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AI-Enabled Seismic Sentinel Initiative: Integrating Predictive Analytics, GPS-Guided Evacuation, and Compliance Frameworks to Strengthen University-Based Earthquake Resilience and Community Protection

Jonathan Q. De Leon
Universidad de Manila, Philippines
athanqdeleon@gmail.com

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ABSTRACT

Urban universities in Metro Manila face heightened seismic risks due to dense populations, aging infrastructure, and limited evacuation routes. This study evaluates the AI-Enabled Seismic Sentinel Initiative, a disaster resilience program developed in compliance with Republic Act No. 10121, CHED Memorandum Order No. 9, and Manila Ordinance No. 8323. The initiative integrates predictive analytics, GPS-guided evacuation, multilingual communication, and compliance frameworks into a cohesive university-based disaster management ecosystem. A mixed-method design analyzed system logs, SMS delivery records, compliance audits, and user feedback to assess reliability, behavioral change, and policy alignment. Results show a 70.6% SMS success rate, predictive alarms with an average 15.3-second lead time, and 80% immediate evacuation participation. Community indicators reveal 85% satisfaction and trust, alongside 70% adoption of evacuation plans. By embedding AI-driven monitoring and compliance integration into institutional protocols, the initiative advances beyond procedural compliance to establish a transformative model of resilience, positioning Universidad de Manila as a leader in disaster-ready universities.

Keywords: *AI-enabled disaster resilience; Seismic Sentinel Initiative; Predictive analytics; GPS-guided evacuation; Compliance frameworks; Community resilience*

INTRODUCTION

Earthquakes are among the most devastating and unpredictable natural disasters, capable of disrupting communities, damaging infrastructure, and causing significant casualties. The Philippines, situated within the Pacific Ring of Fire and intersected by active fault systems such as the West Valley Fault, is particularly vulnerable to seismic hazards (PHIVOLCS, 2024). Metro Manila, the nation's capital, faces heightened risks because of its dense population, aging infrastructure, and limited evacuation routes, making universities especially exposed to disaster impacts (Bernardo, 2018).

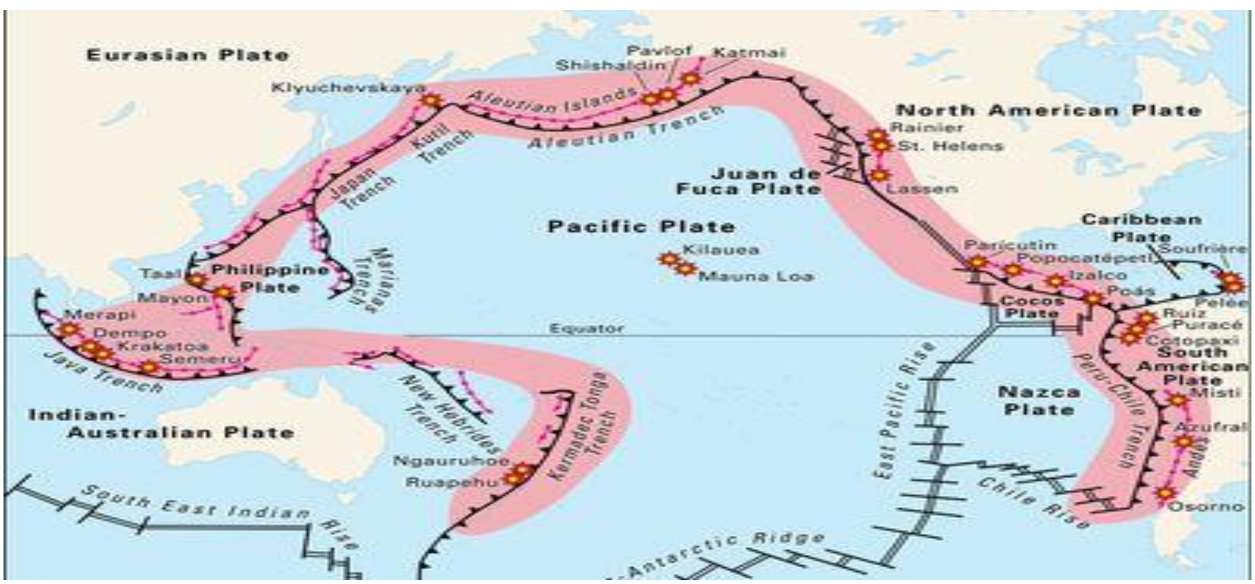
The Universidad de Manila (UDM), located at the heart of Manila, exemplifies these vulnerabilities. Narrow roadways, older campus buildings, and concentrated student populations present serious challenges for evacuation and safety. Previous studies highlight how outdated infrastructure, poor communication, and insufficient preparedness amplify earthquake risks in Metro Manila (Bernardo, 2018; Yumul, 2019; De Guzman & Rivera, 2020). These realities underscore the urgent need for innovative, institution-based resilience strategies that move beyond conventional compliance and toward proactive disaster readiness.

