Internet of Things: Opportunity for Disaster Risk Reduction

V.T. Baloyi
[1]Department of Rural Development and Land Reform
University of Johannesburg, South Africa
*vukosi.thomas@gmail.com

A. Telukdarie
[22]Department of Post Graduate School of Engineering Management
University of Johannesburg, South Africa
arnesht@uj.ac.za

Abstract

The disruptive technologies of the Internet of Things (IoT) are encouraging innovation in different sectors. Smart cities and infrastructure, smart energy, smart industry, and smart health are as a result of the application of the IoT concept. But how effective is IoT in the disaster risk management field? Strengthening capacity for Disaster Risk Management (DRM) has been a trending theme at international conferences. Substantial reduction of new and existing disaster risk is a target. This paper evaluates the potential of IoT technologies in reducing disaster risk, and recommends a framework for Disaster Risk Management Best Practice (DRMBP) on transforming ordinary objects to intelligent devices. A comparative case study analysis on DRM is conducted to contrast the benefits between GPS/Seismic station (not "smart" devices) and M2M devices. Based on the findings, IoT technologies are effective Disaster Risk Reduction (DRR) tools. A framework for how systems will come together (IoT platform) for purposes of DRR is developed and recommended.

Keywords:
Internet of Things, Big Data, Disaster Risk Management and Reduction

1. Introduction

"Earthquakes don't kill people, buildings do"[Dunn, 2016]. Although natural hazards are inevitable, materialization into disasters can be prevented or mitigated[Opadeyi, 2008]. Disasters pose a serious challenge to achieving sustainable development, globally [Twigg, 2015]. This observation is supported by the endless occurrence of disasters in different parts of the world. What is problematic is that even technologically advanced countries like Japan and United States of America, countries that have invested in building networks of Earth Observation (EO) systems, as Disaster Risk Management (DRM) tools, are devastated by disasters [Zhou, 2014].

International agreements like the Sendai Framework (2015) for Disaster Risk Reduction (SFDRR) (2015-2030) acknowledged the significant shift from disaster management to DRM . The rise in human and economic costs encouraged this shift. Safe Site Selection (SSS) which is regarded as a critical phase in infrastructure development is generally not considered. As a result, so much money is invested in building cities in hazard-prone areas. Aleppo, a city in Syria, and Japan[Yamasaki, 2012], are built in active faults, introducing disaster risk, in turn human and economic assets are left vulnerable. It can be argued that unless prevention, mitigation, and preparedness measures are not acted on, disaster risk will not be reduced.

Another key driver for the increasing human and economic costs is the lack of timely risk information, which impends vulnerable communities to relocating to safer sites pre-disaster [Patterson, 2015]. The architectural design of current EO systems do not facilitate Effective Risk Management (ERM). ERM is referred to by Patterson and Executive [Patterson, 2015] as a process that promotes capturing, analysis, and dissemination of risk information. EO systems primary function is to sense environmental data, and stream the data to a data centre where it is stored [Trignet, 2015]. To gain insight from this data, an expert in processing GPS data is required to download the data from the server and process the data using GAMIT or Bernese software. This disconnected approach of risk management does not properly facilitate ERM [9, 11].

Scientific and Technological Advisory Group Report reported that 230,000 peoples were killed by the devastating 2004 Indian Ocean Tsunami. Emphasizing the absence of early warning and evacuation procedures as a contribution to the consequences. What if different systems and applications are connected, how much of human lives and economic assets would have been saved?

The research strives to understand how ERM can be established through systems integration to substantially reduce disaster risk. The Government of India believes that interconnecting devices through the disruptive technologies of Internet of Things (IoT) leverage existing technologies, in turn enhancing operations [Knopjes, 2016] Integrating these systems eliminate the element of human involvement and data processing, enabling autonomous reaction [Rahman, 2014]. The logic of interconnecting devices is based on the belief that a networked system is more valuable than an isolated device, and more intelligent and autonomous applications can be generated if multiple physical systems are interconnected [Knopjes, 2016]. It can then be argued that unless heterogeneous devices and application networks can be connected, disaster risk will not reduce.

