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Optimizing Disaster Management with Blockchain Technology: A Decision Support System for Disaster Risk Reduction and Management

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Abstract: As technology advances, the enhancement and development of disaster-related remains limited, and disaster management at the regional level is prompt to actively collect and deliver information at a fast pace while deriving comprehensive disaster insights in real time. However, many organizations still rely on manual reporting as it requires formatting, sorting and proofreading that leads to time consuming, data duplication and delays in decision-making and inefficiencies due to lack of appropriate tools to enhance the organization's productivity. To address these challenges, the researcher developed a Decision Support System with blockchain technology for Disaster Risk Reduction Management for the Office of the Civil Defense Cordillera Administrative Region. This system standardized disaster risk management system and enables for regional agencies to deliver efficiently in near real-time scenario. Additionally, it facilitates streamlined analysis and secure data storage, allowing duty officers to visualize the current situation more effectively. Future researchers can further enhance the system's functionality by adding recommended features such as AI monitoring and notification, import and export of situational reports from different line agencies, plotting of tropical cyclones related incidents, earthquake and fire incident monitoring.

Keywords: *Blockchain, blockchain technology, cordillera , decision support system, disaster, disaster management, disaster risk reduction and management, tropical cyclones*

1. Introduction

The impact of disasters severely affects many people, results in deaths, destruction of infrastructure, and economy loss. This is evident from global statistics of Natural Disasters Data Book (2011) [1], which reflects that 39% of disasters occurred in Asia and 53% caused deaths worldwide. In response to this situation, extensive recovery efforts are required and this study aims to significant benefits to disaster management preparedness by establishing an interpreting disaster-related information before, during and after the disaster.

One of the disasters affecting the Philippines is tropical cyclones, also known as hurricanes or typhoons depending on the region, are among the most devastating natural hazards on the planet. Globally, they are responsible for significant economic damage, human casualties, and have caused long-term environmental impacts. Similarly, natural hazards such as earthquakes, volcanic eruptions, and landslides disrupts normal communities' functions, causing widespread damage and threats to both environment and human life which requires response to mitigate their effects. Subsequently, International Federation of Red Cross (2019) [2], defined disaster as a sudden calamitous event that seriously obstructs the community or society that causes human, material and environmental losses.

Not to mention, a report from the World Meteorological Organization (WMO) shared that tropical cyclones account a large portion of the world's annual economic losses due to natural disasters, often exceeding billions of dollars in damages each year (WMO, 2019) [10]. Moreover, cyclones have caused widespread displacements and contributed to the increasing vulnerability of coastal and low-lying areas (Cutter, 2020) [11].

Identically, the frequency and intensity of tropical cyclones are anticipated to increase due to climate change, leading to more severe impacts globally. This reflects in the study by Knutson et al. (2020) [21] indicating that while the overall number of cyclones may decrease, the intensity of those that do occur is likely to increase, resulting in more Category 4 and 5 storms. These intense storms bring catastrophic winds, torrential rains, and storm surges that cause massive flooding, infrastructure damage, and loss of life.

Consequently, tropical cyclones pose a significant threat to communities worldwide, particularly in provinces like Benguet, Philippines where mountainous terrain and fluctuating weather patterns can aggravate their impacts. The optimizing disaster management with blockchain technology: a decision support system to DRRM aims to enhance disaster preparedness and

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response strategies by providing real-time data and analytics on tropical cyclone activities. Effective management of such natural hazards is crucial to mitigate their effects on infrastructure, agriculture, and the safety of residents.

With the increasing frequency and intensity of tropical cyclones attributed to climate change, there is an urgent need for systems that can facilitate timely decision-making and resource allocation. Previous studies have shown that implementing advanced information systems can significantly improve emergency response efforts. The Decision Support System for Disaster Risk Reduction and Management (DSS-DRRM) leverages technology to integrate meteorological data, geographical information systems (GIS), and community resources to create a comprehensive platform for stakeholders involved in disaster management.

This study explores the development and implementation of the DSS-DRRM, examining its potential to provide valuable insights and facilitate collaboration among government agencies, local communities, and non-government organizations. By enhancing the capacity to respond to tropical cyclones, the DSS-DRRM contributes to building a more resilient Benguet, Philippines ultimately safeguarding lives and livelihoods.