In response, UDM has spearheaded the AI-Enabled Seismic Sentinel Initiative, a flagship research-driven program that unifies community-centered emergency response, artificial intelligence (AI), and institutional compliance into a cohesive ecosystem for earthquake safety. By integrating AI-enabled monitoring, predictive analytics, and multi-channel communication into the university's disaster management infrastructure, Seismic Sentinel is intended to convert compliance-driven preparedness into proactive resilience.

The system's design is based on well-known theoretical frameworks: Human Computer Interaction for user-centered design (Norman, 2020); Mobile Communication for accessibility (Park et al., 2020); AI in Disaster Management for predictive accuracy (Grigoli et al., 2021); and Crisis Management for preparedness and response (Boin et al., 2019). By guaranteeing both technological dependability and usability, this integration positions Seismic Sentinel as a game-changing paradigm for universities in disaster-prone areas.

The program goes beyond only adhering to Republic Act No. 10121, CHED Memorandum Order No. 9, and Manila Ordinance No. 8323 by integrating AI-driven monitoring and communication into UDM's disaster management infrastructure. It is a flagship research program that reimagines how colleges manage disasters, save lives, and build community resilience. Additionally, the study supports national and international efforts to create resilient academic ecosystems that can maintain operations and protect communities during seismic disasters by placing UDM's endeavor inside the larger conversation on disaster-ready universities.

Philippine Geographical Location



Source: Asian Disaster Reduction Center (ADRC). Information on Disaster Risk Reduction of the Member Countries (2024). Ring of Fire. Britanica. (Accessed November 7, 2024).

Figure 1. Philippine Geographical Location – Map showing the Philippines' position along the Pacific Ring of Fire, highlighting seismic vulnerability and contextualizing the need for AI-enabled disaster resilience technologies such as the Seismic Sentinel Initiative.

The Philippines' placement along the Pacific Ring of Fire is highlighted in Figure 1, which gives a geographical picture of the country. This graphic provides context for comprehending why the nation, and Metro Manila in particular, are constantly at risk from earthquakes. The graphic highlights the Philippines' susceptibility to earthquakes and volcanic activity by placing it at the meeting point of several tectonic plates. The West Valley Fault is a significant risk factor for Metro Manila, according to the Philippine Institute of Volcanology and Seismology (PHIVOLCS, 2024), highlighting the importance of AI-enabled disaster resilience technologies like Seismic Sentinel.

