be composed of a 170 km chain of settlements (named: modules) hyper-connected by the high-speed underground train and/or hyperloop transportation."[264] Figure 20 illustrates the modules, which include residential units and retail, educational, and leisure amenities.[265] While the success of The Line depends mainly on the continuous design and construction of the project, Prince Mohammed bin Salman has emphasized the importance of technology integration into The Line and the entire NEOM project.

Figure 19. A Rendering of "The Line."[266]

[261] NEOM, "Salman Announces Designs for the Line."

[262] "The Line: New Wonders for the World," NEOM, accessed February 23, 2023, https://www.neom.com/en-us/regions/theline.

[263] NEOM, "Salman Announces Designs for the Line."

[264] Paszkowska-Kaczmarek, "The Line," 39.

[265] NEOM, "The Line."

[266] Source: NEOM.

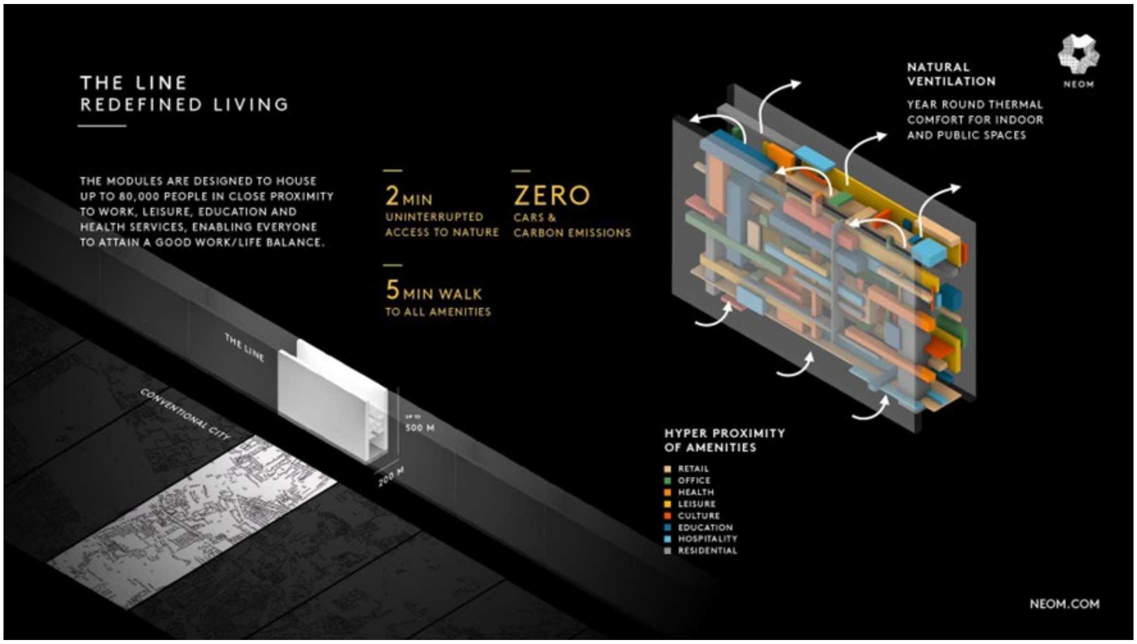

Figure 20. The Line's Modular Design.[267]

2. Integrated Technologies

NEOM utilizes technology as the foundation for building The Line as the next smart city. NEOM project leadership expects a city that leverages technology to adapt to its residents and businesses and becomes a cognitive system. Mostashari et al. define a cognitive system as "one that learns and adapts its behavior based on past experiences and is able to sense, understand and respond to changes in its environment."[268] Beyond a network of sensors and devices that collect data, all of NEOM's services and industries will be linked through an AI system. Ashehri explains that each sector within NEOM "will be closely linked to AI via different applications that are almost in tune with human desires and requirement [s]."[269] The linkage of all sectors to AI indicates that technology will not simply enhance the living conditions of residents and businesses in NEOM but will provide the foundation for living and working in NEOM. To expand on the use of technology,

[267] Source: NEOM.

