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INTEGRATED GEOSPATIAL INFORMATION PLATFORMS FOR EMERGENCY MANAGEMENT DECISION-SUPPORT: TAIWAN'S EXPERIENCES

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ABSTRACT

Taiwan's emergency management practices have rapidly evolved over recent decades, driven by frequent large-scale natural disasters, a desire to enhance inter-agency collaboration, and advancements in geospatial technology. This paper introduces Taiwan's integrated geospatial information systems and initiatives—including the National Geographic Information System (NGIS) initiative, the Civil IoT Taiwan programme, the Platform for Risk Information and Safety Management (PRISM), and the Hualien County Geographic Information Integration Application Platform—and their crucial roles in supporting decision-making at both national and local levels. We present the development history, system architecture, and practical applications of these systems, highlighting their integration of big data, IoT (Internet of Things), 3D spatial modelling, AI analytics, and real-time information exchange capabilities. Case studies such as the 2024 Hualien Earthquake and Hualien County's comprehensive digital governance initiatives are used to illustrate how these systems facilitate effective disaster preparedness, emergency response, and post-event recovery. The Taiwan experience demonstrates how continuous technological innovation, robust cross-agency collaboration, and standardised spatial data management can significantly enhance national and local resilience and operational efficiency in emergency management and other business-as-usual operations.

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INTRODUCTION

Taiwan is situated in a region prone to earthquakes, typhoons, and other natural hazards, making the establishment of effective emergency management systems a national priority to mitigate disaster risks. The New Zealand Society for Earthquake Engineering (NZSEE) undertook reconnaissance to Taiwan following the September 1999 Chi-Chi Earthquake (M_w 7.6) [1], the 2016 Meinong Earthquake (M_w 6.4) [2], and the 2024 Hualien Earthquake (M_w 7.4) (Figure 1). A key observation from these missions is Taiwan's ongoing advancement in geospatial technologies aimed at improving decision-support systems, for business as usual and emergency management. Taiwan, with a land area roughly one-seventh that of New Zealand and a population comparable to Australia's (approximately 23.5 million), is highly mountainous – around one-third of its land lies above 3,000 m and another third below 1,000 m. This distinctive topography, combined with a dense population distribution, poses unique challenges for transport infrastructure and emergency management.

Over the past three decades, rapid economic growth, urbanisation, and technological advancement have brought new challenges and opportunities for integrating spatial data into government decision-making. In response, Taiwan launched the National Geographic Information System (NGIS) initiative in the 1990s, aimed at addressing critical governance issues such as fragmented data formats, inconsistent spatial references, and difficulties in cross-agency collaboration. It initially focused on constructing base maps and setting national data standards, establishing a three-tier architecture to facilitate collaboration and the controlled adoption of new technologies. Its evolution into a policy-driven platform in the 2010s further promoted the integration and value-added use of national geospatial resources, including the nationwide 3D building modelling programme launched in 2019.

Figure 1: Map of Taiwan showing a) locations of recent major earthquakes; and b) limited transport linkage for Hualien – railway, Highways 9 and 8 – susceptible to impacts from earthquakes and typhoons.

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Building on this foundation, the government implemented advanced geospatial initiatives. One significant development is the 'Civil IoT Taiwan' programme, initiated in 2017, which applies big data, AI, and Internet of Things (IoT) technologies to establish a network that leverages real-time sensor data to monitor natural hazards such as weather patterns, seismic activity, and water levels.

The Civil IoT Taiwan programme aims to enhance the timeliness and accuracy of warnings. Complementing this, the 'Platform for Risk Information and Safety Management' (PRISM) was initiated by the National Science and Technology Center for Disaster Reduction (NCDR) in 2009, specifically in response to the urgent need for an advanced disaster intelligence network highlighted by the disastrous 2009 Typhoon Morakot[1]. NCDR, as a key technology advisory body to Taiwan's central government since 2003, is responsible for conducting research and development on disaster prevention and mitigation technologies, transforming scientific knowledge into practical applications, and providing intelligence and decision-support tools for disaster response operations. PRISM provides a centralized decision-support environment for emergency operations by integrating multi-source spatial data, real-time analytics, AI models, and digital twin technology to enable timely and informed decisions during disasters.

The successful integration of these technologies has been demonstrated in both national emergencies and local governance. A prime example at the local level is the 'Hualien County Geographic Information Integration Application Platform', which has played a crucial role in the County's business-as-usual operations as well as emergency management, earning awards for its advanced cross-domain integration and applications of digital twin and GIS technologies. This paper examines the evolution, technical frameworks, and operational impacts of Taiwan's geospatial information systems and initiatives, with a focus on their contributions to disaster prevention, response, and recovery. Through real-world examples, including the 2024 Hualien Earthquake response and various Hualien County digital governance initiatives, we highlight the key factors and lessons learned in building resilient, data-driven emergency management systems.

NATIONAL STRATEGIES AND POLICIES

National Geographic Information System (NGIS) Initiative

Background

Taiwan launched the National Geographic Information System (NGIS) initiative in the 1990s as a strategic response to addressing multiple governance challenges resulting from rapid economic growth and urbanisation.

Key challenges included: managing lifeline utility engineering projects that required road excavation, leading to frequent transport disruptions; balancing land development with environmental protection; making the data formats consistent across government agencies for data sharing and collaboration; unifying coordinate systems; and choosing appropriate accuracy levels between legal standards and implementations.

Cadastral maps from different eras employed various coordinate references, leading to multiple coordinate systems in use concurrently. These different standards caused confusion and errors in mapping and spatial analysis, potentially leading to costly mistakes and safety hazards.

The varying accuracy levels between legal requirements and practical implementations further exacerbated the problems. While laws mandated certain levels of precision and data integrity, the actual practices often fell short due to resource constraints, technological limitations, or lack of expertise. This resulted in unreliable data, undermining confidence in governmental processes and decision-making.

Additionally, the eagerness of many government agencies to adopt new technologies introduced integration difficulties. Without coordinated planning, departments independently implemented advanced tools and systems that were incompatible with each other. This haphazard adoption led to further fragmentation of data and systems, negating the potential benefits of technology advancements and creating additional barriers to effective collaboration.

Development of NGIS

The NGIS programme initially focused on constructing base map data, beginning with major metropolitan areas. The project divided efforts into specialized groups tasked with building databases for topography, cadastre, transportation networks, land use, geology, and socio-economic maps, along with setting national data standards.

It implemented a three-tier architecture: Infrastructure Layer; Data and Toolbox Layer; and Application and Presentation Layer. By delineating attributes of these three tiers, NGIS has promoted a modular and scalable system architecture, which facilitates collaboration amongst stakeholders and enables the controlled and strategic adoption of new technologies. By providing a common platform and guidelines, agencies could implement advanced tools that are compatible with the national system, ensuring that technological progress contributes to governmental efficiency rather than creating additional obstacles.

With the rapid advancement of geospatial technologies, the NGIS programme officially entered its second phase in the 2010s, focusing on policy-driven applications and inter-agency collaboration led by the National Development Council, Executive Yuan (Cabinet), Taiwan. As a national policy platform, NGIS provides a solid policy foundation, enabling various government agencies to carry out spatial information-related initiatives with unified objectives and strategic direction. This approach has promoted the integration and value-added use of national geospatial resources.

In response to the growing maturity of 3D GIS technologies, the National Land Surveying and Mapping Center, under the framework of NGIS policy, launched a national 3D building modelling programme in 2019 and completed the nationwide level of detail 1 (LOD1)[2] models that year. It has been extensively upgrading existing models to LOD2 and LOD3 models, improving the precision and completeness of spatial datasets [3]. This has not only strengthened the core of national spatial data infrastructure but also established a robust foundation for applications across domains such as disaster management and urban planning, continuously guiding the nation's geospatial information toward the era of intelligent applications.

[1] Typhoon Morakot was the worst disaster in Taiwan since the 1999 Chi-Chi Earthquake. It brought the mountainous island up to 3,000mm rainfall within three days, triggering widespread flooding and numerous landslides and debris flows throughout the island, killing nearly 700 people (including a village of over 470 residents buried by landslides).

[2] In accordance with Open Geospatial Consortium (OGC) CityGML standards.

The ‘Civil IoT Taiwan’ Programme

One of the most impactful advancements in disaster management systems has been in the integration of real-time data through the deployment of IoT devices and sensors. By establishing a network of interconnected sensors across the country, it enables the government and the wider society to utilise live data on critical parameters (such as weather patterns, seismic activities, and water levels) to assist with emergency preparedness and enhance decision-making during responses.

The ‘Civil IoT Taiwan’ programme was initiated in 2017 and applies big data, AI, and IoT. Its initial phase focused on establishing the network covering four major areas: air quality, earthquakes, water resources, and disaster prevention and relief (see Figure 2) [4]. The deployment of IoT sensors throughout Taiwan aimed at enhancing the timeliness and accurateness of warnings for flooding, earthquakes, typhoons, water resources, air pollution, etc. This real-time data feeds into dynamic environmental models that update continuously, offering an up-to-the-minute understanding of potential disaster scenarios. The network of strategically placed seismic sensors have enhanced Taiwan’s national earthquake early warning system (EEWS), enabling public warnings to be issued on average seven seconds after a significant quake. Those early warnings have provided precious time for people to get out of a collapsing building or shelter inside road tunnels to avoid rockfalls, saving many lives during the 2024 Hualien Earthquake. Weather stations equipped with advanced meteorological instruments monitor atmospheric changes, predicting typhoons or heavy rainfall events with greater accuracy. These have enabled faster and more precise forecast of typhoon impacts on high-risk areas, enabling better preparedness including issuing early warnings for floods or debris flows.