In this regard, assessing the disaster mitigation is crucial as to enhance the disaster response at different levels, be able to identify strengths and weaknesses from economic and environmental perspectives and supporting effective disaster risk management and resource allocation (Cao et al., 2023, Shuai et al., 2023 [18], Zhang et al., 2021a, Zhang et al., 2021b) [13]. With a systematic analysis of disaster mitigation indicators, aids in determining the level of a regional disaster mitigation capacity including social, economic, institutional and infrastructure aspects (Thanvisitthpon et al., 2020 [14], Liu et al., 2022 [15], Cao et al., 2023 [13]). This is also reflected in several studies that provide an analysis of typhoon disaster mitigation in Hainan and Guangxi, China. Likewise, the developed evaluation index system manifests a significant change in disaster prevention, mitigation and rescue (Wang et al., 2022) [16].

Furthermore, according to the authors (Rafliana et al., 2022) [17], implementing effective post-disaster mitigation strategies will prevent further catastrophic consequences in the future. Understanding and evaluating existing mitigation measures provides valuable insights to protect communities against possible upcoming natural hazards.

With this in mind, international efforts to mitigate the impact of tropical cyclones have increasingly focused on disaster risk reduction and resilience-building. The Sendai Framework for Disaster Risk Reduction (2015–2030), adopted by the United Nations, emphasizes the importance of reducing disaster risks through improved governance, risk assessment, and community preparedness (UNDRR, 2019). This framework encourages countries to invest in early warning systems, infrastructure resilience, and disaster education as key strategies to reduce the vulnerability of populations to natural hazards (García et al., 2021). For example, sentinel Asia is one of the initiative satellite remote sensing to showcase the value and impact of Earth observation technologies including Web-GIS technology to assist in disaster management of the Asia-Pacific region (Kaku, 2019).

Comparatively, the 17 Sustainable Development Goals (SDGs) represent a universal call to action, urging nations worldwide, regardless of their economic status, to collaborate cohesively. Hence, The DSS-DRMM is determined to spur economic growth and monitoring of climate change to preserve our environment. By emphasizing disaster risk reduction for both natural and human-induced hazards, the approach seeks to strike a balance between the economic, social, and environmental aspects of sustainable development. Proactive management is encouraged over reactive management.

In like manner, the Philippines, under the government's efforts, has implemented several programs aimed at reducing the impact of disasters like tropical cyclones. For this reason, the Philippine Disaster Risk Reduction and Management Act of 2010 was established as a comprehensive framework for disaster management, focusing on preparedness, response, and recovery at all government levels (Alcayna et al., 2020) [4]. This act mandates local government units (LGUs) to develop disaster risk reduction plans, establish early warning systems, and allocate funds for disaster preparedness. Also, the application of information technology in disaster management has been growing, with various innovations designed to address the country's unique vulnerabilities. Notably, the Flood Monitoring and Early Warning System (EWS) implemented by the Department of Science and Technology (DOST) is an example of how technology can be leveraged to reduce disaster risks (Castañeda & Perez, 2019) [6]. This system uses real-time data from weather stations and river monitoring equipment to predict floods and issue timely warnings to communities.

At the local level, community-based disaster risk reduction programs have been crucial in enhancing resilience in Cordillera Administrative Region, Philippines. These programs involve training residents in disaster preparedness, conducting evacuation drills, and developing localized early warning systems (Delos Reyes et al., 2020) [12]. The active involvement of communities in disaster management has been recognized as a key factor in reducing casualties and ensuring faster recovery after disasters.

Henceforth, the issue with disaster management, as articulated by Sarra Chaiir, Malika Charrad, Narjes Bellamine, and Ben Saoud (2023) [7], lies in the overwhelming influx of information from myriad sources that decision-makers must contend with. This deluge often compels them to depend on personal experience or external counsel. While some may perceive this as a minor inconvenience, within the realm of disaster management, any hesitation or indecision can increase the loss of lives and property, thereby presenting significant threats.