[268] Ali Mostashari et al., "Cognitive Cities and Intelligent Urban Governance," *Network Industries Quarterly* 13, no. 3 (2011): 3.

[269] Ashehri, "Governance of Artificial Intelligence in KSA," 78.

Joseph Bradley, chief executive officer of Tonomus, explains NEOM's ideal technological integration: "From a technological perspective this means an interconnected, intelligent and resilient environment; where everything works together holistically to provide a predictive, personalized and immersive experience—enabled by autonomous, self-healing services that enhance daily life."[270] NEOM intends to integrate its technological systems into every development aspect, beginning with the design and construction phases.

The design and construction phase for NEOM and The Line began with a full digitization of the project. Regarding transitioning construction machinery to AI, Roger Nickells, head of design and construction at NEOM, says, "When you start from scratch, it is much easier to design for integration as you do not have to retrofit."[271] Throughout the design and construction phases, NEOM intends to drive technological development. Every technological advantage, including DTs, will transition to use during regular operations. Developing comprehensive DTs at the design and construction phase allows NEOM to simulate and test ideas before construction.[272] As Nickells describes, "We need to build, test and [perform a] trial on the digital-twin data-sharing platforms so that simulations enable us to monitor and track performance."[273] Monitoring the performance of services and the city's status also benefits the public safety elements. Like the technologies used in traditional smart cities and Songdo, South Korea, NEOM may utilize integrated technologies for preparedness and response. The data collected and analyzed using ML could anticipate emergencies. Bradley provides further evidence by describing "a cognitive technology ecosystem—future-ready computing and a truly intelligent universal platform that's intuitive, predictive and immersive."[274] While the details and full capabilities of the cognitive technology ecosystem remain under development and proprietary, the emphasis on technology in NEOM has spurred the

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[270] "Changing the Future of Technology & Digital," NEOM, accessed August 4, 2022, https://www.neom.com/en-us/sectors/technology-and-digital.

[271] "The Future of Design and Construction," NEOM, accessed August 4, 2022, https://www.neom.com/en-us/sectors/design-and-construction.

[272] NEOM.

[273] NEOM.

[274] NEOM, "Changing the Future of Technology & Digital."

creation of subsidiaries. In particular, the creation of Tonomus has led to the development of NEOM's metaverse, XVRS.

By investing $1 billion in U.S. dollars, NEOM's technology and digital subsidiary focused on setting the pace for integrated and cognitive technology development in cities.[275] NEOM has developed a cognitive metaverse platform to combine DTs and immersive mixed reality for use within the region. Mystakidis explains that a "metaverse is based on technologies that enable multisensory interactions with virtual environments, digital objects and people."[276] Bradley describes the intentions behind the investment as the "incredible connectivity, frontier technologies, computing power and user choice that power a cognitive community."[277] Though NEOM likely intends to market XVRS to other smart cities, combining DTs and mixed reality could provide a roadmap for the next generation of emergency management and public safety response.[278]

The XVRS platform has yet to receive an overall evaluation but could provide the future for interacting with city services. NEOM's technology and digital subsidiary announced the XVRS platform at Saudi Arabia's LEAP22 event in February 2022, among a series of updates for the project.[279] Saadeh describes XVRS as "the first project of its kind, a 3D cognitive digital twin platform enabling a groundbreaking 'mixed-reality' urban living model."[280] The theoretical use of the platform includes interacting with both the physical and digital city in real time.[281] XVRS portends to provide residents, businesses,

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275 "NEOM to Launch Cognitive Digital Twin Metaverse Platform," Smart Cities World, February 3, 2022, https://www.smartcitiesworld.net/digital-twins/digital-twins/neom-to-launch-cognitive-digital-twin-metaverse-platform; Amira Saadeh, "KSA's XVRS: Cognition at the Heart of the Metaverse," Inside Telecom, February 19, 2023, https://insidetelecom.com/ksa-xvrs-cognition-at-the-heart-of-the-metaverse/.

