Structural Gaps in Disaster Technology Systems: A Longitudinal Review of Post-Event Assessments in Aotearoa New Zealand

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***Abstract*—Over the past decade, Aotearoa New Zealand has experienced multiple large-scale disasters that have exposed recurring challenges in information management, communication, coordination, and technology integration within the emergency management system. This paper analyses eleven major disaster-response review reports published between 2012 and 2024 to examine how technology-related issues are represented in official assessments and to identify structural gaps. Using a mixed-method approach combining keyword frequency analysis and qualitative thematic analysis, the study finds that information and communication dominate review discourse, while explicit references to technology, situational awareness, and common operating picture appear less frequently and inconsistently. Longitudinal synthesis reveals persistent reform themes, including calls for nationally integrated platforms, interoperable systems, professionalised capability, and shared intelligence frameworks. Yet implementation details regarding architectural ownership, standards, lifecycle management, and funding remain limited. The paper advances a structured research agenda organised around four domains: data governance and architecture, decision-support design, ICT resilience and interoperability, and organisational technology governance.**

Keywords—disaster technology governance, interoperability, common operating picture, data governance, system resilience.

I. Introduction

Over the last decade, Aotearoa New Zealand (NZ) has experienced a series of large-scale disasters with severe impacts on communities, infrastructure, and the economy. Major events include the 2010-2011 Canterbury earthquake sequence, which caused widespread loss of life and long-term disruption to the built environment [1]. The 2023 North Island severe weather events, including Cyclone Gabrielle, directly affected more than one-third of the population and caused an estimated loss of between NZ$9 and 14.5 billion [2]. More recent events, such as the fatal landslide at Mount Maunganui after intense rainfall in early 2026, further highlight the ongoing exposure of communities and infrastructure to cascading hazard impacts and the need to strengthen resilience [3]. These events illustrate the frequency and escalating consequences of natural hazards for NZ.

Technology has long been recognised as a critical enabler of effective disaster management [4], [5]. However, within NZ's Emergency Management sector, adoption of technologies has been uneven, with systems facing challenges such as a lack of interoperability, managing large volumes of data, and privacy concerns regarding data usage [6], [7], [8].

Despite the growing body of work on technology in disaster management, limited attention has been paid to how official post-event review reports conceptualise technology issues and their implications for future research and system design. Against this backdrop, this paper analyses disaster review reports produced in NZ between 2012 and 2024 to examine how technology is represented in official assessments. The aim of the study is to propose directions for future research in technology-enabled disaster management.

II. Brief Background

A. Emergency Management Landscape in NZ

Emergency management in NZ is a complex ecosystem of agencies that collaborate under a devolved, three-tier model: locally led, regionally coordinated, and centrally supported [2]. At the national level, the National Emergency Management Agency (NEMA) serves as the system steward, providing strategic leadership and maintaining the National Crisis Management Centre (NCMC) [9]. Operationally, the country is divided into 16 regional Civil Defence and Emergency Management (CDEM) Groups established as joint committees of local authorities responsible for implementing the "4Rs" of disaster management: reduction, readiness, response, and recovery [9], [10]. This sector includes statutory emergency services, such as the Police, Fire Emergency New Zealand (FENZ), health providers, and other professionals, including Search and Rescue [9], [10]. The response network also includes the NZ Defence Force and Lifeline Utilities [9]. The distribution of roles across numerous organisations illustrates the complexity of the emergency management landscape, which shapes how information, technology, and decision-making are distributed during a response.

B. Prior Research on Technology Challenges in NZ

Emergency management practitioners in NZ navigate a technological landscape in which information is drawn from multiple sources in various formats [8]. Although specialised tools like the Emergency Management Information System (EMIS) have been employed, many agencies rely on a wide range of disparate platforms [11], [12]. For example, studies of specific sub-sectors, such as Search and Rescue, illustrate this fragmentation: more than 65 different systems are used, including specialised software and generic productivity tools such as Microsoft Teams and shared spreadsheets [7]

And even with bespoke emergency management software available, practitioners may often revert to "ad hoc" solutions, such as whiteboards, paper documents, and email, because formal technology systems are perceived as less efficient, unintuitive, or poorly aligned with operational realities [11]. Prior research (e.g. on the implementation of GIS) has also highlighted challenges, including the absence of sector-wide standards and mandates, which limited the translation of technical capability into operational practice [13].