Economically, the impact of these disasters is staggering. The 2017 Atlantic hurricane season alone, which included Hurricanes Harvey, Irma, and Maria, caused an estimated $294 billion in damage, making it the costliest season on record (NOAA, 2019). Developing nations are particularly vulnerable due to their limited resources for disaster preparedness and recovery, often relying heavily on international aid and support (Hallegatte et al., 2020) [22]. The Philippines is one of these developing countries.

To concretize, the Philippine Institute for Development Studies (PIDS) estimated the cost of disasters per year in the Philippine economy, based on 1905 to 2017 data, to be around 85 to 422 billion pesos, with 81,302 people killed, 219,874 people injured, 204,336,105 people affected, 6,276,465 homeless, and

210,832,444 total people affected. These staggering statistics point out that disasters need attention in order for the Philippines to cut down on expenses and loss of lives during catastrophic events (Philippine Institute for Development Studies, 2020) [3].

The Cordillera Administrative Region (CAR) in the Philippines is frequently affected by tropical cyclones, leading to significant impacts on the lives, properties, and livelihood of its residents. These cyclones often result in severe weather conditions such as heavy rainfall, strong winds, and landslides, which can cause extensive damage to infrastructure, agriculture, and homes. Given the region's mountainous terrain and the susceptibility of its communities to such natural hazards, there is a pressing need for an efficient and reliable system to manage information related to tropical cyclone events.

In view of a hazard assessment by the Mines and Geosciences Bureau (MGB), 80% (938 out of 1,172) of barangays in the region are highly susceptible to landslides, and 16% (184 barangays) are very highly susceptible. Additionally, 42% (494 barangays) are highly susceptible to flooding, while 17% (198 barangays) are very highly susceptible to this hazard. Planning and putting precautions in place to reduce risk are essential. Since most disasters involve difficulties with information flows, there is still room for improvement in integrating all the data required to consistently create winning plans, identifying weak points, while taking specific risks and hazards into account.

Significantly, landslides are a recurrent problem in the Cordillera Administrative Region, exacerbated by deforestation and unsustainable land use practices. The National Disaster Risk Reduction and Management Council (NDRRMC) has identified Benguet as one of the most landslide-prone areas in the country, with numerous incidents recorded each year during the rainy season (NDRRMC, 2021). These landslides not only result in fatalities but also cut off communities from essential services, making disaster response and recovery efforts challenging.

In the Cordillera Administrative Region, tropical cyclones pose a significant threat. While Benguet is not usually in the direct path of tropical cyclones, it is highly susceptible to the secondary effects of this hazard, such as landslides and flash floods. The region’s steep terrain and heavy rainfall make it particularly vulnerable, often leading to disasters that claim lives, destroy homes, and disrupt agriculture. As a matter of fact, the agricultural sector, which is vital to Benguet's economy, is particularly affected by these natural hazards. Crops such as vegetables and coffee, which are key products of the region, are often destroyed by landslides and floods, leading to significant economic losses for farmers and the local economy (Cruz & David, 2020) [9].

All things considered, information technology has revolutionized disaster management by improving early warning systems, enhancing data collection and analysis, and facilitating communication during emergencies. Satellite-based systems, for example, have become essential in monitoring and predicting the paths of tropical cyclones, providing valuable lead time for communities to prepare and evacuate if necessary (Bettencourt et al., 2021) [5]. Advances in remote sensing and Geographic Information Systems have also enabled more accurate mapping of vulnerable areas, allowing for better planning and risk assessment (Cova et al., 2019) [8]. Specifically, authors Johnson and Lee shared that artificial intelligence and machine learning that are increasingly being used to analyze vast amounts of meteorological data, improving the accuracy of cyclone predictions and helping to identify patterns that may indicate impending disasters. These technologies are crucial in reducing the uncertainty associated with cyclone forecasting and in making more informed decisions about disaster response and resource allocation. Moreover, mobile applications have become vital tools for disaster communication. Applications like the "Safe Philippines" provide users with real-time updates on weather conditions, disaster alerts, and safety tips, allowing individuals to take proactive measures during emergencies. These apps also facilitate community reporting of hazards and damage, improving the efficiency of disaster response efforts.

This study aims to identify system design requirements and determine the specific key features and creation of Decision Support System for Disaster Risk Reduction and Management with blockchain technology approach of Office of Civil Defense-Cordillera Administrative Region (OCD-CAR).