276 Stylianos Mystakidis, "Metaverse," *Encyclopedia* 2, no. 1 (March 2022): 487, https://doi.org/10.3390/encyclopedia2010031.

277 NEOM, "Changing the Future of Technology & Digital."

278 Saadeh, "KSA's XVRS."

279 Smart Cities World, "NEOM to Launch Cognitive Digital Twin Metaverse Platform."

280 Saadeh, "KSA's XVRS."

281 Sofia Serrano, "NEOM Tech & Digital Co. Unveils XVRS, a Cognitive Digital Twin Metaverse Platform," *Campaign Middle East* (blog), February 2, 2022, https://campaignme.com/neom-tech-digital-co-unveils-xvrs-a-cognitive-digital-twin-metaverse-platform/.

and presumably city departments and services with the ability to interact with the physical environment in a mixed-reality setting through the metaverse.

3. Challenges and Limitations

Developing the world's most ambitious smart city concept comes with challenges and limitations, even with $500 billion pledged to the project. This section outlines a few issues while noting potential actions that NEOM could take to address them.

The NEOM project has the potential to drive innovation and improve the use of technology for cities and emergency response; however, the project faces several challenges to its success. Due to NEOM's grandeur and emerging technologies, one significant challenge stems from the enormity of the NEOM project, which ranges from the completion timeline to the foundational technology announced by leadership.[282] Regarding the aggressive timeline and ambitious projects, Algumzi notes, "Applications of robotic services powered by . . . [AI] are not yet fully operational, and . . . with a short timeline for completion (2030), represent a challenging process that requires the collaboration of various entities in the design and development of the city."[283] Developing edge technologies takes time and could face setbacks that jeopardize the projected timeline. Additionally, investor confidence wanes with uncertainty, and some people may not fully understand the technological concepts proposed by NEOM.[284] Grab, Geldmacher, and Ionescu suggest NEOM ought to move as quickly as possible and "work towards the early presentation of a prototype."[285] An opportunity to test the platforms proposed by NEOM's developers would help any potential resident or business begin to understand the practical application. A prototype could help make NEOM seem more real without diminishing the grandeur and ambition of the project, despite internal concerns about proprietary systems.

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282 Vivian Nereim, "MBS's $500 Billion Desert Dream Just Keeps Getting Weirder," Bloomberg, July 14, 2022, https://www.bloomberg.com/features/2022-mbs-neom-saudi-arabia/.

283 Areej Algumzi, "Risks and Challenges Associated with NEOM Project in Saudi Arabia: A Marketing Perspective," *Journal of Risk and Financial Management* 15 (2022): 8, https://doi.org/10.3390/jrfm15090381.

284 Grab, Geldmacher, and Ionescu, "Managing the Risks Associated with the Cyber City Project," 7.

285 Grab, Geldmacher, and Ionescu, 10.

Nevertheless, the grandeur and ambition may also spur additional challenges internal to Saudi Arabia and the broader region.

NEOM's ambitious project goals have propelled Saudi Arabia into the future by aligning with Vision 2030, but internal and regional conflicts may arise. The supporting policy shifts announced by Prince Mohammed bin Salman have started a shift away from the strict fundamentalist Wahhabism faith.[286] Aly describes, "Cinemas have been opened and women are now able to attend concerts and drive, but are still imprisoned if they demand greater freedoms."[287] These policy changes have begun to take hold and attract more international investors and adopters. By developing NEOM, Prince Mohammed bin Salman has demarcated and pivoted toward a different future.[288] However, as Grand and Wolff detail, "That rebranding effort was severely derailed by the murder of [Jamal] Khashoggi."[289] NEOM remains the critical tipping point in Prince Mohammed bin Salman's attempts to modernize Saudi Arabia. NEOM's success could depend on the purported alternate rule of law that will separate it from the rest of Saudi Arabia, as suggested by the prince.[290] New residents, businesses, and tourists must trust the law for NEOM to overcome the cultural challenges.