The second phase of the Civil IoT Taiwan programme (2022-2025) focuses on industry developments and data application through the open-data platform using international standards for data exchanges [5]. The Civil IoT Taiwan platform integrates big data through Application Programme Interfaces (APIs), cloud technology, and data standardization.

API interface technology enables real-time data exchange and sharing among agencies. For example, under the ‘water resources’ category the Civil IoT Taiwan platform provides access to real-time monitoring data from approximately 7,500 sensors including for river levels, rainfalls, water flows, floods, dam structural monitoring, underground water levels, pump stations, water gates, subway water levels, river water quality, dam water quality, agriculture irrigation stations, mobile pumps, sewage discharges, etc [6].

Cloud technology provides stable and flexible data access, preventing system bottlenecks during high-demand periods. Standardisation unifies data from different sources and formats, enhancing compatibility and usability. To ensure broad interoperability across different geospatial GIS platforms, the network implements OGC standards such as Web Map Service (WMS), Web Map Tile Service (WMTS), Web Feature Service (WFS), and GeoJSON for spatial data interchange.

The Civil IoT Taiwan initiative has played a crucial role in enhancing early warning systems such as for earthquakes and floods, buildings and bridges structural monitoring, and intelligent water-saving monitoring for agriculture, etc.

National Arrangements for Applying Technology in Emergency Management

Basic Plan of Disaster Prevention and Protection

The 1999 Chi-Chi Earthquake was a catalyst for Taiwan’s reforms in many aspects including earthquake resilience and disaster management. The Disaster Prevention and Protection Act [7], which came into force in 2000, requires the central government to develop and implement a Basic Plan for Disaster Prevention and Protection. The basic plan sets out the overall long-term strategy for disaster management, highlighting the priorities for national operation plans (of government departments) and local plans (of local authorities). The basic plan shall be reviewed and updated periodically and be adhered to by central and local agencies.

The Basic Plan for Disaster Prevention and Protection 2024-2028 contains a strong focus on applying technologies for disaster management. This includes strengthening technologies for monitoring and forecasting; adapting advanced technologies such as AI and IoT to improve digital decision-making support platform for managing cross-domain disasters; and enhancing the national geospatial platform for decision-making and value-added applications through extensively upgrading existing 2D national maps to 3D [8].

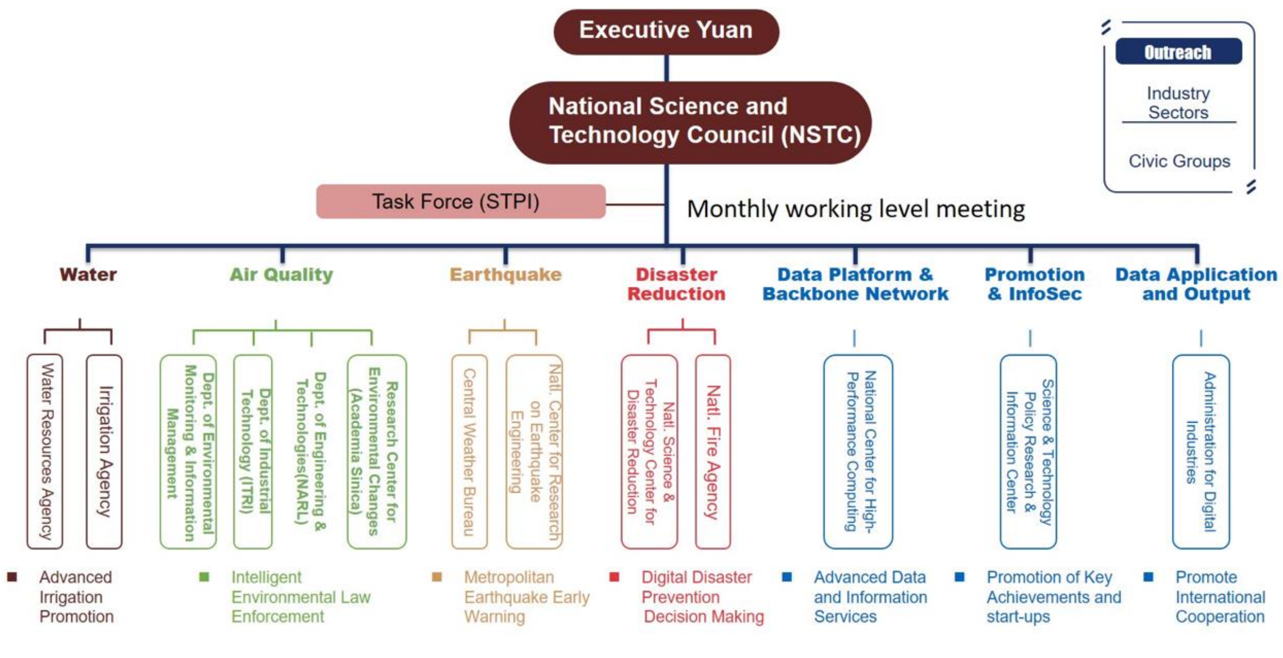


Figure 2: Civil IoT Taiwan governance structure [4].

Figure 3: Central Emergency Operations Center (CEOC) in action.

National Science and Technology Center for Disaster Reduction (NCDR)

The National Science and Technology Center for Disaster Reduction (NCDR) was set up in 2003 as a technology advisory body to Taiwan's central government under the Disaster Prevention and Protection Act.[3] Its core functions include conducting research and development on disaster prevention and mitigation technologies, transforming scientific knowledge into practical disaster risk reduction applications, and providing intelligence and decision-support tools for disaster response operations [9].

As part of the national framework, NCDR is responsible for collecting, analysing, and interpreting real-time disaster information to enhance emergency management efficiency and effectiveness. During emergencies, NCDR plays a crucial role in supporting the Central Emergency Operations Center (CEOC) by leading disaster intelligence analysis and decision-making support (see Figures 3 and 4) [10].

Figure 4: NCDR operating the intelligence analysis unit at the CEOC during an emergency.

NCDR's key responsibilities include:

1. Disaster intelligence analysis and decision support: NCDR operates the intelligence analysis unit at the CEOC, integrating real-time data from other agencies. It applies big data analytics and AI-driven tools to generate critical insights for decision-makers.
2. Interagency and cross-sector collaboration: NCDR collaborates with government departments, academic and research institutions, and non-government entities to enhance disaster response capabilities. It integrates satellite imagery, aerial reconnaissance, and social media analytics to provide comprehensive disaster assessments.
3. Enhancing early warning and response systems: NCDR develops and improves early warning technologies using advanced modelling and simulation tools. It utilises real-time hydrological, meteorological, and geospatial data to strengthen pre-disaster preparedness. Through digital twin technology, NCDR enhances the visualization of disaster scenarios to support emergency planning, exercising, and rapid emergency decision-making.

By integrating disaster intelligence, technological innovation, and interagency cooperation, NCDR strengthens Taiwan's emergency response capabilities and ensures timely and effective disaster mitigation actions.

PLATFORM FOR RISK INFORMATION AND SAFETY MANAGEMENT (PRISM)

The disastrous 2009 Typhoon Morakot highlighted the urgent need for Taiwan to have an advanced disaster intelligence network that could support effective disaster management and decision-making. In response, the development of the Platform for Risk Information and Safety Management (PRISM) was initiated by NCDR, to support emergency response decision-making at the CEOC. Its first generation focused on initial data integration and preliminary GIS applications. It contained information from various government departments and laid the foundational framework for centralized disaster information management. Its users included emergency management personnel across central government agencies.

PRISM's second generation (2014-2022) had enhanced data integration capabilities (2D with temporal data) and improved information exchange efficiency and decision-making coordination. It incorporated more varieties of datasets from government agencies and increased the range of outputs. Its user base expanded to include emergency management personnel from local authorities.

In 2022, PRISM was transformed to a 3D-based system with enhanced real-time monitoring capabilities (the third generation), as the application of 3D technologies and the 'Civil IoT Taiwan' network became established. Its user base has extended to all central and local government agencies and relevant entities. Its web version is publicly accessible [11], with restriction to sensitive data.

[3] NCDR is supervised by the National Science and Technology Council (https://www.nstc.gov.tw/folksonomy/list/448925fe-b34f-4753-90bb-3ff2603b077c?l=en). It has approximately 150 full-time staff and is mainly funded by the central government.

By consolidating diverse data, PRISM can provide targeted information for different types of emergencies such as earthquakes, floods, and typhoons. The system has advanced data integration capabilities and utilises 3D spatial data, temporal sequencing, and AI predictive modelling to enhance real-time forecasting, visualization, and decision-support functionalities. Additionally, PRISM leverages big data analysis for long-term disaster prevention research. Historical data are analysed to identify high-risk locations, enabling evidence-based recommendations and aiding in urban planning and the construction of disaster prevention facilities. This integrated approach has fundamentally improved the efficiency and effectiveness of Taiwan's disaster prevention efforts and response speed.

Smart Disaster Prevention and Decision Support

PRISM collects 620 big data sets from 40 agencies and applies more than 100 value-added assessment technologies, transforming data into intelligence that contributes to effective decision-making (as illustrated by Figure 5). This involves methods such as extensive and in-depth analysis of warning information, spatial data integration, and social media monitoring (crowdsourcing), undertaken by the automated mechanisms.

Warning information analysis and spatial data integration

PRISM can be used for managing different types of emergencies and is routinely activated for managing typhoons and floods, which are the most frequent emergencies affecting Taiwan. The system automatically interprets monitored rainfall, river water levels, and other environmental data, to predict potential disaster impact areas. It employs spatial interpolation algorithms and hydrological models to analyse large volumes of meteorological and hydrological data, providing detailed disaster warning information for decision-makers.

