Forging the Future: Pioneering Approaches in Business, Management and Economics Engineering to Overcome Emerging Global Challenges - 2024

https://doi.org/10.24867/FUTURE-BME-2024-114 Review paper

INNOVATIVE APPROACHES TO NATURAL DISASTER MANAGEMENT: THE ROLE OF AI AND IoT

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Abstract

The aim of this paper is to represent the innovative approaches to the natural disaster management, emphasizing the role of Artificial Intelligence (AI) and the Internet of Things (IoT) in transformation of natural disaster management based on predictive solutions. The paper highlights the improvements in real-time monitoring, early warning systems, and predictive accuracy for natural disasters. The integration of AI and the IoT has revolutionized natural disaster management and prediction. AI algorithms analyze datasets from IoT sensors deployed in vulnerable areas, enabling real-time monitoring and early warning systems. These technologies enhance predictive accuracy for disasters. Machine learning models process historical and real-time data to identify patterns and forecast events with unprecedented precision. This synergy improves emergency response, minimizes casualties, and mitigates economic losses. Possible challenges in implementation of innovative approaches to Natural Disaster Management based on AI and IoT include ensuring data security, managing the high volume of data, and integrating AI-IoT systems into existing infrastructure. The innovative approaches to Natural Disaster Management leads to optimized resource allocation, minimized economic losses, and support of efficient recovery efforts. By integrating these advanced technologies, businesses and economic systems can achieve a competitive advantage, ensuring stability and sustainability in the face of increasing global challenges.

Key words: *Artificial Intelligence (AI), Internet of Things (IoT), Natural Disaster Management, Predictive Accuracy, Real-Time Monitoring.*

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1. Introduction

In the last ten years, a remarkable push for digitalization has been observed in many sectors and industries. This particular transition, which is attributed to the emergence of advanced technological capabilities, has facilitated the emergence of processes that are more responsive, intelligent, convergent, and effective. All these improvements in technology are consolidated under the banner of what is referred to as Industry 4.0, or the Fourth Industrial Revolution. More precisely, Industry 4.0 is a newly created strategy that integrates four fundamental factors through the intersection of physical and cyber systems which enhances interconnectivity and machine-to-machine exchanges of various operations.

The most important factor in understanding Industry 4.0 is that this new phenomenon incorporates several previously unavailable technologies such as AI, Digital Twins, Blockchain, and Cloud Computing. For the first time, AI has introduced possibilities of learning machines and data analytical skills that permit machine predictive maintenance, performing intelligent functions, and analysis of machine behavior, hence minimizing manual intervention in the operation system.

Natural disasters have been one of the threats to human societal and socioeconomic activities. Over the last several years, the development of advanced technologies such as Artificial Intelligence (AI) and the Internet of Things (IoT) have assisted in improving how natural disasters can be handled and managed.

The data has been directly or indirectly gathered through the available IoT devices even from regions with complex topographies and very high temporal and spatial resolutions, enabling the aiding of the emergency service providers with valuable information. However, they can also help management of disasters using proper solutions that help in predicting, detecting, managing, and responding to any risks (Aboualola et al., 2023). The popular use of portable communication devices by citizens and their mass social interaction tends to abide by information social media strategies and allow decision-making and substantial awareness (Yu et al., 2018).

There are high expectations in terms of the capabilities of artificial intelligence and the IoT in the management of natural disasters. However, successfully implementing the above-stated benefits requires collaborative measures on internal disputes and management issues that are encumbered.

The focus on issues like data quality, data integration, and building reliable AI models will be important for ensuring that these new technologies are utilized effectively.

Given the relentless threat of natural disasters, it is reasonable to expect a possible incorporation of AI and IoT in the strategies of disaster management.

2. Disaster management

Disaster management is one of the disciplines that have witnessed a great deal of progress in recent years. This can be accounted for by the increasing occurrence of disasters and the greater-than-ever magnitude of the disasters attributed to reasons such as climate change.