Finally, as with all other IoT systems and data-driven processes, privacy remains a concern with the NEOM project. The collection and security of data present a significant risk to the trust potential residents and businesses have in the developing infrastructure.[291] With the anticipated cognitive environment and constant data collection, fear over who can access data could become a barrier to adoption. Leadership within NEOM has acknowledged the risk and pledged to provide innovative solutions to resolve privacy concerns. As Joseph Bradley describes, "We enable citizens here to control their data

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286 Farag, "The Story of NEOM City," 40.

287 Hend Aly, "Royal Dream: City Branding and Saudi Arabia's NEOM," *Urban Development* (2019): 100, https://doi.org/10.17192/META.2019.12.7937.

288 Dickinson, "Saudi Arabia Is Betting Its Future on a Desert Megacity," 1.

289 Stephen Grand and Katherine Wolff, *Assessing Saudi Vision 2030: A 2020 Review* (Washington, DC: Atlantic Council, 2020), 59, https://www.jstor.org/stable/resrep29468.

290 Grab, Geldmacher, and Ionescu, "Managing the Risks Associated with the Cyber City Project," 7.

291 Algumzi, "Risks and Challenges Associated with NEOM," 7.

privacy, deciding what personal data may be captured, used and stored—by what devices and platforms, for what purpose and in what context."[292] One example of personal control over data takes the form of NEOM's new M3LD platform. As described by a press release from NEOM, "M3LD is able to find out who is in possession of a user's data, monitor how it is being used, and provide recommendations on privacy settings for all their digital accounts."[293] The proposed M3LD platform empowers end users to take more control and make financial gains from their data. Saadeh describes M3LD as an "end-to-end consent management platform."[294] If M3LD can uphold the purported features, NEOM may have developed the reassurance that any resident or business wants and needs. M3LD may also provide a model for other smart cities to empower residents with more control over their data.

When considering NEOM as a case study using IoT and interconnected systems, many questions arise. Limited practical examples exist given the multiple projects still in the design and construction phase.

4. Analysis

At this current stage of development, the people creating the technology and designing the infrastructure have displayed boundless confidence and optimism in the opportunities and potential of the NEOM project. NEOM and its leadership focus on the philosophy of what might be possible rather than the limiting framework of what is possible. The future integration of systems could add systems similar to New York City's DAS, including the ability to dispatch law enforcement, fire suppression, and other city services before emergencies develop into disasters. Emergency managers with access to a system like XVRS could and should leverage the real-time data as SIGINT to predict emergencies and initiate a response quickly. Of the many challenges that NEOM faces,

[292] NEOM, "Changing the Future of Technology & Digital."

[293] "NEOM Tech & Digital Co. Announces M3LD—A Groundbreaking Platform Enabling Users to Control and Earn from Personal Data," PR Newswire, February 1, 2022, https://www.prnewswire.com/ae/news-releases/neom-tech-amp-digital-co-announces-m3ld-a-groundbreaking-platform-enabling-users-to-control-and-earn-from-personal-data-840562733.html.

[294] Saadeh, "KSA's XVRS."

production will likely demonstrate true success or failure. While construction progresses with limited images available, NEOM needs to produce tangible products to make the idea of NEOM a reality.

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VI. FINDINGS AND RECOMMENDATIONS

Try not. Do or do not. There is no try.