Leveraging GIS to overlay historical disaster records and visualize risk regions, using techniques such as weighted overlay analysis and kernel density estimation, PRISM merges data layers from various sources to enable responders to intuitively observe past disaster distributions and high-risk areas for more effective preparation and disaster management.

Mobile Population Data Analysis

Analysing mobile population data in a specific area and its changes could, for example, help authorities monitoring evacuations after debris flow warnings [12] are issued, estimating the number of people trapped in the disaster zone, or monitoring crowd status during COVID (Figure 6).

NCDR's agreement with Chunghwa Telecom (the largest mobile operator in Taiwan) enables the transmission of telecommunications flow data of its every base station every ten minutes. This information feeds into PRISM's automated mechanism to calculate the estimated population and movement in the area.[4]

Social Media Monitoring during Emergency Response

The social media monitoring module within PRISM is activated exclusively during emergency response operations. It integrates keyword-based filtering (e.g. 'flooding', 'landslide', 'road collapse'), geospatial entity recognition, and natural language processing (NLP) techniques to identify and extract disaster-related content in real time. Through geolocation-based text mining, unstructured textual data from social media are converted into structured, georeferenced disaster intelligence. These data points are then visualized on GIS-based interfaces to support rapid event detection, situational awareness, and decision-making for emergency response and resource allocation [13].

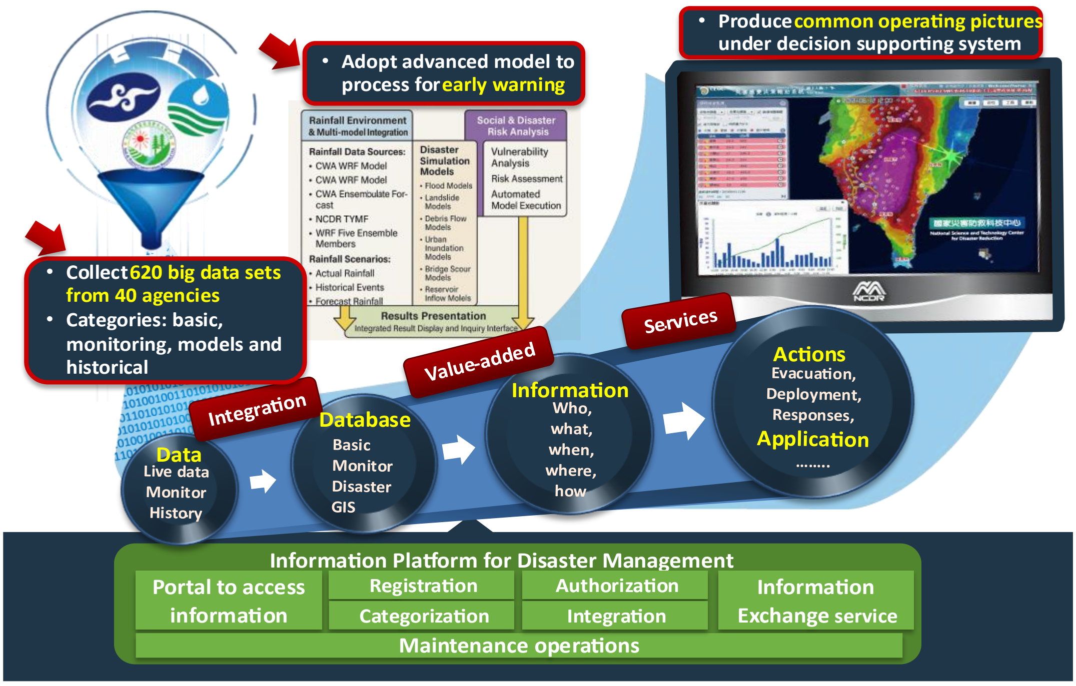


Figure 5: PRISM information value-added mechanism (source: NCDR, 2024).

[4] Chunghwa Telecom has approximately 38% market share (as of December 2024). The estimated population in a disaster zone is calculated based on Chunghwa Telecom's market share in that area. There are currently no similar agreements between NCDR and other telecommunications operators due to their technological constraints.

Figure 6: PRISM monitoring crowd status around markets in Taipei City during COVID through analysing telecommunications flow data (every ten minutes, right insert) and CCTV footage (left insert).

The module strictly processes only publicly accessible content from social media platforms such as X (formerly Twitter), Facebook, and the PTT Bulletin Board System[5]. NCDR has proactively obtained agreements with major local social media groups for retrieving disaster-related information during emergency responses. This enables PRISM to gather and analyse information from the most affected or targeted areas, to provide real-time intelligence for decision-makers.

The module does not crawl private data or access non-public user information; all analysed content resides in the public domain and is openly visible to general users. The implementation ensures both technical rigor and compliance with ethical standards concerning data privacy and public transparency.

In addition to accelerating the collection of emergency-related information, the social media monitoring module plays a critical role in the rapid identification and filtering of misinformation, enabling government authorities to promptly correct false or misleading reports in real time. By leveraging advanced NLP techniques and cross-referencing data from multiple sources, the system can detect and flag potential rumours or inaccuracies circulating online. This not only improves the overall accuracy and efficiency of emergency response operations, but also strengthens public trust and supports transparent, evidence-based decision-making by ensuring that reliable and verified information is disseminated throughout the community during emergency events.

Digital Twin Technology Applications

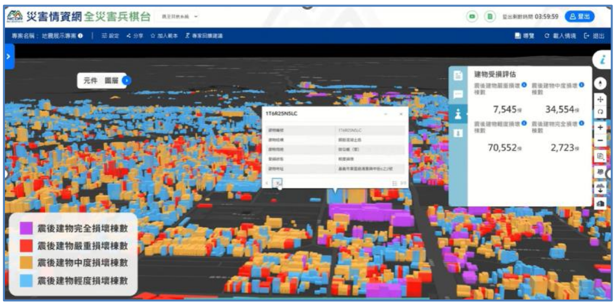
Digital Twin technology creates a virtual replica of real-world objects or systems, providing a predictive and interactive environment for scenario simulation. In disaster prevention, Digital Twins allow decisionmakers to simulate and visualize real-time events by integrating IoT sensor data. These virtual models can enable pre-emptive resource deployment and reduction of disaster losses.

PRISM integrates Digital Twin technology by synchronising real-time IoT data with dynamic 3D GIS models. Using temporal and spatial analytics, decisionmakers can visualise and simulate disaster scenarios with high precision. These interactive models, often built with standards like CityGML or Building Information Modelling (BIM) for structures, and high-resolution Digital Elevation Models (DEMs) for terrain, offer comprehensive situational awareness and facilitate rapid action during emergencies.

The Digital Twin applications are embedded in the scenario simulation sub-platform specifically designed for disaster response exercises (Figure 7). This sub-platform is utilised by the annual national exercises undertaken in September that involves over 500 emergency responders from central and local agencies, as well as international teams. It is also well utilised by various regional and local exercises.

IoT and AI Applications

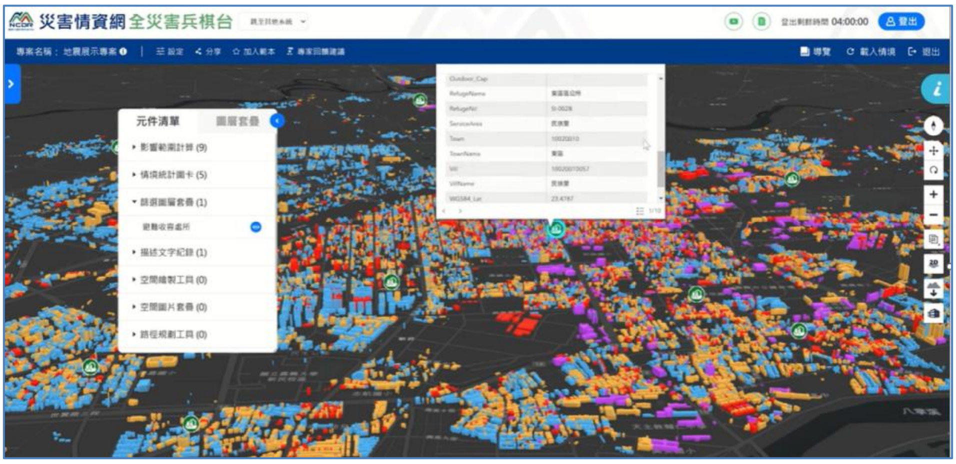
The PRISM network leverages the Civil IoT Taiwan data, integrating monitoring information on water resources, air quality, earthquakes, and disaster prevention and relief.



a) Simulation of building damage following a major earthquake scenario (purple – totally destroyed, red – severely damaged, amber – medium level of damage, blue – minor damage).

Figure 7: PRISM sub-platform designed for exercises (Continued).

[5] PTT (short for 'PTT Bulletin Board System') is a popular Taiwanese text-based online forum, originally developed by students at National Taiwan University in 1995. It hosts a wide range of discussion boards on topics from politics to entertainment and is known for its influence on Taiwanese internet culture.



b) Identifying available emergency shelters, estimating their capacities, and ensuring disaster preparedness.

Figure 7: PRISM sub-platform designed for exercises.

AI techniques—including machine learning models such as Random Forests (RF), Support Vector Machines (SVM), and Convolutional Neural Networks (CNN) —are employed for more accurate disaster monitoring and forecasting. By using computer vision methods to interpret aerial and satellite imagery, and spatial machine learning algorithms that account for geographic context, the network enhances both timeliness and precision in disaster assessment (as illustrated by Figures 8 and 9).