2. Methods

2.1 Research Design

This study utilized a quantitative type of method with design thinking principles. Quantitative data are collected through a survey questionnaire that reflects the usability of the development of DSS-DRRM. Meanwhile, gathered qualitative data are through interviews with the Operations Section team with an open-ended question it provides in-depth information on current operations section practices of gathering data, challenges encountered in disaster data management and desired functionality.

Most data from this study were collected through a survey questionnaire and interviews with Civil Defense Cordillera Operations Section team and Baguio PAGASA Synoptic and Upper-Air Station through a survey questionnaire was used to gather quantitative data.

The gathered data were examined using descriptive statistics to analyze the quantitative data gathered from the interviews. The findings from the analysis were used to provide recommendations for the creation and enhancement of Decision Support System for Disaster Risk Reduction and Management incorporating blockchain technology.

2.2 Development Process

The researcher application of Feature-Driven Development (FDD) focus on delivering client-valued features that can be escalated to a larger project. It is an agile methodology that’s objective with tangible software results efficiently. The iterative nature of FDD guarantees that the development process remains responsive to changes and constantly adapts to client desires. Harvard Business School Dean Srikant Datar [19] uses a four-stage innovation framework that progresses from concrete to abstract thinking. The design thinking stages are as follows clarify, ideate, develop and implement. These stages include identical phases in the software development workflow as shown in figure 1.

Phase 1: Develop an overall model. This phase emphasizes understanding the context of the project particularly its scope while establishing clear objectives, identify current requirements and accumulating the needed data. Based from SRM Tech (2023) [23], this phase serves as the fundamental base of the system that will be built. Initial gathering of crucial data needed to create the overall model and needs to emphasize the key elements of the proposed system development by data gathering and develop outline of the system.

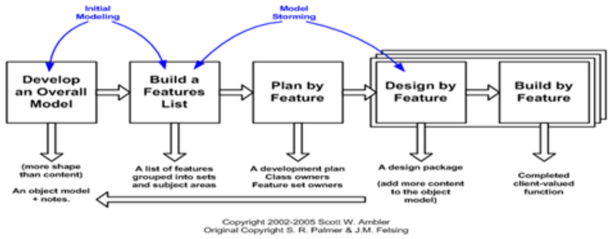

Figure 1. Feature-Driven Development (FDD)

Phase 2: Build a feature list. According to Laura Fitzgibbons [24], describes this phase as creating a list of features with a focus on completing a provided timeline that align with client priorities. Additionally, complex queries or request are broken down into a series of smaller feature sets to complete the required data. This phase aims to create a preliminary design focusing on the user interface, database and interaction flows. Based on the gathered information, this phase generates ideas and concepts, including prototyping and brainstorming.

Phase 3. Plan by feature. Analysis each feature and tasks, evaluating their functionality and assessing their complexity. Launch Darkly (2021) [25] supports this approach, emphasizing the importance of determining the order in which features are developed and implemented to identify potential risks, limitations and dependencies. Feature-base planning builds on the final results of phase 2 which involves assessing from the perspective of each development stage by ranking the identified key features into high, medium and low which will aid prioritize and specify the most important features to include and implement.

Phase 4. Design by feature. Author Rachelle Lynn of Planview shared that this is the process of implementing all the components and determine the functionality. Afterwards, there is a need to review and test the prototype for client inspection. The innovation of proposed system is commenced according to the established design specifications, key components integration and initial user inspection. Also, this phase the user interface can be reviewed and evaluated by the client to verify functionality, address any concerns, and ensure that it meets the final design expectations.

Phase 5. Built by feature. As stated by Lucidchart blog, all feature designs have been implemented and completed. Similarly, the detailed components and prototypes of the features have been built, tested, and approved by the client. The final phase involves usability testing and end-user testing as well as providing of complete technical design, key functional features and completed system based on client satisfaction and achieved the objective.

2.3 Data Analysis

Utilization of 5-point Likert Scale reveal the efficiency of the system which exhibits components and integrate accomplishment that is lighter and uncomplicated. To determine the minimum and the maximum length of the 5-point Likert type scale, the range is calculated by $(5 - 1 = 4)$ then divided by five as it is the greatest value of the scale $(4 \div 5 = 0.80)$. The scale ranged from 5 being the highest with descriptive equivalent of excellent and 1 being the lowest with descriptive equivalent for system acceptability and efficiency.