1.1 IoT and disaster risk management

The expansion and growth of interconnected devices over the internet continue to create an array of opportunities [Da Xu, 2014]. IoT and Big Data analytics provide new opportunities and technologies that drive effective DRM [15, 16]. The integration of independent heterogeneous operating systems in an interoperable ecosystem, System of Systems (SoS), generates huge complex Big Data [Yetis, 2016], useful for disaster prevention and preparedness [Emmanouil, 2015].

Table 1: Themes and effective risk criteria derived from related studies

Themes derived from related studies for analytics generation and replication of findings	
Theme	**Authors**
Interconnecting devices through IoT leverage existing technologies	MAIT [Knopjes, 2016]
IoT can help save lives	Shoker [Kitchin, 2013]
Improved planning and response to disasters can be realized through analytics	Shoker [Kitchin, 2013]
Science and Technology	SFDRR
Criteria for effective risk management	
Effective risk management facilitates data capturing, analysis, and timely risk information dissemination	Patterson and Executive [Patterson, 2015], Vukovic, Joksic and Mihailovic [Vukivic, 2017]
Big Data analytics is imperative for effective DRM	Emmanouil and Nikolaos [Emmanouil, 2015]

The importance of Big Data chain in DRM (prevention and preparedness) is described in [Emmanouil, 2015]. Data generation (IoT), acquisition, storage, and analytics are phases of operation of a big data management system[Kitchin, 2013]. Big Data analytics is a solution to the challenges of modelling and processing large amounts of unstructured complicated data using traditional management tools and processing techniques [16, 17]. Descriptive, predictive and prescriptive analytics, are important methodologies and applications composed in the fourth phase of a big data management system. Therefore, modelling and processing disaster risk information from IoT heterogeneous devices using Big Data Analytics enable timely risk information by (1) extrapolating and interpreting risk data, (2) predicting the future, and (3) providing advice for decision making to vulnerable populations.

2. Research Design

This research will follow the research onion framework that is proposed in literature. This methodological framework is chosen because it clearly defines the roadmap to collecting data throughout the analysis for answering the research questions. The framework is illustrated in Figure 1.

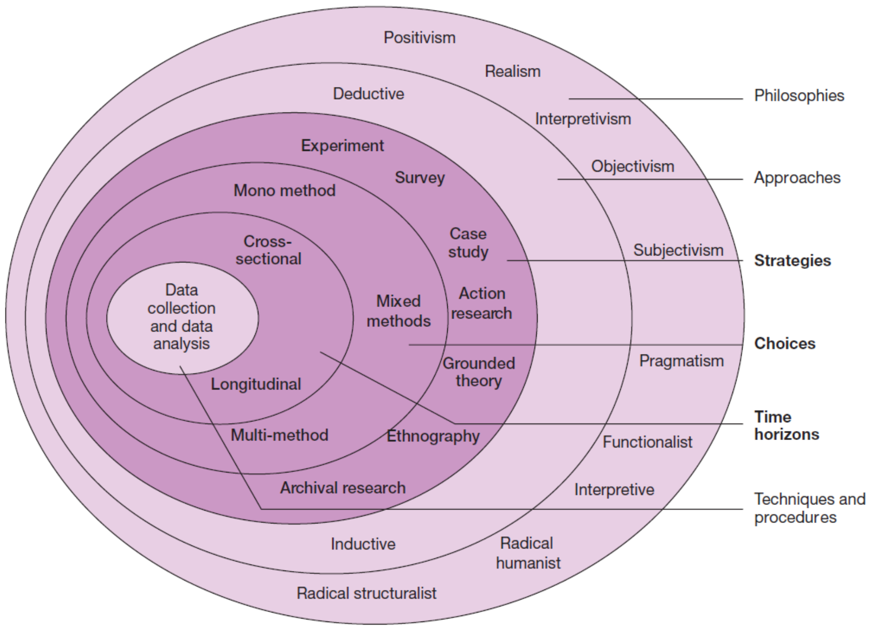

Figure 1: The Research Onion model

The research onion defines the research process adopted. It illustrates the critical stages that need to be covered in the development of the research strategy. The stages include: research philosophy, approach, methodological choice, strategy, time horizon, population and sample, and data collection and analysis. This research process enables the realization of an effective development to the design of the research methodology. The research onion is also selected by the researcher as it is described to be adaptable to any research methodology regardless of the context [Bryman, 2017].