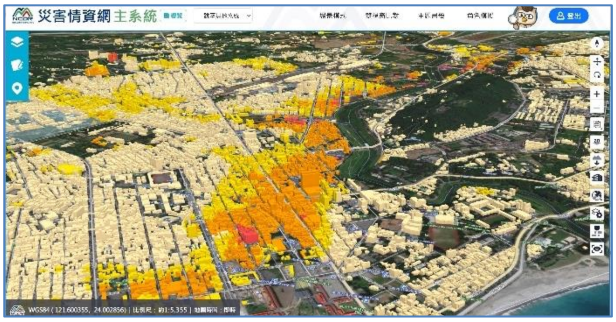


Figure 8: Using Digital Twin for flood risk modelling for Hualien City (simulating rainfall of 650mm in 24 hours).

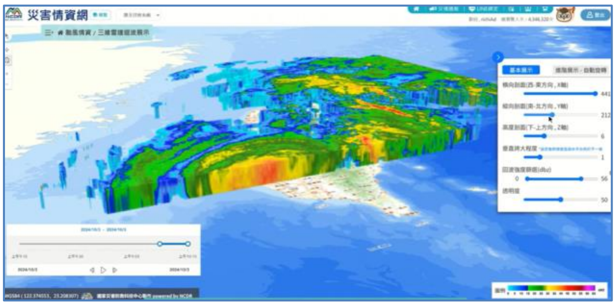
PRISM and Common Operating Picture (COP)

An essential role of PRISM is providing a Common Operating Picture (COP) that enables all government agencies and other disaster response units to understand the overall situation instantly from integrated observations and make informed collaborative decisions.

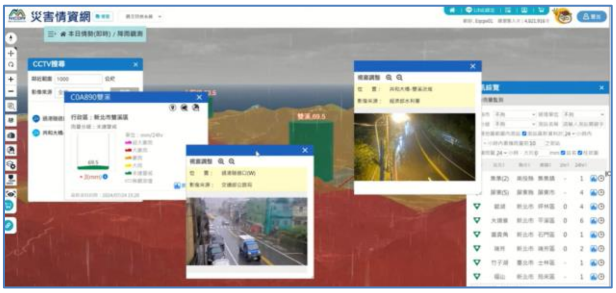
The COP is typically implemented using a hierarchical GIS architecture:

1. Data Layer: A multi-source spatial database (e.g., PostgreSQL, Oracle Spatial) of structured and unstructured vector, raster, and point cloud data, enabling real-time synchronization across agencies.
2. Application Layer: Geoprocessing services perform spatial analyses such as network analysis for evacuation routing, hotspot analysis for resource allocation, and predictive modeling for disaster impacts.
3. Presentation Layer: A WebGIS interface (using frameworks like Leaflet or OpenLayers) provides role-based access and dynamically visualizes data through techniques like choropleth maps, heat maps, Digital Twins, and 3D terrain modeling.

a) Analysing past typhoons with similar paths to identify high-risk areas.



b) Combining (a) with satellite radar reflectivity to provide insights into expected rainfall distribution and timing.



c) Estimating and verifying rainfall through IoT sensor data and CCTV footage, confirming the status of flooding.

Figure 9: Modelling typhoon impact using AI and IoT data.

Through these capabilities, the COP enables situational awareness by presenting authorative, dynamic, real-time views of the impacted environment. Decision-makers can identify spatial patterns, assess risk, and coordinate resources for effective responses.

Case Study: 2024 Hualien Earthquake

Upon the detection of the M_W 7.4 Hualien Earthquake on 23 April 2025, NCDR promptly activated its emergency response operations, leveraging optical sensing, AI-driven analysis, and big data processing to transform disaster information into actionable intelligence, enhancing governmental decision-making and operational efficiency.

While some technical data are restricted to authorised emergency management personnel, important information such as earthquake updates and aftershock distributions are made accessible to the public, given the high level of public concern (e.g. Figures 10 and 11). PRISM's advanced 3D visualisation allows users to better understand the underground distribution of earthquake epicentres and other earthquake impacts. This capability greatly enhances situational awareness for both the public and emergency response teams.

Figure 10: PRISM showing earthquake intensity maps for earthquakes occurred 1-3 April 2024. *(Taiwan's earthquake intensity scale (0-7) was amended in October 2023, with intensity 5 divided to '5 strong, 5 weak' and intensity 6 divided to '6 strong, 6 weak'. [14] The 2024 Hualien Earthquake was the first major earthquake since the change.)*

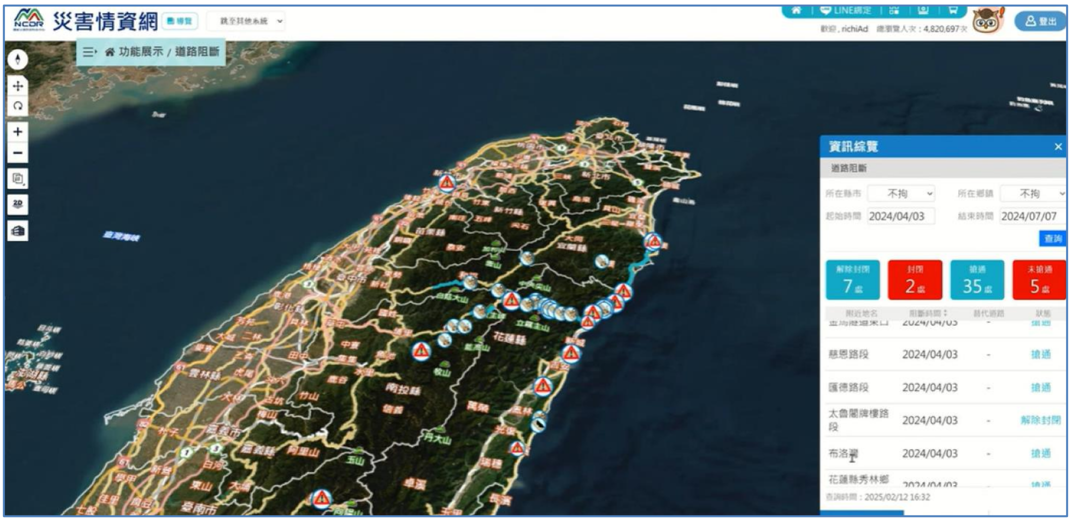
Advanced Emergency Analysis and Computational Support

PRISM's automated response mechanism quickly generated essential disaster intelligence, including seismic intensity distribution maps and high-risk area assessments; mobile population data analysis, estimating affected populations; impact assessment of transportation infrastructure (e.g. Figure 12); risk prediction for structural damage; and slope stability and soil liquefaction risk analysis. This automated extraction of critical disaster intelligence was instrumental in supporting response operations to the impacts of the event.

Figure 11: Monitoring 'felt earthquakes' (intensity ≥4) in the first week of Hualien Earthquake (3-9 April 2025).

NCDR has real-time access to footage of over 212,000 CCTVs[6] (as of May 2025) set up for diverse business needs and managed by various central and local agencies across the country. This enabled prompt evaluations of the earthquake impacts. In some mountainous regions, such as sections of Highway 8 (across Taroko National Park, connecting eastern and western Taiwan), power and communication outages obstructed real-time monitoring. Meanwhile, urban areas had intact power and communication infrastructures, so CCTV footage provided partial but valuable information (Figure 13).

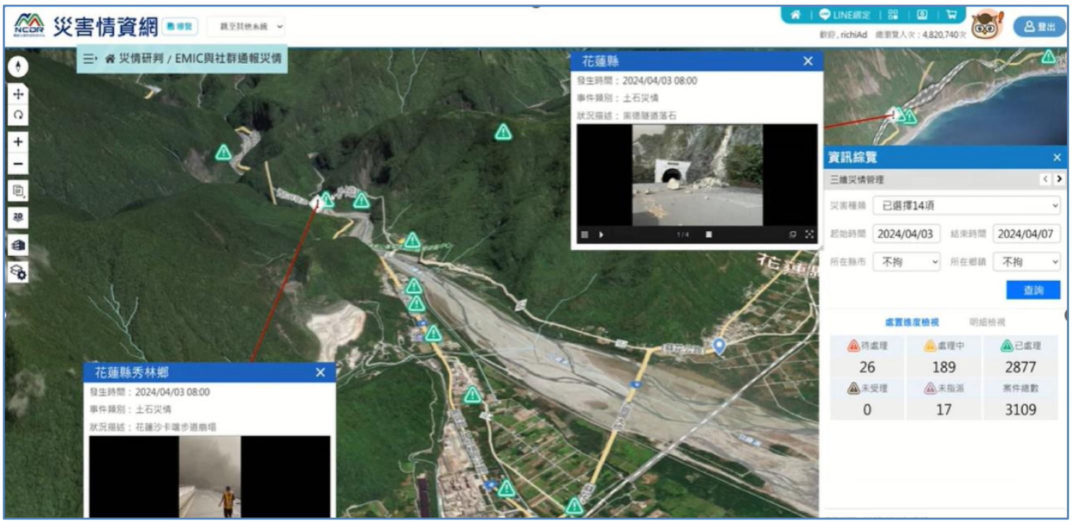
To supplement gaps in ground-based monitoring, the PRISM platform collected images and disaster-related reports from social media, mapping them using geolocation-based text mining to enhance situational awareness. Given the potential for misinformation or unverified content in crowdsourced data, all collected information was manually reviewed by NCDR personnel to verify its credibility—particularly to identify and exclude false or misleading posts—before being provided to the CEOC to support assessment and response decision-making.



a) Monitoring the impacts on Highway 9 (along east coast) and Highway 8 (to the west through Central Ranges) and tracking the progress of emergency repairs and roading status.