Conceptual Framework: IPO Model

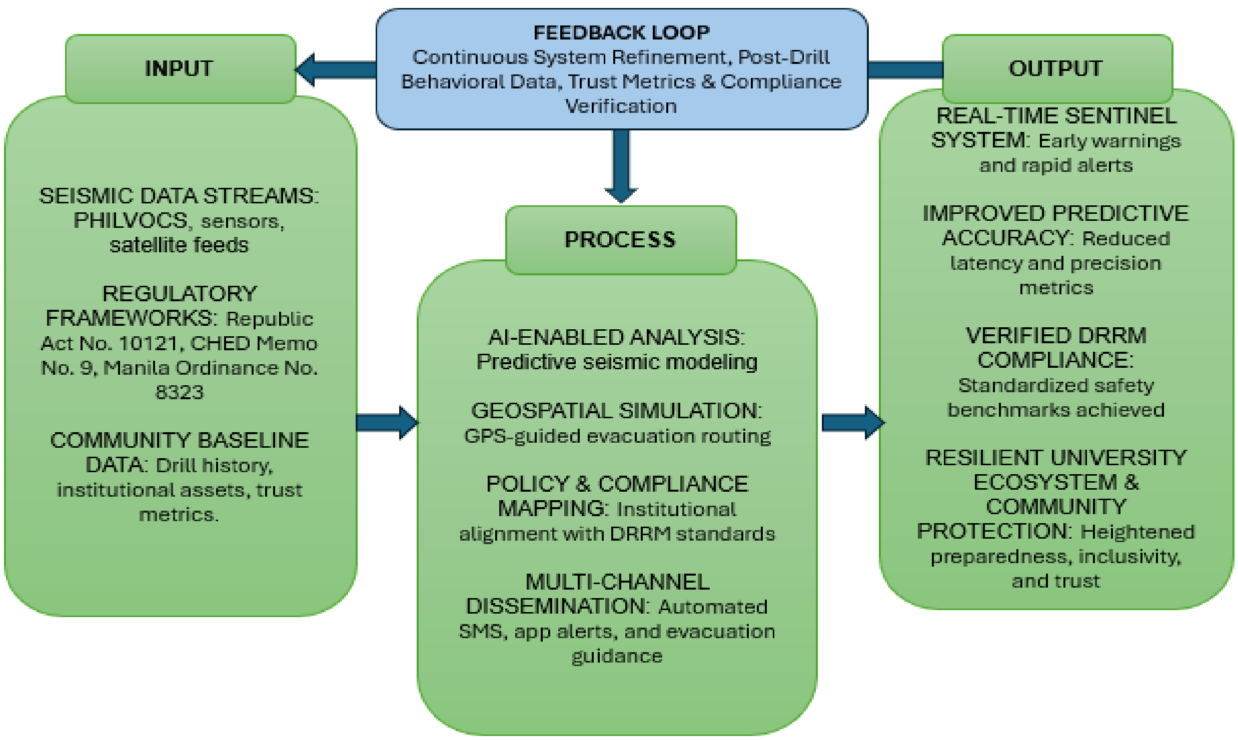


Figure 2. *Input–Process–Output (IPO) Model of the AI-Enabled*

Figure 2. Input–Process–Output (IPO) Model of the AI-Enabled Seismic Sentinel Initiative – Framework illustrating how predictive analytics, GPS-guided evacuation, and compliance frameworks are systematically integrated to strengthen university-based earthquake resilience and community protection.

. The study employs the Input–Process–Output (IPO) Model as a systems-based paradigm that demonstrates how institutional mandates, seismic data, and community inputs are systematically transformed into actionable disaster resilience outcomes. As shown in Figure 2, this model serves as the structural backbone of the research, ensuring that advanced AI technologies are not merely theoretical but are methodically integrated into the Disaster Risk Reduction and Management (DRRM) requirements of the Universidad de Manila (UDM). The operationalization of the AI-Enabled Seismic Sentinel Initiative unfolds across three interconnected stages—Input, Process, and Output—reinforced by a continuous feedback loop.

Input Phase. The framework begins with the collection of critical data streams and institutional resources. These include seismic data from PHIVOLCS, localized IoT sensors, and satellite monitoring systems. Regulatory frameworks such as Republic Act No. 10121, CHED Memorandum Order No. 9, and Manila Ordinance No. 8323 provide compliance anchors, while community baseline data from evacuation drills and trust surveys capture behavioral readiness (De Leon, 2025; De Guzman & Rivera, 2020). Together, these inputs establish a comprehensive foundation for predictive modeling and institutional alignment.

Process Phase. At this stage, advanced computational methods transform raw inputs into actionable intelligence. AI-enabled analysis drives predictive seismic modeling, while geospatial simulations generate GPS-guided evacuation routes (Tanaka & Matsumoto, 2024; University of Texas, 2023). Policy and compliance mapping ensures that all AI-driven actions remain consistent with DRRM standards, including institutional guidelines such as Bicol University AO 750 and Ateneo protocols (Park et al., 2020). Multi-channel dissemination—via SMS, mobile applications, and sirens—ensures that alerts and evacuation instructions reach stakeholders rapidly and reliably (Kolivand, 2024; Ahn, 2023).