3. Research Methodology

Case studies from Japan Ecuador, and Vietnan are evaluated in order to gain knowledge and understanding of different DRR systems [Snyder, 2014]. The purpose of evaluating multiple case studies is to identify the benefits of using EO systems and IoT solutions, to determine which risk management process is effective. Case study strategy is adopted in this research as it allows the researcher to explore and examine in-depth an event, process, program, individual(s), or activity. Through this strategy, the following objectives are executable:

- Evaluate case studies where GPS and Seismic station are used to provide a DRM platform in order to determine application benefits by performing a Within-case analysis.
- Evaluate case studies where IoT technologies are used to provide a DRM platform in order to determine application benefits by performing a Within-case analysis.
- To conduct a comparative analysis of the cases evaluated by performing Across-case analysis in order to contrast DRM approach within the technologies.
- To determine the potential and effectiveness of IoT in disaster risk reduction.
- To define, on basis of the findings of the comparative analysis, a framework supporting Best Disaster Risk Management Practice to significantly reduce disaster risk and promote sustainable development

The case study method is used by to investigate the best practice procurement method, using South African comprehensive universities as samples for the study. The method is also to determine the benefits of geospatial technologies within the construction industry. Through this method, both investigations achieved their objectives. Although the numbers of cases evaluated in both investigations are different, argued that whether a researcher uses single-case or multiple-case, it should not matter. Single-case should not be treated like a single response from a survey strategy. Researchers should target analytic generalization when evaluating case studies. This is crucial, should findings between a case and a previous theory be similar, replication is claimed. Therefore, this research evaluated three cases (documentation), from Japan, Ecuador, and Vietnam, to investigate the potential of the IoT phenomenon within the DRM domain, in order to explain and describe its capabilities in the real world context.

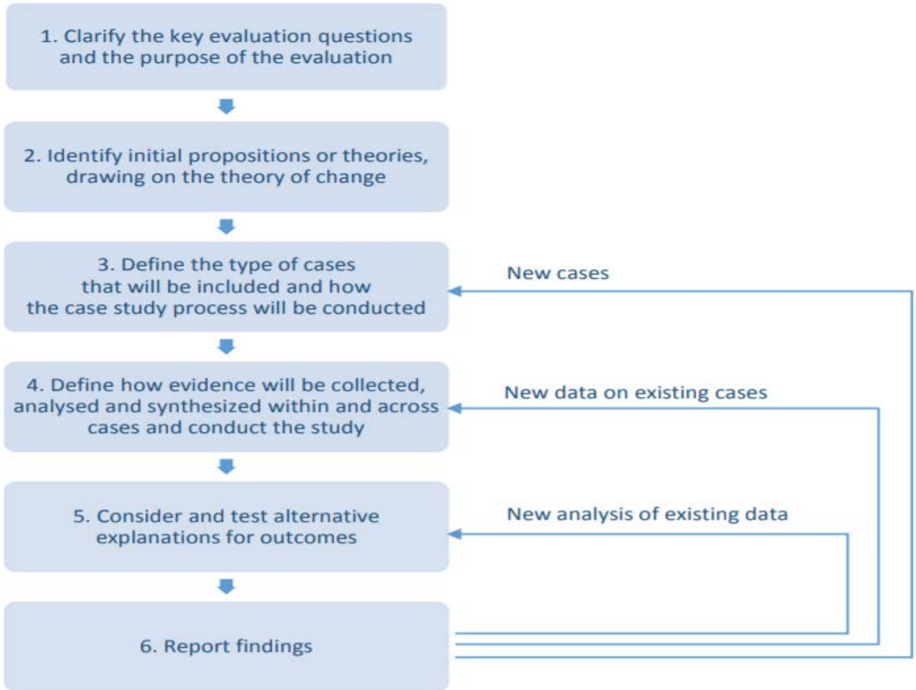

Figure 2: Steps for conducting a comparative case study analysis

To answer the research question; how can the Internet of Things improve Disaster Risk Reduction, a comparative case study analysis between commonly used EO systems (GPS and Seismic stations) and M2M communication (or IoT) solutions is conducted. Comparative case studies involve two or more cases in order to generalize knowledge that address 'why' and 'how' a particular process or programme functions or fail to functions. This research adopts the steps for conducting comparative case studies as illustrated in Figure 2. Comparative analysis is used in the studies by Vukovic, Joksic and Mihailovic [Vukivic, 2017] and Fernandez, Bendimerad and Buika [23] to contrast risk management methods, in order to determine an effective risk management method. The findings are discussed.