Figure 12: Monitoring the impacts and emergency repairs on Highways 8 and 9 through social media monitoring and real-time access to CCTV footage. (Continued)

[6] Approximately 97% of the 212,000 CCTVs are managed by Police for social security reasons. NCDR has access to their footage only when the CEOC is activated.



b) Monitoring the impacts on Highway 8 and tracking the progress of emergency repairs.

Figure 12: Monitoring the impacts and emergency repairs on Highways 8 and 9 through social media monitoring and real-time access to CCTV footage.

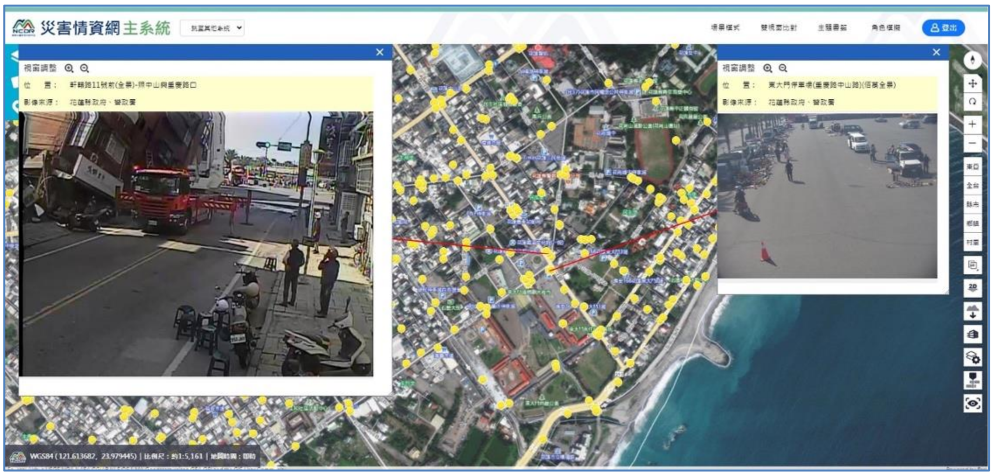


Figure 13: Real-time access to CCTV footage showing earthquake impacts in Hualien City.

(Yellow dots: locations of CCTVs administered by Police. Left insert: showing a collapsed building.)

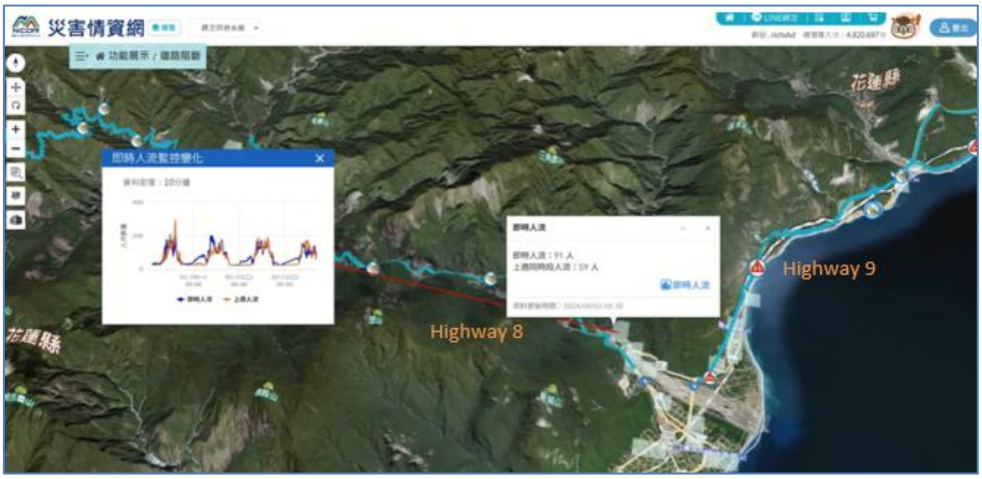


Figure 14: Analysing telecommunications flow data (every ten minutes) to estimate populations potentially trapped in Taroko National Park.

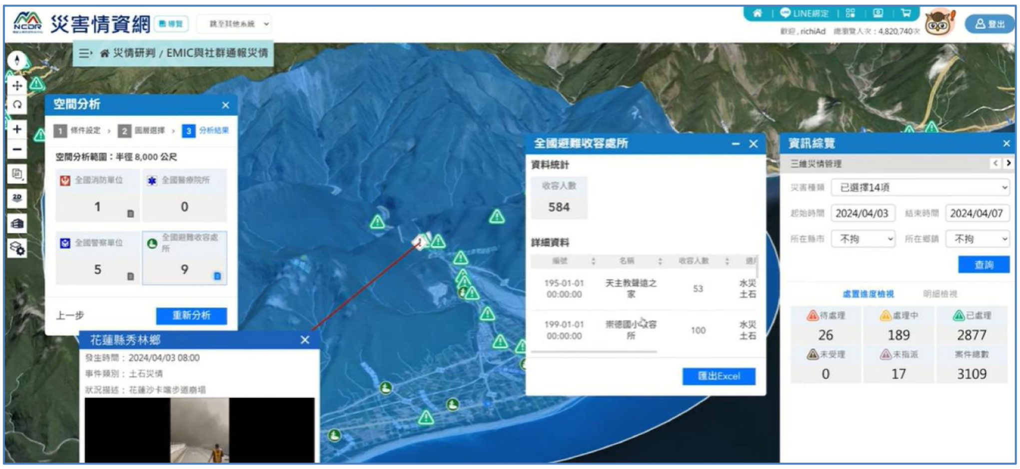
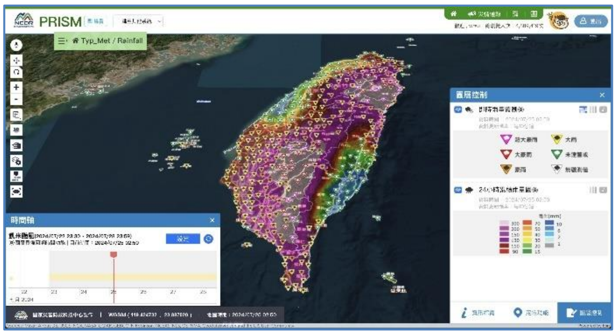
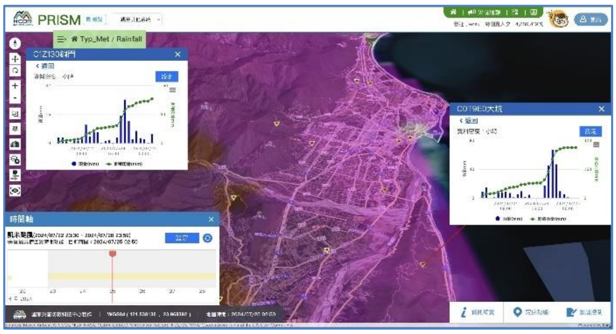


Figure 15: Tracking the earthquake impacts and the capacity of emergency shelters.

Furthermore, the network incorporated on-site 'vehicle detection' survey data from the Highway Bureau [7] and telecommunications flow data to estimate populations potentially trapped in disaster zones (Figure 14). These data were invaluable in estimating the number of vehicles and visitors trapped inside Taroko National Park, which was critical for the organizing of rescue efforts. Additional remote sensing analyses using imagery supplied by various government agencies helped identify damaged infrastructure and potential secondary disaster risks, all visualised through the Common Operating Picture interface. Search and Rescue teams then used GIS network analysis to assess possible routes, guiding emergency operations to the hardest-hit areas more efficiently.



a) Rainfall monitoring during Typhoon Gaemi (light purple indicating accumulated rainfall of 300mm in 24 hours)



b) Hualien City rainfall monitoring during Typhoon Gaemi

Figure 16: Rainfall monitoring during Typhoon Gaemi in late July 2024.

Integrated Detection and Field Investigation Reports

Using multi-source data integration, NCDR combined satellite imagery, unmanned aerial vehicle (UAV) reconnaissance, and crowd sourcing reports to validate high-impact disaster zones (e.g. Figure 15). Key focus areas included landslide risk prediction and total affected landslide areas, supplemented by transport network traffic data to assess the extent of landslide impacts. These integrated investigation reports, which often contained recommendations, were critical for emergency response decision-making [e.g. 15-18].

The impacts of Hualien Earthquake continued due to the ongoing aftershocks, heavy rain, and the typhoon seasons, which triggered further rockfalls and landslides. In late July 2024, the destructive Typhoon Gaemi brought up to 2,200mm accumulated rainfall in some parts of the county (Figure 16), causing casualties, widespread damage, and again cutting off Hualien's highway and railway links before full recovery was achieved. Critical transport routes for Hualien have been closely monitored (e.g. Figure 17).

Figure 17: Real-time monitoring rainfall impact on the transport routes north of Hualien City *(critically vulnerable spots on Highway 9 that had been cut off several times by the earthquakes, rockfalls and debris flows following heavy rain). Colours indicated the amount of rainfall in the areas.*

HUALIEN COUNTY GEOGRAPHIC INFORMATION INTEGRATION APPLICATION PLATFORM

Hualien County is in eastern Taiwan and frequently affected by earthquakes and typhoons. Like the West Coast of New Zealand, Hualien's limited transportation network results in a

[7] The 'vehicle detection' gauges are installed along all national highways and most provincial highways. The gauges record the numbers of vehicles and the types of vehicles passing through the gauges at any given time. These data are provided via the Transport Data Exchange platform (https://tdx.transportdata.tw/data-service/advanced).

smaller and sparse population[8]. Hualien is far less urbanized and industrialized than the western Taiwan and its local finance and public servant manpower cannot compare with the abundant resources of major western cities.

