International Conference on Research in Education and Science
www.icres.net May 18-21, 2023 Cappadocia, Turkiye www.istes.org

Development of Visual Analytics for Campus Centralized Emergency Response and Disaster Assistance System

Aziman Abdullah
Universiti Malaysia Pahang, Malaysia, https://orcid.org/0000-0003-2945-1043

Pang Jieyu
Universiti Malaysia Pahang, Malaysia, https://orcid.org/0009-0003-2518-2672

Abstract: It is essential to save lives during emergencies not only in hospitals but also in colleges and universities. Failure to identify risks and take prompt action during catastrophes and emergency situations could result in the loss of life and property for the campus community. This research aims to explore the feasibility of using data analytics to mitigate the risks associated with disasters and emergencies on campus. A prototype of an online reporting system was developed using cloud services to collect relevant data, analyze it, and present the information in an online dashboard for stakeholders to make informed decisions. The study shows that the use of dashboards has a high potential for effectively mitigating risks and identifying appropriate intervention strategies. This research contributes to the ongoing efforts to improve emergency response planning and management in higher education institutions and can be applied to other universities and large community groups to enhance their disaster and emergency response preparedness.

Keywords: emergency response system, campus safety, higher education, data analytics

Citation: Abdullah, A. & Jieyu, P. (2023). Development of Visual Analytics for Campus Centralized Emergency Response and Disaster Assistance System. In M. Koc, O. T. Ozturk & M. L. Ciddi (Eds.), *Proceedings of ICRES 2023-- International Conference on Research in Education and Science* (pp. 2266-2278), Cappadocia, Türkiye. ISTES Organization.

Introduction

Some higher education institutions possess specialized physical facilities, making them distinctive. They serve both teaching and research purposes, generate employment and economic benefits within their local and regional communities, and offer essential services like medical care and laboratory functions. In essence, universities operate as self-sufficient communities that provide various amenities, including housing facilities, food services, small businesses (such as retail stores and printing presses), and even hospitals(Ayanian & Weissman, 2002). However, they are also vulnerable to emergencies like natural disasters and man-made crises, which can impact their ability to function effectively such as earthquakes(Koshiba & Nakayama, 2021) and flood(Ke et al., 2023), chemical explosion(Balla et al., 2021) and cyber-attacks(Kassem et al., 2019). In

addition, health emergencies such as pandemics and outbreaks of contagious diseases can also pose significant risks to campus communities(Bokszczanin et al., 2023; Schmitt et al., 2021; Xiong et al., 2020). One of the significant challenges is the need to communicate effectively during emergencies. Higher education institutions may have large and diverse populations, including students, faculty, staff, and visitors, which can make communication challenging. Effective emergency response in higher education requires a multi-faceted approach that includes comprehensive planning, training, and resources(Song et al., 2022). Educational institutions should have clear and regularly reviewed emergency plans in place, as well as robust communication protocols and systems. In addition, there should be adequate resources dedicated to emergency response, including personnel, equipment, funding and technology.

This research aims to explore the feasibility of using data analytics to mitigate the risks associated with disasters and emergencies on campus. To achieve the research aims, this study is guided by the following research questions:

1. What type of campus emergencies and disasters occurred?
2. How significant is an online dashboard for emergency and disaster situations on campus?
3. Which visualization techniques are critical and effective for emergency responses on campus?

Literature Review

Campus Emergencies and Disasters

An emergency can be defined as a sudden, unforeseen, and typically dangerous situation that poses an immediate threat to health, life, property, or the environment and necessitates prompt action(Sarwar, 2018). Campus emergencies, ranging from natural disasters to man-made crises, can severely affect the safety and well-being of students, faculty, and staff. Natural disasters like floods, earthquakes, tornadoes, and wildfires can cause significant damage to buildings and infrastructure, leading to transportation disruptions, power outages, and water shortages(Toya & Skidmore, 2007). They can also result in serious injury and loss of life if people are not prepared or evacuated in time. In the context of students, transportation disruptions during floods can have a significant impact on their ability to access food. If food distribution channels are limited or supply chains are disrupted, it can make it difficult for students to purchase affordable and nutritious food. As a result, they may have to resort to eating less nutritious or more expensive food, or even go without food altogether. Furthermore, if transportation disruptions prevent emergency food aid from reaching affected areas, students who are already facing food insecurity may be at an even greater risk of going hungry. This can have a significant impact on their physical and mental health(Othman et al., 2022), as well as their overall wellbeing.