—Yoda, *Star Wars Episode V: The Empire Strikes Back*

Implementing IoT technologies can revolutionize emergency management and response by providing real-time data, improving communication and coordination, and leading to more efficient and effective emergency responses. The availability of IoT systems continues to grow exponentially, including IoT systems used by governmental agencies. IoT can provide SIGINT to inform SA in EOCs, provided the organization prepares for and uses the technology intentionally and integrates systems from daily processes. The case studies presented in this thesis demonstrate how IoT systems used for daily processes can facilitate ongoing monitoring and status updates. Cities can use IoT systems to set baseline data readings and ML to detect anomalies within the community. The IoT systems can signal a change detected to a human intermediary or automatically initiate an emergency response. The early detection and assessment of a change in the environment can help mitigate the intensity of an emergency by sending emergency responders before the situation worsens. Finally, IoT sensors deployed in the community can similarly identify when an affected area has returned to the baseline, allowing the community to return to normal more quickly. While concerns regarding privacy and civil liberties remain prevalent, the case studies also demonstrate a roadmap to mitigate potential risks through the careful documentation of policies and procedures. Looking ahead, Songdo, South Korea, and NEOM in Saudi Arabia provide examples of how new cities can use technology to build a smart foundation while engaging with anticipated residents to meet their needs. As IoT technology evolves, emergency managers must adapt and utilize these advancements to enhance operations and protect communities.

A. SUMMARY OF FINDINGS

The *National Preparedness Goal* and the *National Incident Management System* guide emergency management agencies nationwide. Emergency management agencies develop processes to promote SA by gathering EEIs from pre-identified sources. The gathering of EEIs establishes the simulated response bell curve, as depicted in Figure 21. Public safety agencies initiate a response based on a signal from the community, including 9-1-1 calls. The intensity of the emergency or disaster rises to a peak and falls due to mitigation and response efforts. The jurisdiction returns to normal as the event subsides. In many cases, the sources of information require specialized access and skill sets; however, departments and agencies rely on interconnected systems to provide real-time monitoring and statuses. In many jurisdictions, the gap in maintaining SA to facilitate executive decision-making lies with the availability of personnel to access and interpret departmental systems and disseminate the information. By automating access to the daily information or data and establishing processes to analyze the information quickly, emergency management may bridge the gap and improve decision-making in the EOC.

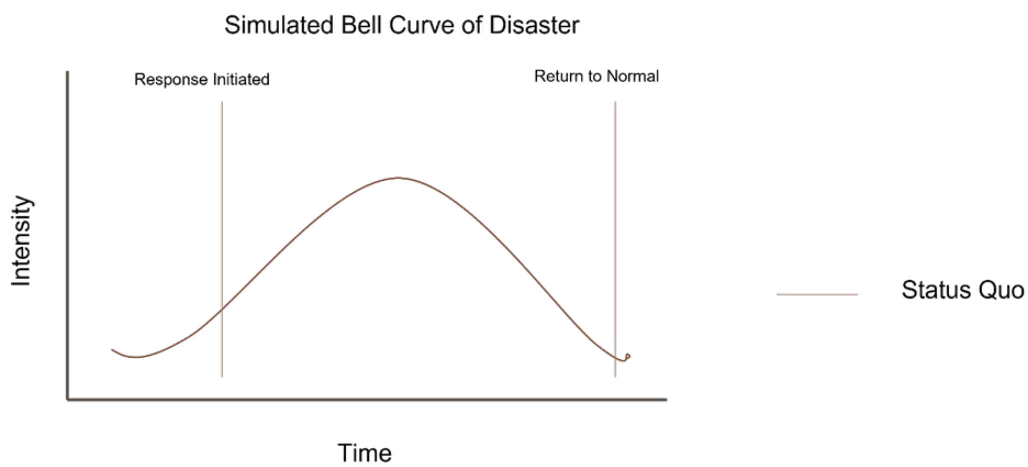

Figure 21. A Simulated Bell Curve of a Disaster, Repeated from Chapter II.[295]

IoT has the potential to revolutionize emergency management by providing real-time data and improving communication, coordination, and decision-making. Consumer- and industrial-grade IoT sensor networks, environmental monitoring, location tracking,

[295] Adapted from Department of Homeland Security, *National Disaster Recovery Framework*, 5, with help from data analyst Cristian Ramirez at the Center for Homeland Defense and Security's Strategic Communications.