In recent years several major public construction projects affecting Hualien have been completed[9]. These developments and the improved transportation connections have generated increasing demands for the integrated analysis of diverse spatial information across different disciplines. In response to these demands and the necessity to coordinate amongst 70 public agencies[10], Hualien County Government launched a 10-year spatial information project in 2018 with funding from the central government. The resulting Hualien County Geographic Information Integration Application Platform [19] has played a crucial role for the County's business-as-usual operations as well as emergency management. In 2022, it won the annual 'Smart National Land Special Award' (jointly established by the National Development Council and Taiwan Geographic Information Society) because of its advanced cross-domain integration and applications on digital twin and GIS technologies.

Development of the Platform

The platform has been developed to address the needs for integrated spatial information for the long-term planning and collaborative implementation of various governmental policies, including urban planning, transportation services, tourism, land resource management, and disaster prevention, response, and recovery.

In its first two years the project focused on establishing the foundation, such as base maps and core datasets. It followed the national policies and standards already established by the NGIS initiative. Its second phase emphasized building a county-wide spatial information sharing platform that comprises a range of applications aligned with public service demands. This phase included extensive cross-departmental and cross-domain proof-of-concept collaborations. The third phase (2024 - 2028) is to deepen the analytical application of cross-domain spatial information and complete a Digital Twin of Hualien, ultimately achieving evidence-based smart governance.

The spatial scope of the platform is the entire territory of Hualien County. The targets for map data collection include internal departments of Hualien County Government, neighbouring local authorities, Taroko National Park[11], and central government agencies stationed in Hualien. The county-wide strategy categorizes all geospatial data into five major types using a pyramid structure:

- base maps: electronic maps, orthophoto maps, and topographic maps (1/1000)
- core datasets: building management, cadastre, household registration, urban planning, and taxation
- departmental business datasets: provided by internal or external parties
- 3D models
- dynamic monitoring data: e.g. CCTV footage, rainfalls, and river levels.

It took the County government 5-6 years to complete the preparation of the five core datasets for sustainable spatial integration. During this period, it overcame challenges stemming from variations in data structure and formats, inconsistent data management practices across departments, vastly different references for locations used by departments that suit their own business needs, actual or perceived requirements for data and privacy protection, institutional inertia, and inadequate digital infrastructure.

The County has achieved measurable results in spatial data integration, system development, and cross-agency collaboration. These include: the integration of multi-dimensional spatial data from central and local government sources; the creation of a multi-sourced 3D digital city; in-depth integration and frequent updates of key operational data; establishment of a spatial validation and cross-referencing mechanism for the core public affairs spatial databases; provision of flexible methods for spatial data sharing; and the development of diverse and innovative smart governance programmes.

The platform consists of 203 categories, encompassing 944 spatial datasets. These include 180 types of static data, 14 types of dynamic monitoring data, and 9 types of 3D models (as of April 2024). All datasets are integrated into a scheduled update and tracking process. Agreements with relevant local and central government agencies are in place, ensuring effective data sharing and continuous updates. Key business datasets are equipped with automated conversion capabilities, which enables frequent updates from data sources without manual handling. This prevents additional resource burdens and associated resistance. Cadastral and building management data are updated daily, allowing for near real-time reflection of changes in land and building records. Household registration and tax data are updated monthly.

The County government has established a mechanism that applies spatial information technologies for cross-domain verification of the accuracy of different departmental datasets. This in turn supports the responsible departments in retrospectively improving the quality and logic of their original data and establishing a cross-agency feedback mechanism for data correction and refinement. This verification mechanism has been embedded in the operational workflows of various County departments. It has improved data quality and spatial consistency and significantly enhanced the effectiveness of public services. This has also increased local tax revenue through more accurately identifying land parcels that are subject to taxes based on the types of land uses. Taking 2021 for example, additional 1,264 tax cases were identified, resulting in additional local tax revenue of approximately NZ $355,000 for that year.

Hualien County Government has actively pursued flexible and diversified collaboration models—including reciprocal agreements, memoranda of understanding, and the application of advanced technologies—to facilitate cooperation across the public, private, and academic sectors. Over 70 public agencies and research institutes utilise the platform to support their operations. The platform is also accessible to members of the public (with restricted access to sensitive information).

[8] Hualien County is the largest local authority of the 22 counties and cities in Taiwan, approximately an eighth of Taiwan's total area; yet it has one of the lowest populations in the country due to its mountainous terrain. Approximately 30% of its population of 315,000 people is indigenous people. (Nationally indigenous people account for 3% of Taiwan's total population.)

[9] These include projects funded by the central or local government, such as the electrification of the railway services for eastern Taiwan, the redevelopment of the Hualien County train station, the improvements of Highway 9, and the construction of social housing.

[10] These include 20 central government departments stationed in Hualien, 25 departments of Hualien County Government, 20-30 local agencies at the township and village levels, and a number of state-owned enterprises (e.g. power, water).

[11] Hualien's economy is heavily relied on tourism industry, centering around Taroko National Park, which is one of Taiwan's most popular tourism areas for domestic and international visitors. It attracted 3.44 million visitors in 2023 [20].

Retrospective Compilation and Spatialization of Building Consent Records

In 2020, the County government launched a comprehensive review and reconstruction of its building management database. This initiative involved the digitisation of all historical building records and the development of a new building management database aligned with the data standards set by the central authorities, enabling scheduled synchronization with the national system.

Each building case was spatially processed, allowing for the geographic positioning of building coordinates. The County government has established a comprehensive database encompassing approximately 50,000 building management cases, overcoming issues related to different addresses (spatial positions) being used for the same building at different times in the historical records. This spatialization enables the overlay and integration of consent data with other business-related spatial datasets for more effective analyses.

Through this centralised system, officials can easily retrieve digital copies of building records, including the full lifecycle of consent details and usage permits, all related applications and approval documents (such as structural drawings and calculations, and architectural design drawings). In 2023, this digital system processed 898 requests involving over 9,000 pages, resulting in an estimated 1,600 hours of the public's waiting time saved.

Earthquake Risk Reduction, Response, and Recovery

To assist Hualien in becoming a resilient city and reducing earthquake damage, the County government has actively utilised its platform to integrate the results of various projects, such as the 'Intermediate Soil Liquefaction Drilling Investigation Project - Building Subsidence Risk', and the 'Greater Hualien Building Seismic Rapid Assessment Project' (as illustrated by Figure 18)[12]. These results are overlaid with other datasets in the platform to assist with developing and implementing risk mitigation strategies, such as programmes for supporting rebuild of aging earthquake-prone buildings and reviews of designated urban renewal zones.

During the response to Hualien Earthquake, the comprehensive building management database played a crucial role for providing building drawings to assist with rescue operations and rapid building assessments (red or yellow placard) processes (as illustrated by Figure 19).

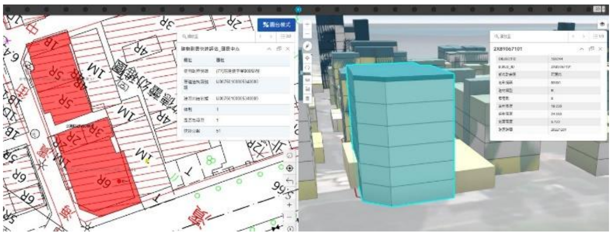


Figure 18: Example of Hualien building seismic rapid assessment results (commenced before the 2024 Hualien Earthquake).

Figure 19: Retrieving records for a multi-storey building that collapsed on 23 April 2024 following two aftershocks greater than magnitude 6. *These records include full lifecycle of consent details, structural drawings and calculations, floor plans, and cadastral details.*

Aerial photos were taken soon after the earthquakes and rendered to create 3D models, which were then overlaid with the 3D lifelines data that was already in the system, to assist in decision-making such as evaluating the impact of collapsed buildings on lifelines (Figures 20 and 21) and assessing the transport routes of heavy machinery for demolishing earthquake-damaged buildings (Figure 22). The 3D modelling was also utilised to evaluate damage to high-rise buildings (e.g. Figure 23).

Figure 20: 3D spatial relationship between the collapsed Uranus Building and underground lifelines (electricity – orange lines, water – blue lines) following the M_w 7.4 earthquake on 3 April 2024. *Power and water supplies to the neighbouring properties were compromised for over two weeks until the demolition of the Uranus Building was completed. Red box indicates the lifelines (electricity) underneath the collapsed building.*

[12] The project, commenced before the 2024 Hualien Earthquake, was to identify high-risk (earthquake-prone) buildings. As of April 2025, it completed earthquake damage simulation results for approximately 1,200 buildings in Hualien's densely developed areas.