Table 1. Interpretation of results

Length	Point Scale	Descriptive Equivalent	Interpretation
1.00 - 1.80	1	Poor	Not Acceptable
1.81 - 2.60	2	Fair	Poorly Acceptable
2.61 - 3.40	3	Good	Acceptable
3.41 - 4.20	4	Very Good	Fairly Acceptable
4.21 - 5.00	5	Excellent	Very Acceptable

3. Result and Discussion

This section manifests and discusses the study's results which consists of system requirements for designing and developing the Optimizing Disaster Management with Blockchain Technology: A Decision Support System for Disaster Risk Reduction and Management and the extent of usability, functionality and productivity of the proposed system.

3.1 Requirements Needed in the Developed Decision Support System for Disaster Risk Reduction and Management with Blockchain Technology

User Activity and Access Logging. Implement a basic user authentication and access system with the following roles: super admin, Emergency Operations Center (EOC) manager, planning coordinator, logistic coordinator, Department of Public Works and Highways (DPWH), Department of Social Welfare and Development Field Office Cordillera Administrative Region (DSWD FOCAR), Department of Health Center for Health Development (DOH CHD) and OCD-CAR Director.

Blockchain technology integration. For documenting and validating OCD-CAR budget and resource allocation records. Additionally, integration of simple smart contract to log and access OCD-CAR resource and fund allocation transactions.

3.2 Features of the Decision Support System for Disaster Risk Reduction and Management with Blockchain technology

The features of the developed system were based on the situational reports received from the regional line agencies such as DSWD FOCAR, DOH CHD CAR and DPWH CAR.

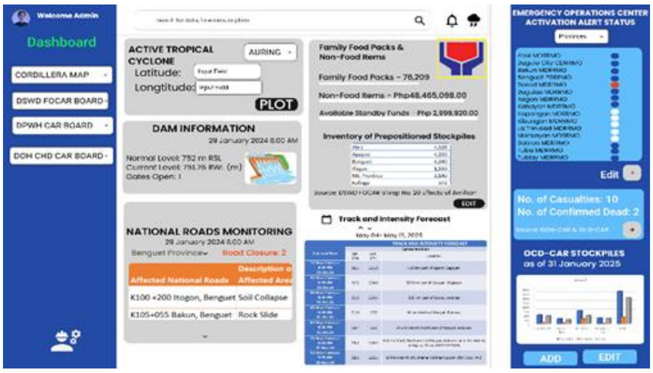

Figure 2. Dashboard of the Decision Support System for Disaster Risk Reduction and Management

Regional Situational Data Dashboard. Display essential disaster incident data that includes active tropical cyclone monitoring, dam information, national roads monitoring in the Cordillera Administrative Region, DSWD stockpiles, casualties monitoring and Office of Civil Defense – CAR stockpiles. Allow users to enter disaster incident data and show key metrics of the system.

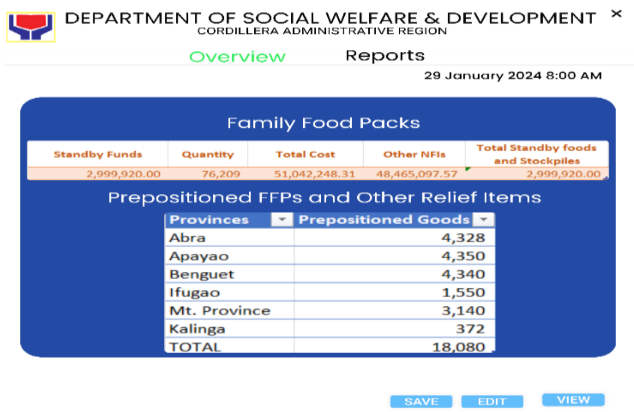

Figure 3. DSWD FOCAR board

Department of Social Welfare and Development board. The content of this board manifest quantity of family food packs (FFP) available and prepositioned FFP's in different provinces in the Cordillera Administrative Region.