and communication networks can help emergency managers predict and prepare for disasters. By integrating IoT systems used by various departments within a jurisdiction, emergency services may respond rapidly, lessen the overall intensity of events, and provide recognition for a return to normal (see Figure 22). Using the available data from a network of IoT systems represents a possible next phase of IoT for cities and government entities. Implementing smart city technologies with IoT could improve the efficiency and effectiveness of city services, infrastructure, and the quality of life of residents. IoT-enabled smart cities may provide emergency managers with real-time intelligence about traffic, energy usage, and other factors affecting emergency response, the goal of which is to flatten the intensity curve.

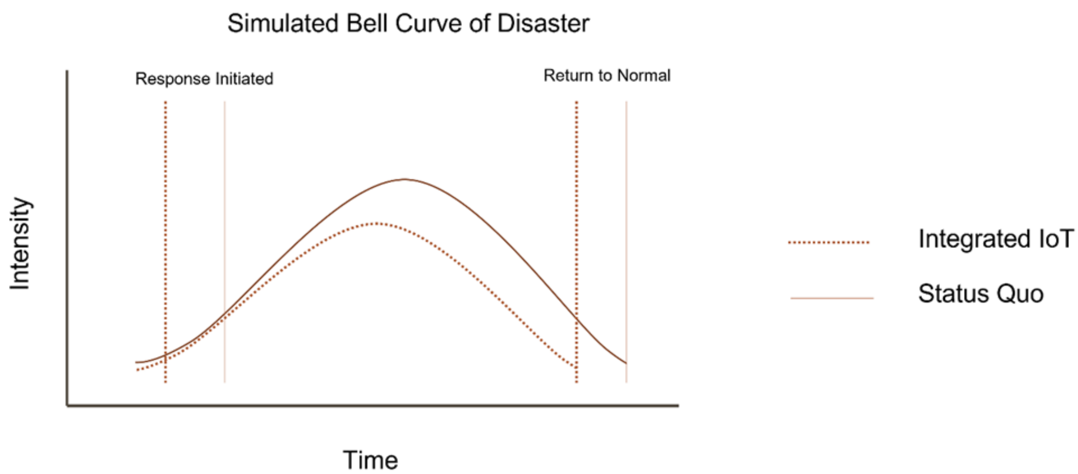

Figure 22. A Simulated Bell Curve of a Disaster with IoT Integrated into Daily Operations.[296]

The case studies presented in Chapter IV demonstrate the potential benefits of smart city technologies in responding to emergencies. These technologies can provide real-time data, improve coordination and communication among different agencies, and ultimately lead to more efficient and effective emergency responses. Chicago's AoT has successfully

296 Adapted from Department of Homeland Security, *National Disaster Recovery Framework*, 5, with help from data analyst Cristian Ramirez at the Center for Homeland Defense and Security's Strategic Communications.

provided valuable data on the city's environment and infrastructure, informing policy and urban design decisions. Using edge computing, AoT has provided the efficient collection and analysis of data by extending the computation to the node. Computing at the edge helps to mitigate privacy and data security challenges to AoT by limiting data transmission and eliminating images after data extraction. Similarly, New York City's DAS has successfully provided valuable information to law enforcement officials by streamlining data collection and dissemination using ML and pattern recognition. In particular, DAS sends an automatic alert to officers regarding potential threats in their area of responsibility for adjudication and subsequent action. Last, Rio de Janeiro successfully implemented centralized IoT, integrating all city systems and departments into the Center of Operations. An entire jurisdiction can overcome artificial barriers using technology such as IoT through careful change management and planning.