Output Phase. The culmination of the model is the creation of a flagship AI-driven resilience ecosystem at UDM. Outputs include real-time alerts, improved predictive accuracy, verified compliance with DRRM frameworks, and strengthened community protection through heightened preparedness and trust (De Leon, 2025). These outcomes position the university as a benchmark for disaster-ready campuses.

Feedback Loop. To sustain adaptability and continuous improvement, the model integrates a feedback mechanism that recycles system performance data, post-drill behavioral observations, and trust metrics back into the Input stage. This loop enables recalibration of AI models, refinement of evacuation protocols, and reinforcement of compliance verification, ensuring that the Seismic Sentinel Initiative evolves with emerging disaster challenges.

Literature Review

Artificial intelligence (AI) has emerged as a revolutionary technology for enhancing detection speed and reliability, contributing to the significant advancements in earthquake early warning systems in recent years. To reduce false alarms and enable timely notifications that lessen mortality and infrastructure damage, machine learning algorithms currently process seismic data more quickly than conventional techniques (Kolivand et al., 2024). Additionally, stable AI-driven systems have proven to perform consistently during seismic occurrences, guaranteeing that alerts are sent out continuously even in difficult circumstances (Ahn et al., 2023). These advancements directly contribute to the assessment of the system's efficacy in identifying seismic activity and providing prompt notifications, which is a primary goal of the current investigation.

Predictive modeling has improved the precision of earthquake forecasts and evacuation instructions beyond detection. Using real-time geographic data, adaptive AI simulations have enhanced evacuation planning's responsiveness and prediction accuracy, enabling organizations to better direct communities during emergencies (Tanaka & Matsumoto, 2024). Predictive analytics could improve evacuation procedures and lower danger, as evidenced by trials conducted in China that showed AI forecasting systems could accurately anticipate most earthquakes up to a week in advance (University of Texas at Austin, 2023). These results are consistent with the objective of evaluating the Seismic Sentinel framework's predictive accuracy of alerts and evacuation instructions.

Universities are widely seen as crucial players in resilience building, especially in areas vulnerable to disasters. To ensure adherence to national laws and ordinances, Philippine institutions have started integrating disaster risk reduction and management (DRRM) frameworks into their operations.

For instance, Ateneo de Manila University incorporates compliance with the National Building Code and regularly conducts exercises to correspond with national DRRM requirements, while Bicol

University codified its DRRM Committee by Administrative Order No. 750 (2023). To make emergency procedures easily available, the University of the Philippines Open University has also introduced a DRRM Dashboard. To establish a baseline for incorporating AI-enhanced disaster response systems, De Leon (2025) carried out a study on the degree of compliance of the Universidad de Manila's Emergency Action Team (EAT) with earthquake safety guidelines. His findings support the inclusion of AI in institutional resilience frameworks by highlighting the need for technology augmentation in addition to compliance.

Resilience is improved at the community level by trust and behavioral preparedness in addition to technology. According to research, frequent earthquake drills greatly increase institutional procedure trust and evacuation compliance (De Guzman & Rivera, 2020). The Office for the Coordination of Humanitarian Affairs (OCHA, 2024) emphasizes that local capacity building and inclusivity must be prioritized in resilience programs, and ReliefWeb (2024) reports that community-based preparedness initiatives in the Philippines improved trust and evacuation compliance by involving affected populations in planning. These findings are echoed by global initiatives. Regional disaster councils, like RDRRMC 10 (2024), highlight the significance of exercises and behavioral participation by emphasizing that disaster resilient families and communities lessen dependency on government rescue efforts. By tracking increases in readiness, evacuation behavior, and trust, these findings support the goal of strengthening community resilience.

To incorporate these aspects of disaster resilience, several models have been put forth. A popular approach in the US is the ShakeAlert system, which employs AI-enhanced seismic monitoring to send out notifications seconds after an earthquake is detected (Allen et al., 2019). The ASEAN Integrated Network for Early Warning in Asia monitors ground vibrations and transmits real-time data across member states using IoT sensors, AI algorithms, and GIS mapping (Rusdi, Salam, & Pitogo, 2023). As an example for university-based resilience ecosystems, the University of Tokyo's Earthquake Early Warning Laboratory has created prediction models that combine seismic sensing with evacuation simulations (Tanaka & Matsumoto, 2024). Although these models show that incorporating AI, compliance frameworks, and community participation into disaster management systems is feasible, their reach is still primarily regional or national.