https://doi.org/10.54389/XWMJ1712

C. Major Disasters and Review Reports in NZ

NZ has experienced several major disasters in the last decade: the 2010 Canterbury earthquake sequence, the 2016 Kaikōura earthquake, the 2017 Cyclones Debbie and Cook, the 2019 Pigeon Valley Fire, the 2019 Whakaari Volcanic Eruption, the 2021 Flooding in Napier, and the 2023 North Island Severe Weather events, including Cyclone Gabrielle. These events have triggered official response review reports. The purpose of the reports is to identify good practices to reinforce and processes to improve, ensuring that "lessons learned" inform preparedness and response actions to future events. Recurring issues highlighted include gaps in information sharing, multi-agency communication, and situational awareness. These issues make the reports a valuable source for examining how technology-related challenges are framed and prioritised within official reviews.

III. Method

A. Study Design

This study uses a mixed-method approach combining keyword frequency analysis and qualitative thematic analysis to examine how technology-related concepts are represented in official disaster response review reports in NZ. The intent is not to evaluate the effectiveness of each response, but to analyse how post-event reviews frame issues related to information, communication, technology, situational awareness and the common operating picture (COP). These reports are treated as institutional artefacts that reflect both operational experience and priorities of organisational learning within the emergency management system.

B. Document Selection

The corpus comprises official disaster-response review reports published between 2012 and 2024, covering major natural hazard events and system-level reviews in NZ. Reports were selected using the following criteria: (1) the report was commissioned or endorsed by a government agency or statutory body, (2) the report focused on response-phase performance or system-level response capability, (3) the report was publicly available in full-text form, and (4) the report related to a significant disaster event or a cross-hazard review of emergency management practice.

The selection resulted in 11 reports covering earthquakes and tsunami [1], [14], severe weather events [2], [6], [15], [16], wildfire [17], volcanic eruption [18], [19], and a system-level technical advisory group review (i.e. TAG review) [20]. The reports were commissioned by a range of bodies, including CDEM Groups, FENZ, independent review panels, and national government inquiries. Together, they represent local, regional, and national perspectives and provide longitudinal insight into learning over more than a decade.

C. Keyword Frequency Analysis

To assess the prominence of selected concepts across the corpus, a keyword frequency analysis was conducted using five predefined terms: *information*, *communication*, *technology*, *situational awareness*, and *COP*. These terms were selected based on their prevalence in prior emergency management research and their relevance to technology-enabled disaster response. Search terms included common plural and grammatical variations. Front and back matter, such as table of contents, reference lists, appendices, and annexes, were excluded from the analysis.

Because reports varied substantially in length (from approximately 6,000 to 89,0000 words), raw keyword counts were normalised to enable comparison across documents. This approach allowed us to balance absolute salience (the number of times a term was used overall) with proportional emphasis (the extent to which a term was central relative to the report length). Normalised frequencies per 10,000 words were then calculated using the following formula:

$$Normalised\ Frequency = \frac{Keyword\ Count}{Total\ Word\ Count} \times 10{,}000 \quad (1)$$

D. Thematic Analysis

To complement the keyword analysis, a qualitative thematic analysis was conducted, focusing on how the five core concepts were described and contextualised within the reports. Relevant sections were identified through keyword searches and close reading and were coded inductively to capture patterns and divergences across reports and over time. Coding focused on identifying recurring problems, reference to tools, systems, and processes, implicit or explicit assumptions about technology use, and linkages between the five predefined terms. Coding was iterative, with themes refined through repeated comparison across reports.

E. Analytical Focus and Limitations

The analysis focuses on how technology-related issues are represented in post-event review reports, rather than on the technical performance of specific systems or tools. As such, the findings reflect the framing, priorities, and learning emphasis of the review processes, which may differ from the operational realities encountered during the response.

Keyword frequency analysis provides an indicative measure of emphasis but does not imply importance or effectiveness. Accordingly, frequency results are interpreted alongside qualitative findings to avoid over-reliance on quantitative counts. A limitation of this study is that the qualitative analysis was conducted by the primary author with no inter-coder validation and may be subject to coding bias. However, the study does not seek statistical generalisation; instead, it aims to identify recurring patterns and gaps that can inform future research and practice.

IV. Findings

A. Keyword Frequency Patterns

The keyword frequency analysis demonstrates a highly uneven distribution of emphasis across the five analysed concepts. Figure 1 summarises the normalised frequency of keywords, illustrating how prominently these concepts feature in the reports over time. Overall, *information* and *communication* dominate the discourse in nearly all reports, whereas *technology*, *situational awareness*, and *COP* appear far less frequently and inconsistently.