Songdo, South Korea, and NEOM, Saudi Arabia, demonstrate how a novel city can build its infrastructure using technology without the concerns and limitations of an existing built environment. Songdo, South Korea, has benefited from technology that integrates daily city functions such as street light management, garbage disposal, and public safety into a cohesive system. Songdo's Integrated Operations Center provides city leaders with a central location to assess the city's status and make dynamic decisions to prevent or resolve issues quickly. The disaster prevention system utilizes traffic, environment, and facility management data to maintain SA by gathering and analyzing IoT data as SIGINT. Building the city from the ground up facilitated the move to a technologically focused system without the need to overcome built environments or limitations; however, the city's development has lacked necessary engagement with the anticipated residents. Any future city should consider involving the expected populations in the development and requirements of the technological system.

Like Songdo, South Korea, NEOM may utilize integrated technologies for data collection and analysis using ML. At the current stage of development, limited practical examples exist given NEOM's multiple projects in the design and construction phase. The future integration of systems could add systems like New York City's DAS, including the ability to dispatch law enforcement, fire suppression, and other city services before emergencies develop into disasters. Still, NEOM recognizes and demonstrates a commitment to maintaining the privacy of individuals and businesses. NEOM proposes new applications that help residents retain control of data shared within its projects. The emphasis on data privacy control is intended to facilitate engagement with future residents.

Emergency management agencies are responsible for developing processes to maintain SA in EOCs to prepare for and respond to disasters. IoT systems present opportunities to integrate systems used daily by departments and agencies actively responding to disasters. The first set of case studies examined systems in smart cities with existing built infrastructure, such as Chicago's AoT, the NYPD's DAS, and Rio de Janeiro's Center of Operations. These systems provide examples of using integrated IoT systems to manage everyday city services and adapting the data as SIGINT in response to a disaster. The final case studies evaluated the development of the novel cities of Songdo, South Korea, and NEOM, Saudi Arabia. The novel cities approach allows technology to serve as a foundation for development. Based on lessons learned from the case studies, the following section provides emergency management with recommendations for utilizing IoT as SIGINT in EOCs.

B. RECOMMENDATIONS FOR EMERGENCY MANAGEMENT

Emergency management maintains a central leadership role in maintaining SA as the facilitators of EOCs. The EOC maintains SA by collecting, processing, and sharing data effectively among response agencies. The following subsections outline recommendations for emergency managers in adopting IoT systems used by jurisdictional partners.

1. Assess the IoT Systems of Key Response Departments and Agencies

The availability and ubiquity of IoT systems and devices continue to grow as technology advances. As discussed in Chapter III, researchers expect the number of connected IoT systems to grow exponentially every decade. While IoT systems do not use a standard network to connect, common connections such as Wi-Fi, Bluetooth, and 5G make integrating IoT systems possible in most cities nationwide. Emergency management agencies should assess the IoT systems currently used by jurisdictional agencies and evaluate whether those systems serve as sources of EEIs. During emergency planning processes, agencies should assess EEIs for new systems as technology improves or is implemented. Emergency management agencies should fully engage with information technology departments to remain aware of systems used by agencies every day.

2. Integrate Everyday Systems into Emergency Planning and Operations

Upon cataloging the systems used daily by response agencies, emergency management agencies should integrate processes and systems into citywide emergency planning, training, exercises, and response. The Rio de Janeiro and Songdo models prove that citywide data and system integration can aid in response to an emergency. This integration solution requires frequent training opportunities and dynamic exercise events to educate staff and test the assumption that the right staff will operate the appropriate EOC systems. Additionally, the emergency management agency staff must familiarize themselves with departmental systems by developing closer relationships with external departmental staff and learning the complexities of each organization to better anticipate barriers to the successful use of each system. Finally, training and exercise development must include heavily resourced imagination to test each department's system in a coordinated fashion. The city departments and partner agencies must participate in training and exercises. This solution could be enhanced by identifying staff from each department as liaisons to develop training and exercises. Only internal knowledge of functions and processes can genuinely inform the development of complex and practical exercises. The city can identify problems and implement solutions with properly tested capabilities before an emergency. Properly tested systems and trained personnel are more likely to succeed during a catastrophic event.