Despite these developments, literature still has gaps. Few studies incorporate both inside a university ecosystem that concurrently addresses detection, prediction accuracy, compliance, and resilience. Most studies concentrate on either the technological aspect of AI-enabled early warning systems or the social aspect of community preparedness. Institutional contexts are understudied in existing research, which frequently focuses on national or regional systems. This is especially true in higher education, where dense populations and few escape options provide specific difficulties. Furthermore, despite the documentation of compliance standards, there is still little integration of these policies into AI-driven, community-anchored systems. By integrating AI into a premier university-based disaster resilience program that integrates seismic detection, predictive evacuation assistance, policy compliance, and community trust, the AI-Enabled Seismic Sentinel Initiative fills this gap. By accomplishing this, Universidad de Manila contributes to both local preparedness and the worldwide conversation on disaster-ready campuses by setting an example for earthquake resilience, life safety, and community protection.

METHODOLOGY

Research Design

The AI-Enabled Seismic Sentinel Initiative at Universidad de Manila was evaluated in this study using a mixed method descriptive–evaluative approach. System logs, SMS delivery records, and compliance checklists in accordance with Republic Act No. 10121, CHED Memorandum Order No. 9, and Manila Ordinance No. 8323 were used to collect quantitative data. These datasets assessed institutional

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compliance, prediction accuracy, and system efficacy. User feedback and interaction logs were used to gather qualitative data that revealed information about trust, satisfaction, and evacuation behavior.

The Input–Process–Output (IPO) framework served as a guide for the design; inputs included community involvement, institutional protocols, and seismic data; processes included AI-enabled detection, predictive modeling, compliance integration, and communication strategies; outputs included timely alerts, improved resilience, verified compliance, and predictive accuracy. By combining technical performance with behavioral outcomes, this strategy guaranteed methodological rigor and established Universidad de Manila as a paradigm for higher education institutions prepared for disasters (De Leon, 2025; Kolivand et al., 2024; Tanaka & Matsumoto, 2024).

Participants and Sampling

A triangulated set of instruments was used in the study to record both socio-behavioral reactions and technical system performance. The following main instruments were used to collect the data:

System Interaction and User Logs (Tables 1 & 2): GPS coordinates, alert preferences, and real-time evacuation status were linked to User IDs via automated tracking to track mobility patterns and system interaction (Park et al., 2020; Universidad de Manila, 2024). To assess institutional preparedness, these records recorded distinct Interaction IDs, exact Timestamps, and qualitative comments (De Leon, 2025).

Table 1. *User Data (App User Data for Alerts and Location Tracking) – Records of user IDs, phone numbers, GPS coordinates, alert preferences, and evacuation status.*

User ID	Phone No.	Location (Latitude, Longitude)	Alert Preferences	Evacuation Plan	Received Alert	Evacuation Status
U001	09171234567	$14,609^{0}$, $121,017^{0}$	High	Yes	Yes	Evacuated
U002	09172345678	$14,554^{0}$, $121,047^{0}$	Moderate	Yes	Yes	Not Yet Evacuated
U003	09173456789	$14,630^{0}$, $121,021^{0}$	High	No	No	Not yet Evacuated

Table 2. *System Interaction Logs – Detailed logs of user interactions with alerts and evacuation plans.*

User ID	Phone No.	Location (Latitude, Longitude)	Alert Preferences	Evacuation Plan	Received Alert	Evacuation Status
U001	09171234567	$14,609^{0}$, $121,017^{0}$	High	Yes	Yes	Evacuated
U002	09172345678	$14,554^{0}$, $121,047^{0}$	Moderate	Yes	Yes	Not Yet Evacuated
U003	09173456789	$14,630^{0}$, $121,021^{0}$	High	No	No	Not yet Evacuated

Seismic Performance Metrics: Technical reliability was measured using SMS Delivery Reliability logs and Predictive Accuracy tables that compared expected versus actual lead times to validate the AI's detection precision (Ahn et al., 2023; Kolivand et al., 2024).