3.1 Findings

A comparative analysis of three case studies of disaster risk management in Japan, Ecuador, and Vietnam is conducted using the method described. Different risk strategies used in these cases are GPS and Seismic Network (Japan), and M2M communication network (Ecuador and Vietnam). The effective risk management elements described in Vukovic, Joksic and Mihailovic [Vukivic, 2017] and Patterson and Executive [Patterson, 2015] are used to define the criteria for comparison analysis.

4. Summary of the Cases

4.1 Case Study: Japan (Coordinates magazine)

Multiple GPS stations data is used to predict and validate the Kumamoto earthquake in Japan. However, it is difficult to achieve the prediction using GPS stations data only as the analysis did not show abnormal crustal changes in the horizontal (x and y) and vertical (height) coordinates. This earthquake measures at magnitude M7.3 on the Richter scale by the local seismological network.

After the foreshock occurred (14 April 2016), evacuated vulnerable population returned to their residents. However, an unexpected main shock occurred (16 April 2016), 28 hours after the foreshock. The main shock led to fatalities and infrastructure being destroyed. 86411 houses were completely destroyed, 1720 peoples injured, and at least 50 people were killed.

This situation is as a result of unavailability of GPS data for processing by a risk expert. Data is only available 2 days after observation by GPS sensors. Sensor data is not available in real-time. Human intervention (risk expert) is key for downloading and processing of data as the process is not automated. Risk process is not end-to-end, rather a disconnected approach. GIS software is used for visualization of processed data. Earthquake warning communication is limited to a local magazine customer.

4.2 Case Study: Ecuador

Ecuador is characterized by frequent earthquakes and volcanic eruptions due to the country's geological setting within the Pacific Ring of Fire. In general, the country is at risk from major hazards including geophysical, meteorological, hydrological, and climatological events, making the country exposed and vulnerable. As exposed and vulnerable Ecuador is, the country did not have multi-hazard monitoring and forecasting systems in place. The Institute of Geophysics of Ecuador has since 1983, monitored seismic and volcanic activities throughout the country. Resources such as capacity, finance, and technology transfer are key impediments to Ecuador strengthening resilience, increasing preparedness, reducing disaster risk, consequently, realizing sustainable development. With capacity and finance serious constraints to budgets for hazard monitoring systems, the Institution has to search for affordable real-time systems that will enable the Institution to carry-out its responsibilities. To improve the country's EWS, the Institution installed an M2M communication solution that monitored the deformations of Galapagos Island and Cotopaxi volcanos. In addition to providing an effective DRR strategy (obtaining good results); it is through Free Wave Technologies' that maintenance costs of the monitoring stations are reduced to zero [24, 25]

4.3 Case Study: Vietnam

Vietnam is frequently hit by disasters such as flash floods. Due to the concentration of hilly terrains, the speed of flash floods is devastating when it hits local residents. To worsen the situation, Vietnam did not have a flash flood warning system available or installed to warn local residents. This situation kept on increasing the numbers on human and economic losses of the area. In collaboration with Japan, Vietnam initiated a project with the objective to design a monitoring and early warning system to assist the exposed local residence in evacuating to safer sites before flash floods hit. M2M communication solution (model) as shown in Figure 3 is adopted in Vietnam. Interconnected sensor devices, through the internet, that measure the amount and traveling speed of water are installed as shown in Figure 4.