3. Engage with the Community to Understand the Use of IoT Systems

In every case study presented in this thesis, privacy remains a significant concern regarding the type and amount of data government agencies collect. Addressing the privacy challenges requires the engagement of internal and external stakeholders with a supporting communication strategy to affirm that concerns will be met ethically and with integrity. As Chicago's AoT and New York City's DAS demonstrate, proactively engaging with community members and organizations with documented policies governing IoT systems demonstrates a necessary level of transparency. Ensuring the public remains aware of integrated public data is the first step to mitigating privacy concerns. Additionally, using and demonstrating publicly available data during exercises and special events may prove to the community that the agency will use the data only as described in the policy. In a book on governing technology, Andrew Barry describes how exercises, pilot implementations, and special events provide opportunities for governments to demonstrate the use of technology "otherwise impossible to demonstrate in public by other means."[297] Technological challenges involve the technical connection to systems, vulnerabilities to cyber threats, vulnerabilities to physical disruption, and a need for redundancy. Mitigating the technological challenges requires total organizational commitment, from leadership to the frontline staff, including budgetary and training commitment.

C. AREAS OF FUTURE RESEARCH

Technological development speed remains unparalleled in the local government, but every emergency management agency should remain aware of current advancements and best practices. The following subsections provide some areas of future research needed to help emergency management agencies prepare for and integrate IoT systems.

1. Policy Analysis That Assesses Access to Privately Owned IoT Systems

Integrating government-owned and operated IoT systems represents the low-hanging fruit of data integration. Cities must still engage with the community to detail the uses and limitations of collected data; however, IoT's ever-expanding use cases provide infinite data collection opportunities. The first area of future research includes a policy analysis to assess local government access to private IoT systems that could provide a pathway for access. The research should consider data storage requirements, training and exercises, passive or active data sharing, and triggers for access. An effective policy would include limitations and liability considerations.

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[297] Andrew Barry, *Political Machines: Governing a Technological Society* (London: Bloomsbury Academic, 2001), 19, https://doi.org/10.5040/9781474213110.

2. Best Practices in Privacy Policy Development

Each case study examined in this thesis highlighted privacy concerns of residents and businesses as a challenge to implementing IoT systems. While Chicago's AoT and New York City's DAS provided examples of proactive policy development, an area of future research includes a policy analysis of the best practices for preserving privacy while maintaining an operational capability. The research should include the successes and failures of privacy policies for IoT systems. The research should also detail allowable and prohibited system uses.

3. How Can Local Governments Effectively Maintain Comprehensive IoT Systems?

Maintaining advancements in technology and capability could present an issue for most emergency management agencies. As Russas describes, "Emergency managers will still be faced with the challenge of strategically identifying the right fit among all the available tools and technologies, and then properly integrating the tool into their systems."[298] In every case study examined in this thesis, the jurisdiction utilized public–private partnerships to develop the baseline IoT system capability. In the case of Rio de Janeiro, the relationship with one private entity failed to meet the jurisdiction's needs.[299] An area of future research would include how emergency management agencies effectively integrate and maintain IoT systems from the jurisdiction and the private sector.

D. CONCLUSION

The implementation of IoT technologies has the potential to revolutionize emergency management and response by providing real-time data. By detecting changes in the built environment early, emergency management agencies can initiate an emergency response before a situation worsens, potentially mitigating a disaster. While privacy and civil liberty concerns persist, cities can reduce risks by carefully documenting policies and

[298] Michael E. Russas Sr., "Correcting Blindness in the Nerve Center: How to Improve Situational Awareness" (master's thesis, Naval Postgraduate School, 2015), 60, https://www.hsdl.org/?abstract&did=790374.

[299] Gaffney and Robertson, "Smarter than Smart," 11.

procedures. Future technologies will change how residents and cities interact with their natural or built environments. As IoT technology evolves, emergency managers must adapt and take advantage of these advances to improve operations and safeguard communities.

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