Community Resilience Survey: A 5-point Likert scale survey was administered to 100 participants comprising 60 students, 25 faculty, and 15 Emergency Action Team members to measure User Satisfaction, Trust, and Perceived Preparedness (De Leon, 2025; Tanaka & Matsumoto, 2024).

Compliance Audit Checklist: A researcher-constructed rubric was used to verify institutional alignment with regulatory standards, including Republic Act No. 10121, CHED Memorandum Order No. 9, and Manila Ordinance No. 8323 (De Leon, 2025).

Statistical Treatment of Data

To be able to ensure validity and reliability while evaluating system efficacy and community resilience, the gathered data underwent several statistical procedures. To assess user satisfaction and trust levels and to describe the demographic distribution of the 100 participants, descriptive statistics such as frequency counts, percentages, and weighted means were used (De Leon, 2025; Tanaka & Matsumoto, 2024). By comparing seismic detection timestamps with alert receipt durations, notification latency was evaluated using Mean Lead Time calculations to evaluate the Process stage of the IPO model.

This validated the average lead time of 15.3 seconds (Ahn et al., 2023; Kolivand et al., 2024). By analyzing transmission data to determine the success rate of attempted alerts, SMS dependability was investigated, offering insight into the robustness of communication channels (Park et al., 2020). Lastly, recurrent patterns in user behavior and recommendations for enhancing geographic evacuation routes were found using thematic analysis of qualitative data from interaction logs and open-ended feedback (Park et al., 2020; Universidad de Manila, 2024).

Mathematical Formulas for Data Analysis

To quantify the effectiveness of the AI-Enabled Seismic Sentinel Initiative, the following formulas were applied (De Leon, 2025; Tanaka & Matsumoto, 2024):

1. Mean Lead Time (MLT)

$$MLT = \frac{\sum(T_{receipt} - T_{detection})}{N}$$

Where:

- $T_{receipt}$: Timestamp of alert reception.
- $T_{detection}$: Timestamp of initial P-wave detection.
- N: Total number of successful alert transmissions (Ahn et al., 2023; Kolivand et al., 2024).

2. Weighted Mean (WM)

$$WM = \frac{\sum(f \cdot w)}{N}$$

Where:

- f: Frequency of responses.
- w: Weight assigned (1–5).
- N: Total respondents (100) (Park et al., 2020; Tanaka & Matsumoto, 2024).

RESULTS AND DISCUSSION

The AI-Enabled Seismic Sentinel Initiative generated multiple layers of evidence from system logs, compliance checklists, and user feedback. In system Effectiveness, SMS delivery achieved a 70.6% success rate among attempted alerts (Table 3). Analysis of failed SMS deliveries revealed both technical and behavioral causes: network congestion during peak hours and outdated or inactive phone numbers among users. These gaps highlight the need for redundant communication channels and regular updating of user contact information.

Table 3. *SMS Delivery Reliability of Seismic Sentinel – Percentage of delivered versus failed SMS alerts*

Delivery Status	Percentage
Delivered	60
Failed	25

In predictive Accuracy, lead times averaged 15.3 seconds, all within the expected 10–20 second range (Table 4).

Table 4. *Predictive Accuracy and Lead Time Metrics – Comparison of expected versus actual lead times for seismic events*

Seismic Event	Expected Lead Time (Seconds)	Actual Lead Time (Seconds)
Event 1	10-20 seconds	18 seconds
Event 2	10-20 seconds	15 seconds
Event 3	10-20 seconds	13 seconds

In compliance, full adherence was documented with Republic Act No. 10121, CHED Memorandum Order No. 9, and Manila Ordinance No. 8323 (Table 5).

Table 5. *Compliance Results with DRRM Frameworks – Documentation of adherence to Republic Act No. 10121, CHED Memorandum Order No. 9, and Manila Ordinance No. 8323*

Regulatory Framework Compliance	Compliance Status
Republic Act No. 10121	Complied
CHED Memorandum Order No. 9	Fully Complied
Manila Ordinance No. 8323	Fully Complied

And in community Resilience, 80% of users evacuated immediately, 70% had evacuation plans, and 85% expressed positive satisfaction and trust (Tables 6–8).