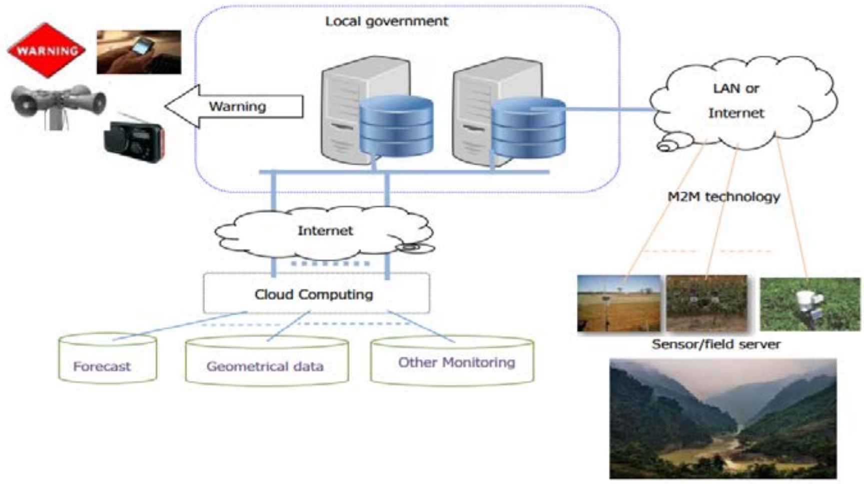

Figure 3: Operating M2M with Big Data Analytics as a DRM system in Vietnam

Figure 4: M2M direct interconnected devices installed in Namtramy district, province of Quang Nam, Vietnam (A and B: Sensors, C: Transmitter, D: Weather Station, and E: Connected Alarm for EWS)

Table 2: Summary of the benefit service rendered by each system installed in each case study (Within-case analysis findings)

Within-case analysis to extract system benefits		
Japan case study [GPS and Seismograph network]	Vietnam case study [M2M solution]	Ecuador case study [M2M solution]
Data can be used for deformation analysis and predictive analysis. However, in requires human intervention to download and process the data.	Sensors monitor change in water level and flow speed. Operation of the M2M solution requires no human intervention. M2M communication solution gathers information of disaster risk status in the area. Developed servers and information processing algorithms process information gathered from M2M sensors, send SMS or/and email alerts when sensors detect flood above the set threshold (i.e. processing the data from sensors requires no human intervention). Server information is accessible for viewing of water level and flow speed in near real-time.	Development of an intelligent network through the interconnection of: Volcanic gases monitoring, Accelerometers installed in the cities of the country, Meteorological stations, GPS CORS and borehole sensors for earthquake monitoring Remote digital cameras transmit images on real-time situational awareness Real-time information dissemination to other machines and operators Real-time telemetry system and cost-effective solution of FreeWave M2M devices reduced maintenance costs of monitoring stations to zero: The M2M solution allows for diagnostic testing of remotely connected devices, tracking their performances in real-time. M2M solution plays a critical role in enabling the Institution to issue early warning to vulnerable population for their relocation to safer sites: M2M connection at different distances in Ecuador has proven to be highly reliable and stable, M2M communication solution created opportunities for engineers at the Institution to optimize application and processes.

Table 3: Across case analysis of the benefits identified in the case studies (GPS + Seismic network vs M2M communication)

System	**Risk identification**	**Risk monitoring**	**Analysis capability**	**Forecasting and predictive capability**	**Hazard Early warning communication to population at risk**
GPS stations	Data acquisition functionality [Requires human intervention]	Functionality (ground measurement)	Requires human intervention	Requires human intervention	Requires human intervention
Seismic stations	Requires human intervention	Functionality (ground measurement)	Requires human intervention	Requires human intervention	Requires human intervention
M2M devices	Automated	Automated	Automated	Automated	Automated

5. Discussion of Findings

The comparative analysis conducted demonstrate the gaps EO systems have to fully function as an effective risk management tools. The analysis also demonstrates the potential of IoT (M2M) within the field of DRM. Discussion of the findings is related to previous knowledge extracted by other researchers. This is important as it allow the research to align towards analytic generalization of the sample cases selected. More importantly, similarities in the findings of this research will enable replication, a key element emphasised by. This discussion is based on important themes discussed in the literature review (Table 1), aligned towards answering the research question.

The research design adopted in this research provided a structured and logical sequence, linking empirical data to addressing the research question. It is also important to note that even though the findings of this research using multiple case studies cannot generalize the entire population, they provide important knowledge and lessons. Organizations need information and communication technologies to remain competitive in the global economy.

5.1 Interconnecting devices through IoT leverage existing technologies

Ordinary, standalone objects like GPS and Seismic station are criticized in the literature [Knopjes, 2016]. Interconnected devices in the cases of Vietnam and Ecuador provide better services, proving to be valuable devices than ordinary objects. Japan's case study demonstrates that earth observation systems operating in isolation are not effective measures or solutions to solve the problem the world is facing of disaster impact. Normal objects need to be connected in order for machines to communicate, process, and disseminate necessary risk information at earliest times.