Man-made disasters, such as accidents, acts of terrorism, or violence, can also cause harm to people and property, and immediate emergency response measures may be required(Park, 2011). Examples of such disasters include chemical explosions(Morshidi et al., 2018; Mulcahy et al., 2013), mass shootings(Kowalski et

al., 2021), and cyber-attacks(Ramim & Levy, 1 C.E.). Furthermore, the call for digital transformation of higher education has increased the vulnerability to cyber-attacks as universities become more reliant on technology especially for academic operation. As a result, universities have experienced significant data breaches involving the personal information of students, staff, and alumni. For example, in 2018, a hack of the University of Yale in the United States put the personal information, including social security numbers and addresses, of 119,000 students and staff at risk(Hailey Fuchs, 2018). Such cyberthreats not only disrupt educational processes and create barriers to learning, but are highly potent to cause significant emotional distress and trauma. This can affect their academic performance, mental health, and overall sense of student's wellbeing.

Hybrid disasters, which are a combination of natural and man-made disasters, can have compounded effects and are more complex to respond to. Covid-19 can be considered a type of hybrid disaster because it has both natural and human-made elements. On the one hand, it is caused by a natural virus that originated in animals and spread to humans(A. Zhu et al., 2023). On the other hand, its impact has been intensified by human activities such as international travel(Hohlfeld et al., 2022) and the lack of effective public health measures(Ullah & Harrigan, 2022) in some areas. Furthermore, the pandemic has led to various other disasters, such as economic downturns (Hyman et al., 2021) and social unrest(Warsame & Price, 2021), which are also man-made disasters extending the critical impact on higher education. The pandemic has also created significant mental health challenges for students. The stress and uncertainty of the pandemic, coupled with the social isolation and disruption to routine, have led to an increase in anxiety, depression, and other mental health issues(Bokszczanin et al., 2023). The impact of campus emergencies' events can be severe and long-lasting. Some of the other consequences include:

1. Loss of life and injury: Emergencies can cause injuries and loss of life, particularly if individuals are not properly prepared, treated or evacuated. For example, three students in China die in laboratory explosion (Zhuang Pinghui, 2018).
2. Property damage: Emergencies can cause significant damage to buildings and infrastructure, leading to disruptions in transportation, power outages, and water shortages. For example, Tropical Storm Allison caused 10 million gallons of water inundated the UTHSC-H Medical School basement, resulting in over 1 million gross square feet of space being unusable for several months(Goodwin & Donaho, 2010).
3. Reputation damage: Emergencies can damage the reputation of the institution and negatively impact the enrollment of future students.
4. Legal liabilities: Emergencies can lead to legal liabilities, such as lawsuits from individuals who were harmed or injured during the event.

Higher education institutions should prioritize the safety and wellbeing of their communities, recognizing that human life is priceless and that recovery from injuries can take a significant amount of time. Even though structures and objects can be reconstructed or replaced, the loss of life or the impact of an injury can have a long-lasting effect on the individuals involved and their loved ones. Therefore, it is crucial to invest in

emergency response systems that can provide a swift response to emergency situations on campus.

Emergency Response System

An emergency response system in higher education refers to a comprehensive set of policies, procedures, and resources put in place to address emergency situations on a college or university campus. These systems are designed to provide a rapid response to emergency situations, including natural disasters, medical emergencies, and violent incidents, with the goal of ensuring the safety and security of students, faculty, staff, and visitors. The significance of an emergency response system in higher education cannot be overstated since environment in campuses are dynamic with thousands of people living, learning, and working in close proximity to each other(R. Zhu et al., 2020).