Information is the most prominent concept across all reports analysed, with normalised frequencies ranging from approximately 7.6 to 63.2 references per 10,000 words, indicating sustained and pervasive attention regardless of hazard type, event scale, or review scope. *Communication* is the second most frequently referenced concept and is also strongly represented across the reports. Normalised *communication* frequencies generally range from approximately 5.8 to 25.8 per 10,000 words, with higher values appearing more frequently in reports published from 2018 onwards.

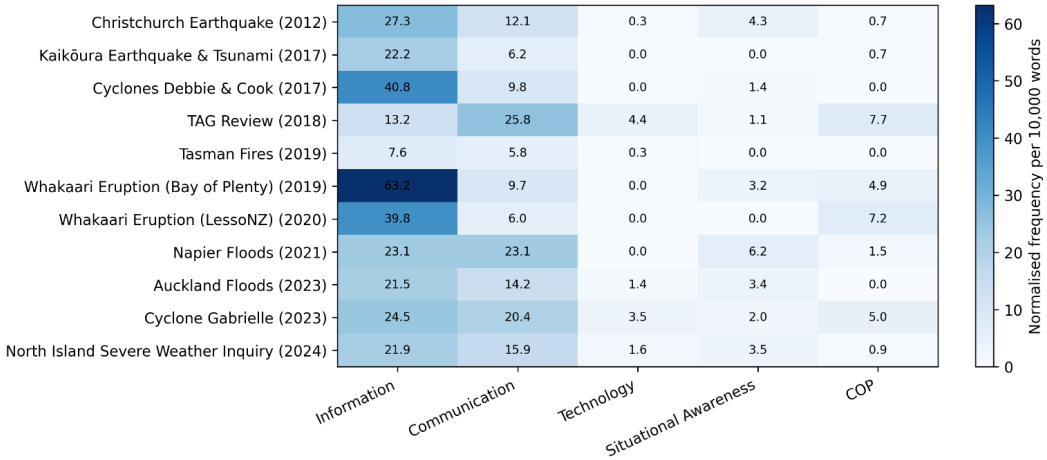

Figure 1. Heatmap of normalised keyword frequency per 10,000 words across disaster response review reports.

In contrast, reference to *technology* is minimal across the reports. Six of the eleven reports record zero or near-zero normalised frequencies for technology-related terms. Even in reports published after 2020, explicit references to technology remain low, typically in the range of approximately 1.0 to 1.6 per 10,000 words. Only a small number of reviews exceed this range, and even in these cases, technology is referenced far less frequently than *information* and *communication*.

References to *situational awareness* appear intermittently across the corpus and with moderate frequency in a subset of reports. Where present, normalised frequencies typically range from approximately 2.0 to 6.1 per 10,000 words. Three reports contain no references to situational awareness, indicating that the concept is not consistently embedded in post-event review language.

The reference to *COP* is also inconsistent. *COP*-related terms are almost absent in reports published between 2012 and 2017 and only begin to be mentioned more in later documents.

B. *Qualitative Findings*

1) Information and Communication

Across the reports analysed, *information* issues are most associated with data gaps, analytic limitations, and the failure to convert raw inputs into actionable intelligence. Several reports describe inaccurate or incomplete datasets (e.g., inconsistent victim list [19], rapidly changing magnitude estimates [14], missing telemetry data [2], [6], etc.), limited predictive modelling capacity [17], and inadequate integrations of local or indigenous knowledge [6], [18]. In multiple cases, large volumes of data were collected but not synthesised coherently.

Communication issues, by contrast, are consistently linked to breakdowns in transmission, coordination, and authority. Reports describe delayed or unclear public warnings [14], [16], [21], overlapping or inconsistent messaging among agencies [17], overreliance on digital platforms during power outages [6], [16], and uncertainty regarding who was responsible for issuing declarations or making evacuation decisions [17]. Structural ambiguities, such as unclear tasking pathways, insufficient liaison mechanisms [6], [16], or fragmented communication channels [19], [21], frequently contributed to operational confusion, even where information was available.