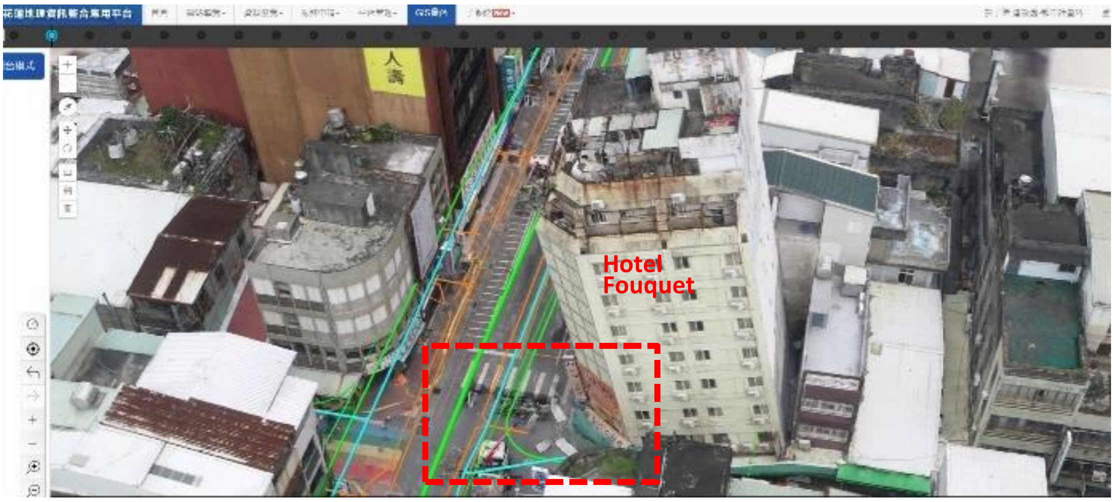
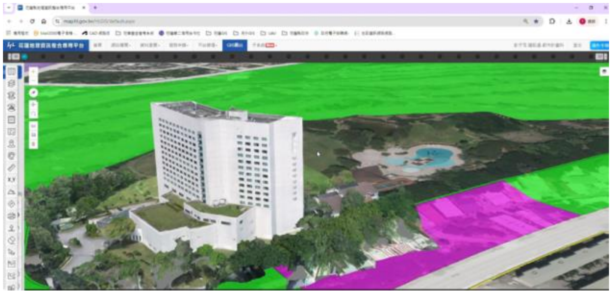
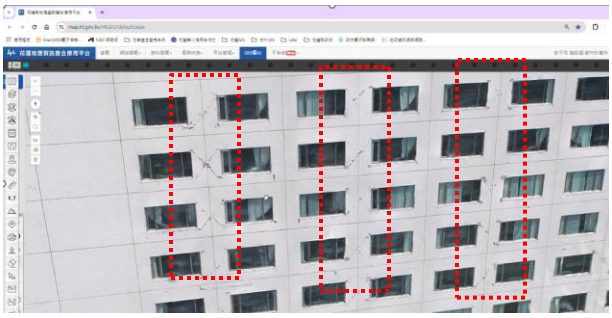


Figure 21: 3D model of the severely damaged Hotel Fouquet in relation to the underground lifelines (electricity – orange lines, telecommunications – green lines, water – blue lines) immediately following the two large aftershocks on 23 April 2024. *Red box indicates the lifelines adjacent to the hotel building.*

Figure 22: Assessing the transport routes and accessibility of heavy machinery for demolishing Hotel Fouquet. *Red box highlights the width of the road (10.77m).*



a) Establishing the earthquake damage model of a high-rise hotel (located by river), utilising UAV images taken after the 3 April 2024 Hualien Earthquake.



b) Close-up views of the 3D model (seen in (a) above) showing shear cracking (highlighted by red boxes).

Figure 23: Assessing damage of a high-rise hotel building via close-up views of 3D model utilising UAV images.

The application in supporting the County's earthquake recovery initiatives is illustrated by Figure 24. By incorporating and overlaying different datasets, including 3D models, the platform allows users to quickly review detailed information of each building or each floor of the building.

Applications for Other Business-as-Usual Operations

In alignment with the central government's 'Nation and Innovative Economic Development Programme (2017–2025)' [21, 22] Hualien County Government has initiated several programmes utilizing the platform for value-added processing of data and analytical applications. These include enhancing the efficiency and effectiveness of agricultural surveys, enforcement of non-compliant land uses, and urban design reviews.

Agricultural Surveys

As a major agricultural county, Hualien had long relied on labour-intensive fieldwork for crop surveys, where personnel visually estimated the growth status and yield of crops on-site. This traditional method is time-consuming and lacks verifiable accuracy in its estimations. To address this, the County government implemented a cross-departmental collaboration initiative, aimed at promoting smart agricultural surveys for key crops.

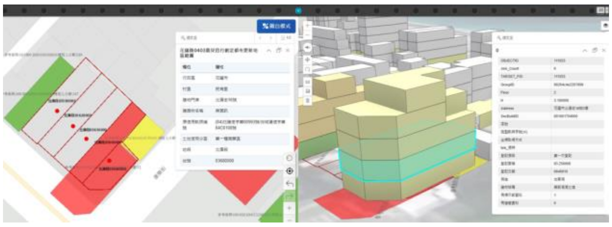
By conducting dedicated aerial photography, overlaid with cadastral and property right information, the system could estimate crop growth situation and crop yields. This approach has significantly enhanced the effectiveness of survey results and delivered substantial cost savings particularly when applied on surveying large areas of crops.

Inspection and Enforcement of Non-Compliant Land Uses

The County government has adopted specialized image processing systems, in conjunction with UAV photography, to assist in carrying out land use inspections. These efforts are supported by the integration of various spatial datasets, including cadastral, land ownership, and historical imagery.

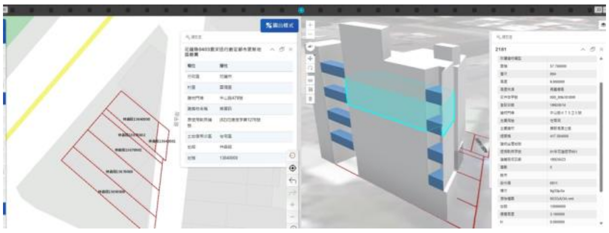
Once UAV images are uploaded, the automated image processing system would check and compare land ownership information, trace historical land use changes, and measure land areas, enabling fast and accurate spatial interpretation and analysis of non-compliant land uses. It also addresses the challenges relating to the inaccessibility to some land parcels or the human resource constraints for inspecting large areas. This approach has significantly improved reporting efficiency and ensured fairness and quality in law enforcement.

a) Left image: red lines indicating the designated urban renewal area following the Hualien Earthquake. Right image: showing the details of individual buildings (or individual floors) in the urban renewal area.



b) Left image: seismic rapid assessment (commenced before the 2024 Hualien Earthquake), with red colour indicating high risk. Right image: showing the details of the individual floor (e.g. residential usage).

c) Left image shows the rapid building assessment results following the Hualien Earthquake, with red box highlighting the building (shown in the right image) receiving a red placard.



d) Left image: red lines indicating the designated urban renewal area following the Hualien Earthquake. Right image: showing the details of individual buildings (or individual floors/units) in the urban renewal area.

Figure 24: Utilising 3D models and integrating various datasets to support earthquake recovery policy implementation following Hualien Earthquake.

Urban Design Reviews

For areas subject to urban design reviews, the County government encourages developers to include 3D building design models in their project submissions. These models are supplemented with detailed environmental modelling by the County government before being uploaded to the information platform.

This enables urban design review committee members from various disciplines and the developers to use 3D spatial visualisations and integrated virtual-real Digital Twin simulation environments to thoroughly examine the review targets (as illustrated in Figures 25 and 26). This process enhances the quality of communications and interaction across all aspects of the review processes, including the articulation of design concepts, focused discussion of review issues, and clear exchange of opinions. It also helps ensure that developments and environmental aesthetics advance in a balanced manner.

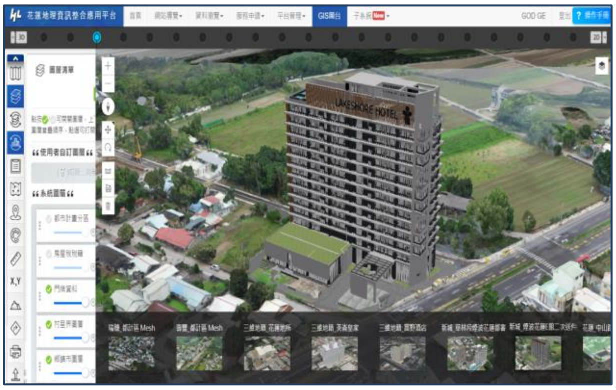


Figure 25: Integration of virtual and physical 3D spatial information for urban design review.

Figure 26: Utilising 3D Digital Twin technology at the urban design review meeting *(attended by council officials, independent reviewers, and the developers).*

DISCUSSIONS

Cross-Agency Spatial Intelligence Task Force

Following the devastating Typhoon Morakot in 2009, the need to coordinate spatial information during emergencies became evident. In response, the Executive Yuan (Cabinet) approved the 'Operational Mechanism and Workflow of Spatial Intelligence for Major Disaster Reconnaissance' [23] in 2010, establishing the cross-agency Spatial Intelligence Task Force.

This task force is coordinated by NCDR and comprises over a dozen agencies including: the Office of Disaster Management (under the Cabinet), Ministry of National Defense, Ministry of the Interior (including the National Land Surveying and Mapping Center, Land Administration Department, and the National Airborne Service Corps), Ministry of Transportation and Communications (Civil Aviation Administration, and Highway Bureau), Water Resources Agency under the Ministry of Economic Affairs, Ministry of Agriculture (including Agency of Rural Development and Soil and Water Conservation, and Aerial Survey and Remote Sensing Branch), Taiwan Transportation Safety Board, Taiwan Space Agency, and National Central University's Research Center for Space and Remote Sensing.

These agencies utilise various remote sensing platforms such as satellites, aircrafts, and UAVs to collect spatial data before, during, and after disasters. In times of emergency, when the CEOC is established, the spatial intelligence task force is activated upon the recommendation of NCDR to the Office of Disaster Management, Executive Yuan (Cabinet). After the task force obtains remote sensing data of the affected area, the information is promptly uploaded to the NCDR system and displayed in PRISM. This ensures that all relevant agencies can immediately access up-to-date situational intelligence for rapid assessment and decision-making. This collaborative mechanism between the task force and PRISM facilitates the efficient flow of critical spatial information, supporting a coordinated and evidence-based emergency response.