There are several challenges remaining in the emergency response and disaster assistance system. The process of collecting data for emergency response and disaster assistance generates a massive amount of information, including reports, images, videos, and audio that cover various aspects of emergency and disaster situations(Pettet et al., 2022). Unfortunately, the sheer volume of this data often overwhelms emergency agents who lack the necessary tools to filter or refine it for future use. As a result, they may struggle to identify trends or patterns in the data, leading to delays in decision-making or even misinterpretation. In addition to the challenges mentioned earlier, the continued use of conventional and paper-based reporting systems as a primary practice in emergency response and disaster assistance can compound existing issues. Although these approach practically workable and less relying on technologies, these methods of data collection and reporting can be time-consuming and prone to errors, further exacerbating the challenges faced by emergency agents, personnel and victim. This can result in further delays in decision-making and potentially cause critical information to be lost or misinterpreted. There are several issues that can arise in emergency response systems:

1. Communication failures: Communication failures between emergency responders and victims or between different agencies can hinder the effectiveness of emergency response efforts.
2. Resource allocation: Emergency response efforts require the allocation of resources such as personnel, equipment, and supplies. Inadequate resource allocation can lead to delays or insufficient response efforts.
3. Inadequate training: Emergency responders must have adequate training to respond effectively to different types of emergencies. Inadequate training can lead to mistakes and ineffective response efforts.
4. Coordination difficulties: Emergency response efforts often involve multiple agencies and organizations, and coordinating their efforts can be challenging. Lack of coordination can result in duplication of efforts or conflicting response strategies.
5. Limited accessibility: People with disabilities or limited mobility may have difficulty accessing emergency services or evacuating during emergencies. Emergency response systems must be accessible to all members of the community.

6. Technological limitations: Emergency response systems rely heavily on technology, and technical failures or limitations can hinder their effectiveness. It is essential to have backup systems and contingency plans in place to address technical issues.

It is therefore crucial to develop and adopt modern and efficient systems for data collection, analysis, and reporting to improve emergency response and disaster assistance. To achieve the goal of improving emergency response and disaster assistance, implementing an information system that utilizes data-driven decision making appears to be a promising strategy.

Data-driven Emergency Response

Data-driven emergency response in the campus involves the use of data analytics and real-time information to improve emergency preparedness and response. With the availability of various data sources, such as sensors, social media, and other digital platforms, it is possible to collect and analyze data to detect early warning signs of potential emergencies, track the spread of an ongoing crisis, and inform decision-making during and after the emergency. It has become an increasingly important strategy for improving emergency preparedness and response efforts. According to a report by the United Nations Global Pulse initiative, data-driven decision making can help emergency responders and disaster relief organizations gain real-time situational awareness and make more informed decisions during emergencies(Emmanuel Letouzé, 2012) . By leveraging data from a variety of sources, including social media, sensors, and other data streams, emergency response teams can gain insights into the situation on the ground and take actions more quickly and effectively.

One of data-driven emergency response model that frequently adopted in research is Decision-Making Trial and Evaluation Laboratory (DEMATEL). DEMATEL uses a multi-criteria decision-making approach to evaluate different factors and their interrelationships in order to make informed decisions(Gabus & Fontela, 1972). The method involves constructing a matrix of the relationships between different criteria or factors, and then using that matrix to identify the most important factors and the causal relationships between them. Studies has shown the applicability of DEMATEL in the context of emergency management(Song et al., 2022; Zhou et al., 2017). One limitation of DEMATEL is that it relies heavily on the availability and quality of data to construct the interrelationship matrix. The accuracy and usefulness of the final results of a DEMATEL analysis depend on the quality of the data used in the matrix construction. Here are a few specific issues related to data acquisition that may limit the effectiveness of DEMATEL:

1. Incomplete data: If there is missing data for some of the criteria or factors being evaluated, it can be difficult or impossible to construct a complete interrelationship matrix. This can lead to inaccurate or incomplete results.
2. Biased data: The accuracy of the interrelationship matrix depends on the quality and objectivity of the data used to construct it. If the data is biased or incomplete, it can lead to incorrect or incomplete results.

3. Data collection costs: Acquiring and processing data can be a time-consuming and costly process. Collecting and processing data may require significant resources and expertise, which may not always be available.
4. Data complexity: The data used in DEMATEL can be complex and difficult to obtain. In some cases, the data may be proprietary or confidential, making it difficult to access or use in a DEMATEL analysis.

All the issues mentioned are related to data. Whether it is incomplete, biased, costly or complex, the first and foremost step is to make the data available or acquiring data in a cost-effective manner. Therefore, this study proposes a cloud-based with low-code software development approach for developing the emergency response system in campus environment.

Method

The method for developing the emergency response system in this research is illustrated in Figure 9.