Recently however one paper demonstrated an economic analysis of natural disasters, in particular a focus on the need to develop specific economic policies in response to disasters (Botzen et al., 2019). The authors conducted a systematic review of models and empirical studies dealing with the estimation of direct and indirect losses from natural disasters, integrating processes, theory, and evidence concerning most key standard, computational, and empirical approaches. The research adds to the literature on disaster risk perception and management specifically in understanding the processes and strategies that can be employed to curb the effects of disasters when they happen on the economy of the country and its various operations.

Another study attempted to assess the importance of big data in natural disaster management. The presence of information technology, they indicated, has altered the strategies that human societies use to manage natural disasters with a view of minimizing human pain, economic pain, and losses. They systematically reviewed the previous studies on big data in natural disasters and their management and focused on the current state of the art of the technology of meaningful intervention (Arslan et al., 2017)

The results from these studies point to the fact that management of natural disasters cannot be effective if implemented in isolation, but that several approaches inclusive of data and policy measures as well as community resilience are adopted.

To deal with the prevailing gaps that exist because of the institutional capacity and economic challenges there are management principles that constitute business continuity about the disaster recovery pole. It is also very important to mitigate the impact of disasters, especially in terms of protecting human lives, displacement of people, and damage to key services. Disaster management, includes disaster preparedness, mitigation, response, and recovery (UNDRR, 2019).

Considering the prevention, preparedness, mitigation, response, and recovery, the function of the disaster management system is very important, especially in an economic view. Their impact goes beyond the loss of lives and can engage the destruction of industries, disruption of supply chains, and even exhausting government attention and resources on reconstruction activities after the disaster. It is established in the studies that spending on disaster preparedness and mitigation solutions would cut the amount of recovery expenditures and save the economy from deleterious needs and losses (Hallegatte & Vogt-Schilb, 2016). This is more so applicable to developing nations where disasters affect the vulnerable most and achieving the sustainable development goals is a challenge (UNDRR, 2019).

Disaster management can be further sophisticated with the help of advanced technology such as Big data, AI, and satellite surveillance, as has been observed by Arslan et al. (2017). Water-related disasters have overwhelmed the emergency response professionals developing natural disaster management industries and resulted in the loss of lives, stability of economies, and sustainability of societies to future occurrences and impacts.

3. Artificial Intelligence

The traditional disaster management strategy comprises of four steps: mitigation, preparedness, response, and recovery. These steps include activities that take place before and after a calamity in order to help limit suffering, avert loss of lives and boost efforts toward saving and aiding the affected. This covers arranging rescues and the restoration of the area after disasters occur, in order to shield the people and the facilities from such risks in the future (Cutter et al., 2014; UNDRR, 2019). The Sendai framework has been clear about the importance of advancement on technology to curb the difficulties brought by natural disasters (United Nations, 2015). As disaster management entails action, the aim of disaster management is, to develop methods that help to prepare for a disaster, help to respond to a disaster in the shortest time, and help to utilize all the necessary means of repair, restoration of the activity and prevention of further consequences (Hallegatte et al., 2013).

Artificial Intelligence (AI) keeps gaining application in disaster risk management (DRM) in domains like hazard identification, vulnerability assessment, consequence prediction and devising strategies to mitigate risk. For instance, regression models with data from past occurrences can be employed by AI to indicate the future crisis scenarios that the networks would be facing due to the impacts of disasters (Arslan et al., 2017). Additionally, spatial regression models can assess vulnerability and help design resilient infrastructure (Ahmadi et al., 2024). AI's applications extend into preparedness by offering efficient early warning systems and optimizing evacuation plans (United Nations, 2015).