Case Study: 2024 Hualien Earthquake

Immediately after the M_w7.4 earthquake struck Hualien on 3 April 2024, the cross-agency Spatial Intelligence Task Force was activated alongside the CEOC. The Taiwan Space Agency and National Central University's Research Center for Space and Remote Sensing provided pre- and post-earthquake satellite imagery, which was used to identify initial landslide locations (e.g. Figure 27). These interpretations were swiftly shared with search and rescue teams to support decision-making. Over the following days, additional high-resolution images from UAVs and aerial surveys were undertaken by various agencies. This allowed for comprehensive assessment of the scale of the earthquake impacts.

Figure 27: Comparing satellite images before and immediately after the 3 April 2024 earthquake, showing large areas of landslides along Highway 8 (through Taroko National Park) and Highway 9 (along the coast).

One critical application involved identifying a landslide dam at the upper stream of Wanli Creek, a remote area, on the day of the M_w 7.4 earthquake [24]. The task force immediately acquired remote imagery and high-resolution photos enabled the CEOC to promptly evaluate downstream risks and determine the response strategies. The dam, containing an estimated 550,000m^3 of water accumulated, located about 20km upstream from Wanrong Village, which lies approximately 10m above the riverbed (Figure 28). Initial assessments suggested the dam posed no immediate danger.[13] The authorities implemented contingency measures, including monitoring the changes of the lake using UAV and satellite imagery, holding public briefings, and setting up community alert mechanisms.

Another quake-induced dam was identified at the upper stream of Mugua Creek on 19 April 2024 following close monitoring [25, 26]. It had estimated 460,000m^3 of water accumulated and was about 5km from the downstream electricity infrastructure, 17-21km from the downstream villages (which are 10-20m above the riverbed).[14] The dam was assessed as posing no immediate danger, and monitoring and community alerting mechanisms were put in place accordingly.

The ongoing aftershocks, heavy rain and typhoons heightened the risk of the two quake dams, keeping the authorities and communities on alert. The monitoring and contingency measures concluded in mid-August 2024 [27, 28], when both dam structures were naturally breached by Typhoon Gaemi in late July 2024. The breaching of these quake lakes did not cause any casualties or additional damage, thanks to ongoing intensive monitoring and preparedness.

These cases exemplify the task force's essential role in disaster response, showcasing the effective integration of multi-agency spatial data coordination and timely decision support.

Figure 28: Impact assessment of a quake dam on upper stream of Wanli Creek (identified on 3 April 2024 following the M_w 7.4 mainshock) [24]. *The dam was approximately 20km from the downstream Wanrong Village that lies 10m above the riverbed.*

Effectiveness of Integrated Geospatial Information Platforms

PRISM played a central role in the national response to Hualien Earthquake. Its effectiveness can be evaluated across several key dimensions:

- Response time improvement: PRISM significantly reduced the time from seismic event detection to the delivery of situational reports and visual products. Real-time integration of seismic data, population distribution, and infrastructure status enabled decision-makers to act within minutes.
- Decision quality enhancement: Compared to traditional manual processes, the GIS-enabled interface within PRISM allowed for layered visualization of hazards and resources, resulting in more accurate resource allocation and prioritization of response actions.
- Efficient information integration: PRISM served as a Common Operating Picture (COP) platform, merging satellite imagery, GNSS displacement data, real-time crowd-sourced reports, and government datasets. This comprehensive integration cut down the time and manpower traditionally needed to compile a disaster overview.
- Enhanced analytical capabilities: Through embedded spatial modelling, PRISM enabled post-earthquake impact assessments by analysing epicentre, magnitude, and shaking parameters to identify priority areas requiring immediate attention. These analyses were validated through post-event field surveys.
- Cross-agency coordination: PRISM supported synchronized data sharing between NCDR, CEOC, and agencies such as the Central Weather Administration, Ministry of Transportation, and local governments. This

[13] Aerial photos of 4 April 2024 showed that the landslide dam was overflowing. (The comparisons of satellite images indicated that the dam formed in early March 2024.) Aerial photos of 18 April 2024 showed that the lake was about 670m long, 78m wide, 36m deep (surface area of 3.5 hectares, c. 550,000m^3). [24]

[14] Aerial photos of 20 April 2024 showed that the lake was about 700m long, 130m wide, 29m deep (surface area of 5.6 hectares, c. 460,000m^3) [25, 26].

interoperability enhanced inter-agency efficiency and reduced information silos during critical hours.

These improvements illustrate PRISM's contribution to transforming emergency response into a data-driven, real-time coordinated operation positioning it as a vital tool in Taiwan's emergency management infrastructure.

Similarly, the Hualien County Geographic Information Integration Application Platform has significantly enhanced the County's responses to the 2024 earthquakes. The improvements are demonstrable when comparing with its responses to the 2018 Hualien Earthquake (M_w 6.4) that killed 17 people and caused severe disruptions to the city.

FUTURE DIRECTIONS AND CONTINUOUS IMPROVEMENTS

This study has demonstrated the advance in Taiwan in utilizing integrated geospatial information platforms to support decision-making during emergency responses as well as for business-as-usual operations. Priorities for future directions and continuous improvements include:

Policy Advocacy Directions

- Develop comprehensive data-sharing regulations encompassing technical standards and administrative procedures, safeguarding data privacy and security.
- Encourage government investment in advanced communication infrastructure, particularly in known communication vulnerability hotspots identified through GIS analyses.
- Further build spatial data infrastructures to support large-scale, real-time integration and analysis of multi-source disaster information.
- Invest in education and training for professionals in relevant fields, ensuring that there is expertise to develop, maintain, and apply advanced technologies.

Strengthen Cross-Agency and Cross-Sector Collaboration

- Develop standardised operating procedures for information sharing that align with Open Geospatial Consortium (OGC) and ISO spatial data standards.
- Conduct regular joint exercises across multiple agencies, using clear metrics to evaluate GIS-based decision support.
- Implement federated spatial database systems, maintaining agency autonomy while allowing seamless data exchange.
- Collaborate with the private sector to bring additional resources, technological innovations and applications.

Technology Integration and Implementation

- Advance integrated platforms combining GIS, AI, IoT, and Digital Twin technologies, with well-defined technical specifications to ensure interoperability.
- Prioritize IoT sensor deployment in high-risk areas to enhance real-time data collection, aided by spatial statistical analysis to optimize sensor placement.
- Create deep learning models optimized for spatial data to better predict disaster impacts. These models can inform infrastructure planning, helping to identify vulnerable areas and prioritize reinforcement or relocation efforts. They also support the optimization of evacuation routes by analysing traffic patterns, population density, and accessibility. In disaster response, AI can assist in resource allocation, ensuring that aid reaches the areas in greatest need promptly.
- Develop lightweight GIS solutions specifically designed for low-connectivity environments. Develop modular GIS components that can operate independently during network outages and synchronize updates once communication is restored.
- Utilise augmented reality (AR) technology, overlaying GIS data on field responders' visual devices for instant situational awareness.
- Utilise edge computing for GIS, deploying spatial analysis at the network edge to reduce latency.

Community Engagement

- Develop user-friendly mobile applications and utilise social media platforms to keep residents informed and connected. Features such as real-time alerts, interactive maps showing safe zones and shelters, and channels for reporting emergencies enhance communication between authorities and the public.

International Collaboration

- Undertake collaborative research projects with global institutions to accelerate advancements in areas like predictive modelling, real-time data integration, and community engagement strategies.
- Participate in joint training exercises and simulations with other countries to enhance readiness and interoperability in responding to large-scale disasters or transnational events.
- In recent years, Taiwan has also exported its smart IoT sensor technology and the PRISM platform to several other countries, particularly in Southeast Asia, to support disaster risk reduction and strengthen resilience through international technical cooperation.

CONCLUSIONS

As climate change amplifies the intensity and impacts of natural hazards worldwide, the development and application of sophisticated systems like PRISM or Hualien's information platform becomes increasingly critical. The examples from Taiwan demonstrate that successful implementation requires not only technical solutions but also organisational alignment, standardised procedures, ongoing capability development, and the incentives for collaboration.

Taiwan's progress encompasses four complementary dimensions:

- Policy dimension: The implementation of open data policies and cross-agency data sharing has not only enhanced the coherence and efficiency of decision-making, but also successfully reduced information silos between different institutions.
- Governance dimension: The unique roles played by NCDR are crucial in the development and applications of new technologies for disaster management across central and local agencies. The establishment and operations of the cross-agency Spatial Intelligence Task Force since 2010 has demonstrated the effectiveness of integrating multi-agency spatial initiatives for timely decision-making in disaster responses.
- Information dimension: The shift from traditional statistical tables to GIS-based 3D visualisation has provided a common 'visual language' that has greatly facilitated communication and coordination amongst diverse stakeholders.
- Technology dimension: Taiwan has continuously adopted innovative tools, such as sensor networks, real-time monitoring platforms, and Digital Twin applications, which

have enhanced the timeliness and spatial accuracy of situational awareness, enabling a more rapid and effective response.

The integration of GIS with emerging technologies like AI, IoT, and Digital Twin offers promising avenues for further enhancing resilience to natural hazards. By transforming scattered data from different fields into actionable intelligence through GIS-based spatial analysis, these systems enable more effective preparation for, response to, and recovery from disasters.

Integrating real-time data into the geospatial information platforms enhances its predictive capabilities and allows for more responsive decision-making. Emergency management agencies can leverage this information to deploy resources proactively, issue timely evacuation orders, and communicate effectively with the public. Additionally, real-time data supports simulations and scenario planning, helping authorities to anticipate the impacts of disasters under varying conditions.

A crucial factor to success is to develop, utilise, and improve such systems continuously in the business-as-usual context, rather than treating it as a special one-off exercise or arrangements only for emergency responses. Taiwan's experiences offer valuable lessons for New Zealand and other hazard-prone jurisdictions in strengthening inter-agency collaboration and integrating innovative technologies into emergency management practice.

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