Japan's case study further demonstrated the challenges to access sensor data. Even when the data is available, a scientist is still required to download and analyse the data in order to gain situational awareness of the state of possible risk. The same applies to seismic data: human intervention to interpret data is needed. However, M2M communication solution (or IoT) proved to be an efficient system in Ecuador.

5.2 Effective risk management facilitates data capturing, analysis, and timely risk information dissemination

The primary functionalities of EO (GPS and Seismic stations) approaches of monitoring crustal deformations cannot improve the situation of losses in human lives. The case study in Japan revealed limitations of GPS and Seismic stations when used for risk management. Functionalities of these EO need to be added in order to conduct an effective risk management process Arcadius, Gao, Tian & Yan (2017). Their current architectural design does not satisfy the approach required to substantially reduce new and existing disaster risk.

However, the architectural design of an IoT platform allows for a near real-time situational awareness. With Ecuador's geological setting at the Pacific Ring of Fire, GPS and Seismic station networks could not provide the services needed by the people at the specific time. This explains the increasing losses in economy and human lives. People at risk are aware of what is to come.

5.3 Big Data analytics are imperative for effective DRM

After receiving sensor data via a network, big data analytics and algorithms process and analyse the data in order to determine and identify possible earthquake or volcanic eruptions from the mounted digital cameras. This tends to be in agreement with the theory provided. Connecting heterogeneous networks is improving the quality of life. Algorithms and processing software like Hadoop software, with large distributed algorithms are able to process large data sets in order to gain insight in near real-time. Predictive analytics of Big Data chain allow timely risk information to be communicated; before disasters strikes, improving disaster preparedness. This is demonstrated by the cases in Ecuador and Vietnam through M2M solutions.

6. Revisiting the Research Question

6.1 How can IoT improve DRR

Based on the findings of the comparative analysis, the researcher is in agreement with MAIT (2016) on the potential that the Internet of Things has within the DRM sector. It is important to mention that although the intervention of IoT addresses disaster risk challenges, GPS and Seismological networks have a significant role to play in the IoT infrastructure. Being guided by the case findings, SFDRR recommends investment in IoT for reduction of existing disaster risk and prevention of new risks [26, 27]. Previous related work in the literature review argued that IoT will bring effective disaster preparedness. Zambrano, Perez, Palau and Esteve [28]; proposed the adoption of IoT in everyday living, as the communication solution improves the quality of living. This research has proved these theories argued in the literature review.

6.2 Defining Theory

The researcher recommends that a Disaster Risk Management Best Practice (theory) be defined: Interconnectivity of heterogeneous devices and application networks in an interoperable ecosystem forms a framework for Disaster Risk Management Best Practice [29, 30]. Such a framework aims to assist nations in achieving the priorities for actions set by the international agreement of the Sendai Framework (2015) for Disaster Risk Management (2015-2030). These priorities include:

- Understand underlying disaster risk.
- The strengthening of disaster risk governance for the management of disaster risk.
- Ensure resilience by investing in disaster risk reduction measures.
- Enhancing disaster preparedness for effective response.

This framework is illustrated in Figure 5.