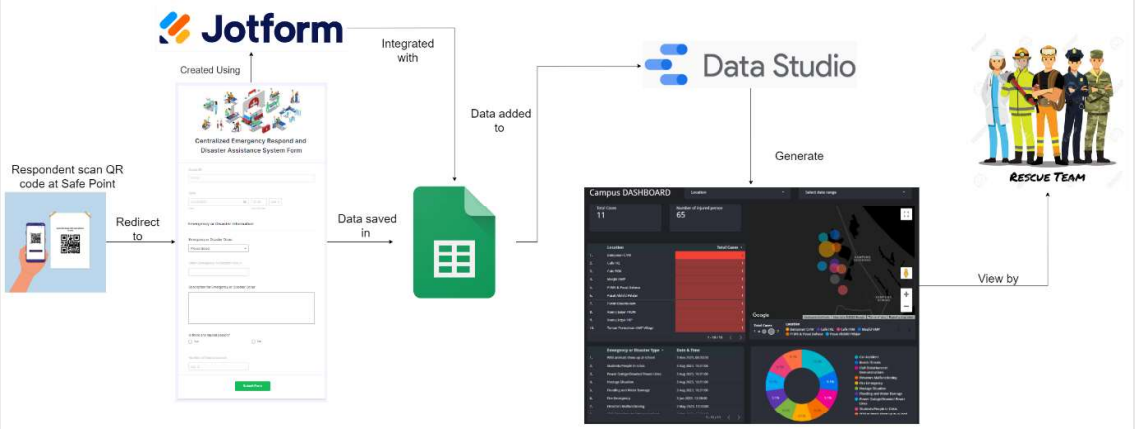

Figure 9: Method for Developing Emergency Response System

Step 1: Data acquisition with cloud-based form creator

There are various types and service providers that provide cloud-based form creation with low-code approach. In this study, we adopt the service from JotForm. It is an online form builder that allows users to create custom forms for a variety of purposes. The platform offers a wide range of form fields and customization options, making it easy for users to create forms that match their branding and meet their specific needs. Using JotForm to create an emergency report form with closed-ended, open-ended, short-form, and extended-form questions that respondents can fill out on their mobile phones by scanning a QR code at a safe point. The form collects data such as the date, time, location, emergency type, number of people injured, injury condition, and an image related to the emergency incident. The data is stored in JotForm and integrated with Google Sheets.

Step 2: Data visualization with cloud-based dashboard creator

There are many types of software that can be used for creating dashboards. Google Looker Studio is a valuable tool for developing dashboards, which can be used to visualize data collected from various sources, including Google Sheets. For this research, location data was essential, and the longitude and latitude of each location were imported into Google Looker Studio as data sources. To provide a geographic context for the data, a bubble map visualization was used to pinpoint the selected locations on the map. The size of the bubble represents the number of incidents that have occurred at each location, with different colors used to differentiate between locations. Additionally, a table with a heatmap was utilized to display the overall number of occurrences at each location, with lighter colors indicating a higher incidence rate. Figure 4 provides an overview of the dashboard used for this research.