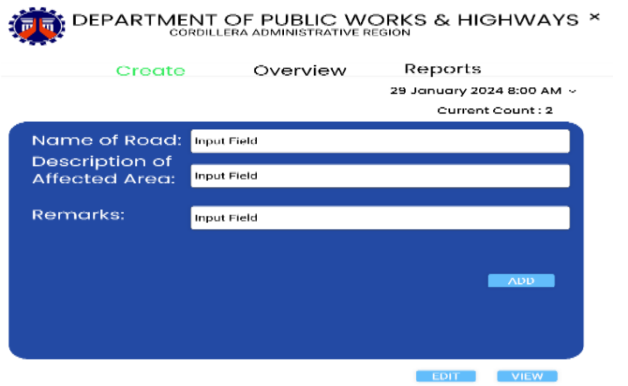

Figure 4. DPWH CAR board – Creation of report

Department of Public Work and Highways (DPWH) board. The DPWH board covers the name of affected national roads, description of affected area and remarks. It also reflects the count of affected national road due to tropical cyclone.

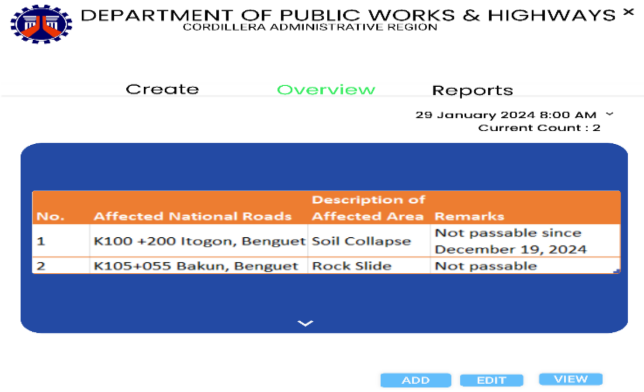

Figure 5. DPWH CAR board – Overview of report created

Department of Health Center for Health Development (DOH CHD) board. The DOH CHD board reflects the name, gender, address, hospital, date seen and date discharged of casualties. Included also the management of the dead and missing persons that covers time period covered, province category, municipality category, name, address, age and remarks.

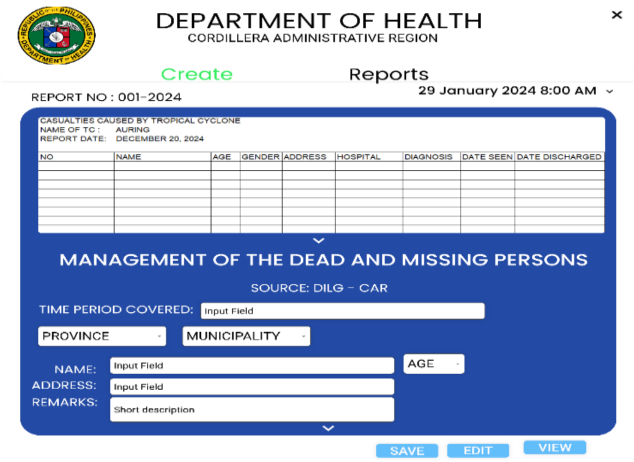

Figure 6. DOH CHD CAR board – Creation of the report

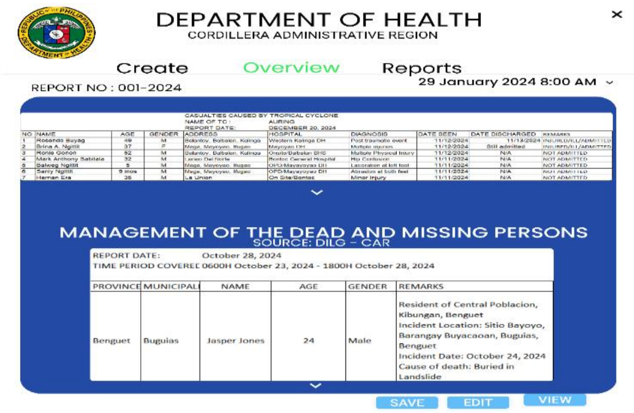

Figure 7. DOH CHD CAR board – Overview of the report created

3.3 Level of Usability of DSS for DRRM with Blockchain technology

The respondents were from the personnel of Operations Section Team of Civil Defense Cordillera. System usability reflects the ease of use of a system and can be measured by considering the context of use of the system that is described in ISO 9241 (Shojaei, D. et.al, 2013) [20].