Table 6. *Evacuation Response Behavior of Seismic Sentinel Users – Distribution of immediate, delayed, and non-evacuation responses*

User Action	Percentage
Evacuated Immediately	80%
Delayed Evacuation	15%
Did Not Evacuate	5%

Table 7. *User Satisfaction and Trust in Seismic Sentinel – Survey results on satisfaction and trust levels among users.*

Satisfaction Level	Percentage
Very Satisfied	60%
Satisfied	25%
Neutral	10%
Dissatisfied	5%

Table 8. *Evacuation Plan Adoption and Preparedness – Percentage of users with and without evacuation plans*

Evacuation Plan Status	Percentage
With Evacuation Plan	70%
Without Plan	30%

The findings validate the Seismic Sentinel system's technical dependability and social efficacy. Even though the SMS delivery success rate is good, the 25% of unsuccessful efforts show the need for additional communication routes. The AI-enabled detection and modeling methods were validated by predictive accuracy, which was consistently within the expected range (Kolivand et al., 2024; Tanaka & Matsumoto, 2024). The initiative's compliance results show that it is completely in line with local and national DRRM guidelines, enhancing institutional credibility (De Leon, 2025). The influence of the system is further highlighted by community resilience indicators: high rates of quick evacuation and satisfaction indicate behavioral preparation and trust, while the 30% lacking evacuation plans point to places that could benefit from increased preparedness efforts (De Guzman & Rivera, 2020; OCHA, 2024). When combined, these results establish Universidad de Manila as a paradigm for disaster-prepared universities, demonstrating how AI innovation, compliance integration, and community involvement can come together to improve resilience (ReliefWeb, 2024).

CONCLUSION

The AI-Enabled Seismic Sentinel Initiative demonstrated efficacy, accuracy, compliance, and reliability. The results highlighted both community empowerment, evidenced by high rates of immediate evacuation, preparedness planning, and user trust—and technical dependability, as shown by consistent alert delivery, predictive accuracy, and full adherence to DRRM standards. By integrating AI detection, predictive modeling, compliance frameworks, and community involvement, the initiative proved that a balanced approach combining technological innovation with behavioral preparedness can foster resilience in academic communities.

Ultimately, the Universidad de Manila is positioned as a national and international model for disaster resilience in higher education, showing how academic institutions can lead in enhancing community protection and ensuring life safety (De Leon, 2025; Kolivand et al., 2024; Tanaka & Matsumoto, 2024; OCHA, 2024; ReliefWeb, 2024). By integrating predictive analytics, GPS-guided evacuation, and compliance frameworks, the AI-Enabled Seismic Sentinel Initiative demonstrates how universities can advance earthquake resilience and community protection, setting a benchmark for disaster-ready campuses worldwide.

Recommendations

To strengthen the AI-Enabled Seismic Sentinel Initiative and ensure its viability as a model for disaster resilience in higher education, several actions are recommended:

1. Enhance communication reliability. SMS alerts should be complemented by redundant channels such as radio broadcasts, sirens, and mobile applications to address delivery gaps and ensure uninterrupted dissemination of warnings.
2. Improve predictive accuracy and responsiveness. Incorporate adaptive AI/ML models, conduct routine sensor evaluations, and maintain continuous technical calibration and innovation to sustain reliability and responsiveness (Kolivand et al., 2024; Tanaka & Matsumoto, 2024).
3. Maintain regulatory compliance. Conduct regular institutional audits to ensure full adherence to Republic Act No. 10121, CHED Memorandum Order No. 9, and Manila Ordinance No. 8323, with transparent documentation to reinforce institutional credibility (De Leon, 2025).
4. Expand community preparedness. Extend training programs to the 30% of users without evacuation plans and conduct frequent evacuation simulations to reinforce rapid response behavior and inclusivity (De Guzman & Rivera, 2020; OCHA, 2024).
5. Foster stakeholder engagement. Utilize forums, feedback systems, and participatory planning to sustain high levels of satisfaction and trust. Consistent involvement of students, faculty, and the Emergency Action Team will promote a resilient institutional culture.

Taken together, these measures will ensure that Universidad de Manila not only sustains technological reliability and compliance but also advances predictive analytics, GPS-guided evacuation, and community protection — solidifying its position as a national and international leader in disaster-ready universities (ReliefWeb, 2024).

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