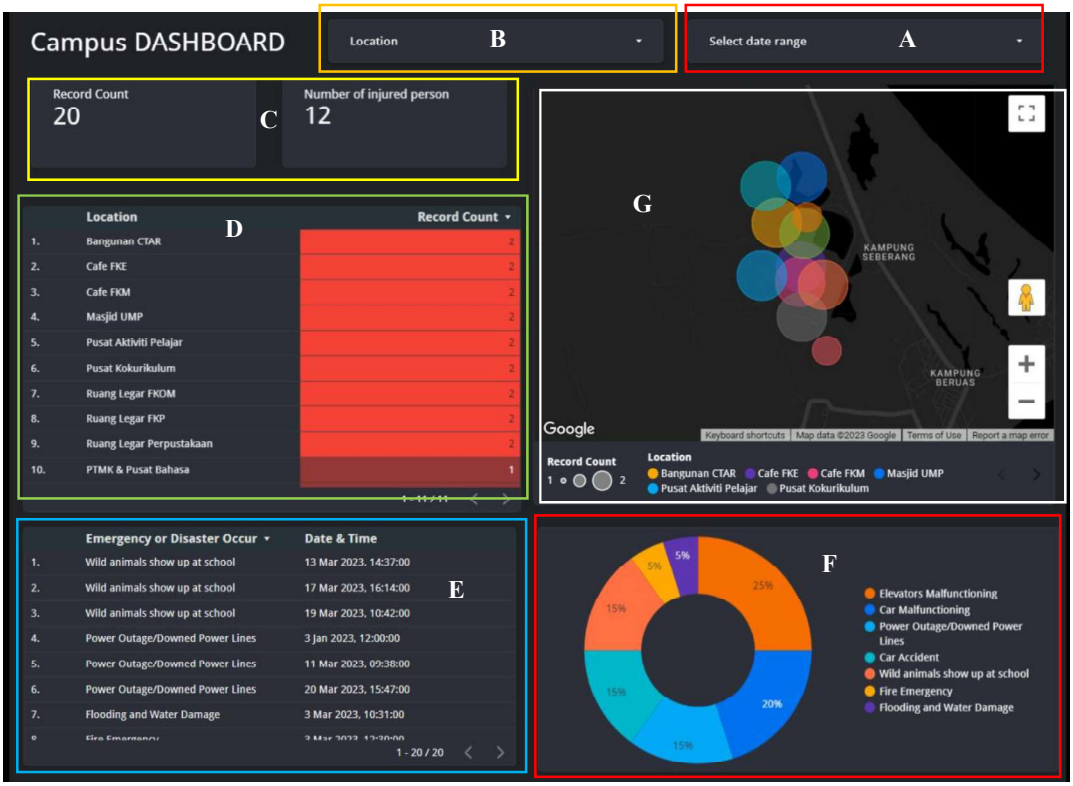

Figure 10: Method for Developing Emergency Response System

Results

The findings from this study are organized based on the research questions as follow: -

1. How significant is an online dashboard for emergency and disaster situations on campus?

   An online dashboard for emergency and disaster situations on campus is a significant tool in data-driven emergency response. By utilizing data analytics and real-time information, the dashboard

provides critical information for stakeholders to make informed decisions and take appropriate actions. It offers situational awareness by indicating the level of emergency and urgency for each emergency type and helps identify those who may be affected, enabling emergency responders to deploy resources more effectively and efficiently. Additionally, the dashboard displays the suggested required personnel for the University Health Centre and Emergency Department, as well as the number of available personnel for both departments. Inclusion of the level of emergency and urgency for each emergency type, along with personnel information, can further enhance the overall response to emergency and disaster situations on campus. Therefore, an online dashboard is an essential tool for effective data-driven emergency response on campus.

2. Which visualization techniques are critical and effective for emergency responses on campus?
   There are several visualization techniques that emergency responders can use to effectively respond to incidents on campus. Real-time dashboards are one such technique, providing stakeholders with critical information about the incident, such as the level of emergency and urgency, and the number of available personnel for responding to the situation. With real-time updates on the situation, these dashboards can help emergency responders deploy resources more effectively and efficiently. Another critical and effective visualization technique is the bubble map. A bubble map displays data using circles or bubbles of different sizes, colors, and positions on a map to represent specific values. It is an effective tool for visualizing spatial patterns and relationships between data points, such as the location and severity of incidents. By using longitude and latitude coordinates, emergency responders can quickly identify the location of the incident and determine the severity of the situation based on the size and color of the bubble. This visualization technique provides a quick and intuitive way for emergency responders to understand the situation and make informed decisions. Additionally, the bubble map can be used to visualize other relevant data, such as the distribution of emergency resources, to help responders allocate resources effectively. Overall, both the real-time dashboard and bubble map are critical and effective tools for emergency responses on campus.

Discussion

Based on Figure 10, the dashboard contains a dropdown list, date range control, scorecard, table with heatmap, bubble map, table, and pie chart. The combination of the mention elements can be an effective collection of tools for showing and analyzing data in a dashboard, such that: -

A. Date range control: Date range control which label with the label A enables users to customize the time period during which data is displayed. This is especially useful for tracking trends over time and assessing data changes across multiple time periods.
B. Dropdown list: Dropdown list which label with the label B enables users to filter data based on a selected location. This can assist users in focusing on the data that is most pertinent to their needs and make it easier to compare data across regions.