In the response stage, AI-based communication tools have proven useful for improving decision-making and enhancing situational awareness, which is critical for effective rescue efforts. These tools ensure seamless communication among those involved in relief operations (Hallegatte & Vogt-Schilb, 2016). Post-disaster recovery also benefits from AI, as it can assess damage to structures and support recovery planning by tracking progress in rebuilding efforts (Ahmadi et al., 2024). Furthermore, AI techniques are being applied to enhance infrastructure resilience, such as using fuzzy set theory and expert judgment to evaluate critical infrastructure resilience (Dick et al., 2019). Deep learning and machine vision have also been used to detect threats to power systems and prevent failures through predictive maintenance (Dick et al., 2019).

4. Internet of Things

The Internet of Things (IoT) is gaining popularity among businesses and the scientific community alike as it is a novel and developing concept (Dijkman et al., 2015). Out of the various perspectives offered by various authors, IoT concerns the integration of different devices, systems, and processes over the system consisting of the Internet with the help of data transferring (Gubbi et al., 2013). Their visions of IoT include boundless, ubiquitous, and persistent wireless links between people and machines, services, and devices. This approach not only eliminates the need for individuals to be present in the environment and physically interact with devices and systems, but it also improves the capabilities to observe, interact, and control systems from a distance (Ashton, 2009). When presenting the IoT in the context of disaster management several arguments on the advantages of the use of IoT are provided including monitoring, control, quality evaluation, cost, and time optimization (Al-Turjman, 2017). A cognitive data delivery framework satisfies the data transmission challenges that appear in a large network during disasters as proposed by Al-Turjman (2017), thus improving the network's performance. Also, IoT is very helpful in the early warning and monitoring systems of geohazards such as landslides, rockfalls, and earthquakes (Mei et al., 2020). Implementing IoT systems into DRM procedures has the potential to provide twining speed and analytical accuracy in hazard forecasting, and decision-making efficiency which would cut costs in any response or recovery process.

In addition, these pieces of data from IoT such as sensors, detectors, and embedded computers can also be manipulated by artificial intelligence (AI), therefore helping to prevent hazards out of the prompt.

The Sendai Framework for Disaster Risk Reduction stresses the need for institutional strengthening of disaster risk management and IoT can assist in moving towards this need by bringing an adaptive decision-making context (UN, 2015). Also, less uncertain technologies have been demonstrated using IoT to support critical infrastructure protection. For example, a novel approach by Schultz et al. (2020) suggested the application of signal-processing technologies for critical infrastructure resilience enhancement. Yet, notwithstanding its potential benefits, there are some concerns regarding the effective utilization of IoT, including technical uncertainties and risks of the use of IoT. These concerns are important to address particularly with regard to boosting the trust and adoption of IoT technologies in disaster management (Sundmaeker et al., 2010).

5. Conclusion

In conclusion, the use of modern technology such as AI and IoT is changing the way natural disasters are being managed. People are able to integrate advanced technologies into all stages of disaster management: prevention, preparedness, response and recovery, assisting in faster, smarter and better use of predictions, policies and resources. Predictive Analytics tools of AI enhance hazard detection and the assessment of risk by sifting through voluminous data and envisaging the possible disaster events. While IoT provides comprehensible communicative applications and surveillance for ecological hazard through its connected devices to assign hazardous disasters manageable levels. Such changes and improvements lead in decreasing not only the duration but also the accuracy of the actions in disaster management and risk surroundings and thus less human operations are exposed for with the help of these strategies. With the help of appropriate laws, these technologies and systems in the disaster response methods may increase situational awareness, improve evacuation strategies, as well as enhance recovery strategies aimed at evaluation of property damage and mapping of rebuilding activities. In addition to this their involvement in the enhancement of critical asset protection and disaster risk management is very important in the effort of reducing the risk. Nonetheless, barriers exist that require resolving relative to the implementation of technology, data safety, and investment in infrastructure. Collaboration with stakeholders in this manner will ensure that optimal utilization of AI and IoT in address the problem of natural catastrophes is assured. In general, it can be highlighted, that the use of these techniques increases the likelihood of development of more efficient and flexible disaster management systems recovering lives and belongings of people and communities.

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