2) Technology

Although the term *technology* appears infrequently in several reports, there are extensive references to digital systems, telemetry, dispatch platforms, and communication infrastructure [6], [21]. This indicates that technological capability is often embedded within operational narratives rather than treated as a distinct analytical category in post-event reviews. Across the reports, technology functions as the underlying architecture supporting information management and communication, yet it's most often discussed in the context of infrastructural weakness, system incompatibility, or operational fragility [2], [6].

A recurring *technology* theme concerns system incompatibility across agencies. For example, geospatial tools used by one agency were blocked by another agency's controls, preventing real-time intelligence sharing [6]. Similarly, the 111 emergency call systems operate on separate dispatch platforms that cannot reconcile tasking data among Police, FENZ, and Ambulance services, limiting cross-system visibility during surge demand [2]. These cases highlight architectural misalignment rather than isolated faults.

Technological fragility under infrastructure disruption is another dominant pattern. In both the Auckland floods and Cyclone Gabrielle, public messaging relied heavily on digital networks, even as cell towers, fibre and electricity networks failed [2], [6]. River flow telemetry and rain gauges malfunctioned during peak impact periods, reducing the reliability of data precisely when it was most needed [2], [6]. Such failures highlight the vulnerability of digitally dependent systems under stress. National coordination infrastructure is also identified as a constraint. Several reports describe the NCMC as outdated and technologically constrained [2], [6], raising concerns about the resilience of national-level coordination facilities.

3) Situational Awareness and COP

Challenges to *situational awareness* are frequently described as "intelligence gaps", where breakdowns are associated with weaknesses in information quality and analytic process [1], [2]. Reports indicate that data was often available, yet insufficient analytical capacity, structured intelligence processes, or specialist integration limited the production of actionable insight [1], [2], [17].

COP challenges centre on coordination misalignment and a lack of standardisation across agencies. Reports describe incompatible reporting formats, divergent terminology, and siloed ICT environments that limited the consolidation of information into a validated shared overview [15], [17], [19]. In several events, duplication of effort, inconsistent public messaging, and loss of continuity during shift handovers were linked to the absence of a coherent shared picture [1], [17].

4) Recommendations from a decade of review reports

Reform recommendations exist throughout all eleven reports. Core concerns such as interoperability, intelligence capability, leadership clarity, and the need for a COP have recurred since the 2012 Christchurch Earthquake review. However, recent reviews (2023-2024) shift from improvements in advisory coordination toward mandated professionalisation, nationally prescribed ICT reform, and structural reconfiguration of system leadership[2], [6], [21]. This progression suggests growing recognition that operational weaknesses reflect architectural and governance limitations rather than isolated technical failures.

a) Professional and National Leadership.

Early reviews acknowledged the significant commitment of local staff and volunteers but identified capability gaps, noting that emergency management was not a full-time function [1]. Recommendations from the reports evolved from establishing a trained leadership cadre to formal accreditation of Controllers, and more recently, to nationally accredited full-time roles and deployable Emergency Management Assistance Teams [20]. The reports also reflect the ongoing institutional calibration, from strengthening the former Ministry of CDEM mandate to establishing NEMA and subsequently reconsidering its scope across the "4Rs" [2], [20]. These shifts highlight the movement from informal coordination to capability standards and governance.

b) Technological architecture and resilience.

While calls for COP are longstanding, the specificity of proposed solutions has intensified over time. Early recommendations focus on improving intelligence products and information displays [1]. Subsequent reports have specified the need for a shared, interoperable digital platform capable of real-time data exchange among emergency services [15], [19]. Recent inquiries go further, advocating for nationally mandated ICT integration with dispatch systems and end-to-end tracking [2], [17]. Following widespread infrastructure failures in multiple events, recommendations also emphasise hybrid resilience design, incorporating low-tech redundancies alongside digital systems.

Notably, several structural recommendations have recurred across multiple reviews but remain only partially implemented, including upgrading the NCMC, strengthening intelligence functions, and standardising training. The persistence of these themes indicates a widening gap between reform rhetoric and system redesign.

V. Discussion

Recurring operational challenges reflect not isolated technological breakdowns but systemic weaknesses across four interrelated domains:

A. Data Governance and Architecture

Although *information* is the most dominant concept in the review corpus, the primary challenge is not merely the availability of data but its integration, validation, and governance. Recurring references to "intelligence failures" point to architectural weaknesses in the structure, sharing, and verification of information within the emergency management system.