C. Scorecard: Scorecard which label with the label C gives a succinct total case happen and total number of people injured, allowing users to quickly determine the level of safety on the campus.
D. Table with heatmap: Table with heatmap which label with the label D shows data in a tabular fashion, with color-coded cells indicating the relative significance or value of each data item. This can help users see trends and patterns in the data more quickly.
E. Table: Table which label with the label E shows the emergency type, date and time data in a tabular fashion, with rows and columns that facilitate data sorting and filtering.
F. Pie chart: Pie chart which label with the label F displays the relative proportions of emergency type categories. This can be helpful for rapidly determining the most significant or pertinent categories.
G. Bubble map: Bubble map which label with the label G displays data spatially, using bubbles or markers to indicate the position and magnitude of cases. This is very effective for illustrating spatial trends in data.

The potential impacts of using a dashboard in emergency and catastrophe situations are significant and can extend to multiple sectors, including:

1. Society: Society 5.0 recognizes the importance of leveraging technology to improve safety, security, and quality of life for all members of society (Deguchi et al., 2020) The use of a dashboard in emergency and disaster response is a prime example of how technology can be used to achieve these goals. By providing the public with real-time updates and accurate information, the dashboard can help to minimize panic and misinformation, while also ensuring that individuals take appropriate safety measures.
2. Government: The use of a dashboard in emergency and catastrophe situations is an example of how digital government can be leveraged to improve the delivery of public services. Digital government refers to the use of digital technologies, such as online platforms and data analytics, to enhance the efficiency, effectiveness, and transparency of government operations (Misuraca et al., 2020).
3. Industry: A dashboard can be an invaluable tool for protecting critical infrastructure and facilities during emergencies or natural disasters. By utilizing data-driven decision-making in emergency response systems, it becomes possible to identify potential threats and deploy necessary resources to secure vital infrastructure and facilities with a preventive management approach for the long term. This approach aligns with the global trend towards the fourth industrial revolution (Duan & Da Xu, 2021).
4. Environment: The efficiency gained from data-driven decision making has a significant impact on the environmental issue. Optimization of resource utilization is possible to be done when there is data available either for real-time action or future scenario planning especially on the logistic and resource planning. This somehow affect directly the environmental in term of carbon emission especially from fires (Wiedinmyer & Neff, 2007).
5. Academia: This study contributes a new insight into the body of knowledge for sustainable higher education itself. Greater attention can be made among scholars and academia on the importance of emergency response systems empowered with data analytics.

Conclusion

The findings of this study highlight the importance of data-driven decision-making in emergency response and disaster management systems at higher education. By utilizing cloud-based services such as online form creator and online dashboards, universities and communities can gather and analyze data to inform emergency response plans and improve the safety and security of individuals on campus. Furthermore, the study's emphasis on sustainable development goals underscores the need for emergency response systems that prioritize building resilience and preparedness for emergencies scenarios. As such, investing in smart campuses with robust emergency response systems can contribute to achieving these goals, making them an essential resource for decision-makers and stakeholders in emergency management and disaster preparedness. In summary, the link between campus emergencies and emergency response systems is clear. By implementing data-driven decision-making with cloud technologies, universities and communities can improve their emergency response and disaster management systems, ensuring the safety and security of individuals on campus while contributing to sustainable development goals.

Limitation and Recommendations

While this study offers important insights into emergencies and disasters in higher education, it is also subject to certain limitations. The effectiveness of visual analytics on emergency response and disaster management depends on factors such as the availability of resources and infrastructure, as well as the capacity of stakeholders to implement and use these technologies effectively. For example, the use of smartphone is essential to lodge an emergency report. In certain emergency cases where a person panics or passes out, there is a high possibility the person will be unable to use the technology effectively. As for future research, findings and limitations from this study could provide the way how to explore additional questions related to emergencies and disasters in higher education. Some potential areas for further investigation are:

1. Factors that influence the occurrence of emergency and disaster cases could be examined in future research. For instance, this study revealed a significant incidence of elevator malfunctioning on campus, and further research could explore contributing factors such as mechanical failure or improper maintenance to reduce the frequency of lift malfunctions.
2. The relationship between emergency and disaster cases and their effects on mental health could be investigated in future research. This study did not explore this connection, and additional research could identify successful approaches for delivering psychosocial support and increasing mental health resilience in affected communities.
3. Future research could be conducted to identify effective strategies for improving community readiness and resilience for emergency and disaster situations. Emergency preparedness and resilience are crucial for mitigating the effects of catastrophes and disasters.

Acknowledgements

The authors gratefully acknowledge the financial support from Made in UMP Research Grant Scheme with project reference PDU223002-3 from Universiti Malaysia Pahang.

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