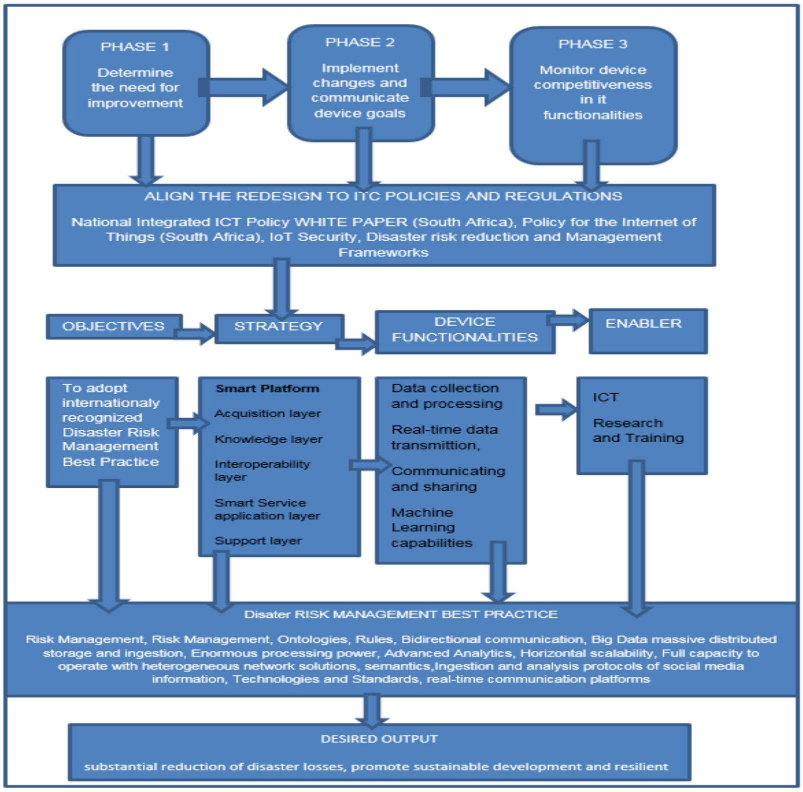

Figure 5: Recommended framework for adopting DRMBP through device connection in IOT ecosystem (Author)

7. Conclusion

One of the many contributing factors that lead to disaster losses is not having the necessary information at the right time. The study determined the opportunity for IoT solution to improve disaster risk reduction. The researcher conducted an exploratory study, analysing multiple cases, in order to determine if IoT is the appropriate technology to improve risk reduction. The findings revealed that IoT is the right technology for the reduction of human and economic losses. Technology transfer is moving slowly, capacity is a challenge to most countries, and financial constraints contribute to countries not affording to implement such solutions.

This study recommends to countries; hazard prone or not, to invest in IoT technologies, as it is proving to be efficient systems for everyday living. Based on the findings of this research, for countries to realize the Priorities for Action as outlined in the Sendai Framework (2015), they need to consider investing in these industrial technologies (Industry 4.0 as a whole).

References

Dunn, P. T., Ahn, A. Y. E., Bostrom, A. and Vidale. J. E., Perceptions of earthquake early warnings on the U.S. West Coast *International Journal of Disaster Risk Reduction, vol* 20, pp 112-22, 2016.

Opadeyi, J., Spence, B., Miller, K. and Griffith-Charles, C.,Incorporating Geoinformatics into Disaster Preparedness and Management Operations: A Caribbean Regional Approach *West Indian Journal of Engineering, pp* 54-68, 2008.

Twigg, J.,Disaster risk reduction. London: Humanitarian policy group overseas development institute), 2015.

Zhou, Y,. Li, N., Wu, W., Wang, L., Liu, G and Wu, J., Socioeconomic development and the impact of natural disasters: some empirical evidences from China *Natural hazards* 74 541-54, 2014.

Yamasaki E., What we can learn from Japan's Early Earthquake Warning System *Momentu, vol* 1-pp 26, 2012.

Patterson, T and Executive, C. C. S., The use of information technology in risk management'. IBM Corporation White Paper), 2015.

TrigNet., National Geo-spatial Information, 2018.

Knopjes, 2017] MAIT., Internet of Things (IoT) for effective disaster management. Digital India Action Group–White Paper), 2016.

Rahman, A., Liu, X. and Kong, F., A survey on geographic load balancing based data center power management in the smart grid environment *IEEE Communications Surveys & Tutorials, Vol* 16, pp 214-33, 2014.

Da Xu, L., He, W and Li, S., Internet of things in industries: A survey *IEEE Transactions on industrial informatics*, vol 10, pp 2233-43, 2014.

Emmanouil, D and Nikolaos, D., Big data analytics in prevention, preparedness, response and recovery in crisis and disaster management. In: *18th International Conference on Circuits, Systems, Communications and Computers (CSCC 2015)*: Recent Advances in Computer Engineering Series) pp 476-82, 2015.

Yetis, Y., Sara, R. G., Erol, B. A., Kaplan, H., Akuzum, A and Jamshidi, M., Application of big data analytics via cloud computing. IEEE World Automation Congress (WAC)), 2016.

Kitchin, R., Big data and human geography: Opportunities, challenges and risks *Dialogues in human geography, vol* 3, pp 262-7, 2013.

Vukovic, D., Joksic, J and Mihailovic, D., Comparative analysis of methodologies for risk management of strategic investment projects, 2017.

Bryman, A., Social research methods. Oxford University Press, 2015.

Snyder. C. S., A Guide to the project management body of knowledge: PMBOK (R) guide. Project Management Institute, 2014.