It exhibits from Table 2 that the mean score of the DSS for DRRM with Blockchain technology in terms of Functionality is 4.38 with a descriptive equivalent of Excellent, described as "Very Acceptable". It also evident that acceptability, suitability and learnability of the system has the highest means of 4.83, interoperability comes second with then mean of 4.67 while user interface design gained the lowest mean with 3.33, labeled as "Acceptable." Therefore, the developed Cordillera DSS for DRRM with Blockchain technology is convenient, as the results show that the system's functionality is acceptable, suitable and effective for monitoring of duty personnel in the Cordillera RDRRMC Emergency Operations Center. This leads to easier data access and retrieval, as well as more efficient task management and workload distribution.

Table 2. Functional Standpoint for the Usability Level of the DSS for DRRM with Blockchain Technology

Indicator	Statistical Range	Descriptive Equivalent	Descriptive Interpretation
Acceptability	4.83	Excellent	Very Acceptable
Simplicity	4.5	Excellent	Very Acceptable
Suitability	4.83	Excellent	Very Acceptable
Interoperability	4.67	Excellent	Very Acceptable
User Interface	3.33	Good	Acceptable
Overall impression	3.67	Very Good	Fairly Acceptable
Learnability	4.83	Excellent	Very Acceptable
Mean	**4.38**	**Excellent**	**Very Acceptable**

Table 3 indicates that the overall usability of the system is rated at 4.42, which corresponds to the descriptive rating of Excellent and equivalent interpretation as "Very Acceptable". The data shows that most indicator including operability, interaction and accessibility are highly tag as Excellent. In contrast, the attractiveness had received the lowest rating of 3.33 highlighting the need to enhance in the user interface design. Overall, the developed DSS for DRRM with Blockchain technology is highly accepted, effectively handled with errors and security.

Table 3. Usability Standpoint for the Usability Level of the DSS for DRRM with Blockchain Technology

Indicator	Statistical Range	Descriptive Equivalent	Descriptive Interpretation
Operability	5	Excellent	Very Acceptable
Interaction	4.5	Excellent	Very Acceptable
Accessibility	4.83	Excellent	Very Acceptable
Attractiveness	3.33	Good	Acceptable
Mean	**4.42**	**Excellent**	**Very Acceptable**

Finally, productivity refers to how the system elevate the efficiency of producing more outputs in a manner of time. Based on the results, table 4 has an average score of 4.67 in terms of productivity, that results to "Excellent" descriptive equivalent and "Very Acceptable" as interpretation result. Despite the stability is the lowest with an average of 3.17, rated as "Acceptable."

Table 4. Productivity Standpoint for the Usability Level of the DSS for DRRM with Blockchain Technology

Indicator	Statistical Range	Descriptive Equivalent	Descriptive Interpretation
Stability	3.17	Good	Acceptable
Time-saving	5	Excellent	Very Acceptable
Resource utilization	4.83	Excellent	Very Acceptable
Changeability	4.67	Excellent	Very Acceptable
Mean	**4.67**	**Excellent**	**Very Acceptable**

2. Conclusion

This section presents the conclusion of the developed Decision Support System for Disaster Risk Reduction and Management with Blockchain Technology as follows:

- The results indicate that the system design and development required information gathered from various situational reports of regional agencies. This includes forecast of tropical cyclone, DSWD FOCAR family food packs, non-food items, and inventory of prepositioned stockpiles, DPWH-CAR roads monitoring, OCD-CAR stockpiles and DOH CHD CAR reports on casualties and confirmed fatalities
- The features integrated into the developed system can still be enhanced while the current version includes the following a regional situational data dashboard that displaying essential disaster incident data. Additionally, blockchain technology has been integrated for recording and verifying OCD-CAR budget and resource allocation transactions.
- Overall, the developed system is highly acceptable in terms of functionality, usability, and productivity, demonstrating efficiency and reliable performance. Therefore, implementing this system supports Cordillera Regional Disaster Risk Reduction and Management Council Emergency Operations Center duty personnel in visualizing near real-time data, management of data disaster reports and effective management of resource allocation.

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