Interoperability concerns are framed primarily as system compatibility problems, yet they also reflect deeper institutional fragmentation. Currently, there is no nationally mandated schema governing how data should be captured or exchanged between multiple agencies. As a result, raw information may be available, but its transformation into coherent intelligence remains inconsistent.

Future research should therefore focus on multi-agency data governance frameworks and interoperable data schemas for federated response systems. There is also a need for real-time validation mechanisms under degraded infrastructure conditions. Research also needs to explore privacy-preserving data-sharing models that reconcile individual data protection with urgent operational necessities of disaster response.

B. Decision-Support Design and Cognitive Load

Frequent references to "intelligence gaps", in which large volumes of inputs failed to yield actionable insights, suggest that the challenge is not solely on data acquisition but of presentation, prioritisation, and sense-making within high-pressure conditions. *Situational awareness* depends on how information is structured for decision-makers. The *COP* is frequently proposed as a solution; however, it is rarely defined in terms of design, usability, maturity benchmarks, or performance criteria, offering limited guidance on how shared visibility should be implemented, evaluated or sustained.

This opens an important research avenue into decision-support design, not only for emergency operation centres but also more broadly for interoperable emergency management networks. Future studies could examine cognitive load modelling in crisis environments, visual analytics frameworks for multi-agency coordination, and empirically grounded COP maturity models. Distinguishing between symbolic adoption of a COP and actual user-tested integration is important in federated systems, where shared understanding cannot be assumed.

C. ICT Resilience and Interoperability

Technology in the review corpus is most visible at the point of failure. Digital platforms, telemetry, dispatch tools, and public communication channels are described as fragmented, fragile, or incompatible under large-scale stress. Recommendations often call for redundancy mechanisms such as satellite connectivity or low-technology backups. However, redundancy is typically framed as a collection of backup tools rather than as a systemically designed hybrid architecture. Reports seldom articulate resilience thresholds, performance standards under cascading failure, or integration logic for digital and analogue systems.

Future research should therefore move beyond tool adoption toward system resilience architecture. This includes modelling communication continuity under compound hazard conditions, designing digital-analogue communication ecosystems, and examining governance models for nationally mandated ICT platforms. A comparative analysis of federated versus centralised emergency ICT systems may also illuminate the structural enablers and barriers to integration.

D. Technology Governance and Implementation

Across the reports, reform language is strong. Calls for national operating platforms, mandated interoperability, standardised intelligence products, and improved lessons management recur consistently. Yet implementation detail remains limited. Questions of architectural ownership, funding models, technology lifecycle management, vendor neutrality, and standards enforcement are seldom addressed.

At the same time, many recommendations emphasise enhanced training, professionalised controllers, and deployable surge teams. This suggests a systemic reliance on human coordination to compensate for fragmented digital infrastructure. While leadership and capability development are essential, they may inadvertently mask structural weakness in technology integration. This reveals a governance gap. The increasing prescriptiveness of recent reports toward nationally mandated ICT platforms suggests growing recognition that interoperability cannot be achieved through voluntary coordination alone. Future research should examine the political economy of shared emergency ICT systems, mechanisms for enforcing interoperability standards, and institutional pathways linking post-event lessons to procurement and architectural design. Sustained infrastructure changes are critical to advancing disaster technology capabilities.

VI. Conclusion

This study analysed eleven major disaster response review reports produced in NZ between 2012 and 2024 to examine how technology-related issues are represented in post-event assessments. While *information* and *communication* dominate review discourse, explicit references to *technology*, *situational* awareness, and *COP* are less frequent and inconsistent. Longitudinal analysis indicates that recurring operational breakdowns reflect structural misalignment rather than a simple absence of technological tools.

Across the corpus, persistent challenges cluster around four interrelated domains: data governance and architecture, decision-support design, ICT resilience and interoperability, and technology governance. Repeated calls for reform indicate that technological innovation alone is insufficient. Future research should prioritise governance models for shared emergency ICT infrastructure, hybrid digital-analogue resilience architectures, decision-centred information design, and institutional mechanisms for system redesign.

Advancing disaster technology capability requires sustained attention to data governance, decision-support design, resilient communication infrastructure, and institutional mechanisms that align procurement, standards enforcement and system lifecycle management. Without this alignment, reform will continue to produce rhetorical integration without architectural consolidation.

Acknowledgements

This work was supported by the Resilience to Nature's Challenges. Generative AI tools were used to assist with manuscript editing and document navigation. All analytical design, interpretation, and conclusions are the authors' own.

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