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The Adaptive System: Networks, Relationships, and Boundaries in Disaster and Emergency Management

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ABSTRACT

Disaster and emergency management (DEM) systems face increasing complexity, with overlapping hazards and diverse actors. Understanding how such systems function adaptively is essential for improving coherence and resilience. While DEM research recognises interdependence, less is known about how relational and structural dynamics interact to shape performance. This study addresses that gap by examining Aotearoa New Zealand's DEM system through a Constructivist Networked Grounded Theory (CNGT) approach, integrating complexity and network theory. Data from 40 participants revealed the system as a complex adaptive network - a dynamic web of relationships, roles, and feedback loops. Three interlinked themes emerged: fluid boundaries that influence inclusion and legitimacy; relational enablers such as trust, learning, and cultural partnership; and systemic frictions that constrain adaptation. Across these themes, information flow proved central to coordination quality. The findings suggest that effective DEM requires shifting from control to stewarding the relational and cultural conditions that sustain collective learning and adaptability.

1 | Introduction

Disasters are increasingly defined by systemic transformation, where risks emerge through interdependencies across the built, social, economic, and natural environments (Bosher et al. 2021; Norman 2006). Urban growth concentrates risk within dense infrastructure and populations, while climate-driven hazards escalate the intensity and unpredictability of threats (Wisner et al. 2014). These converging pressures generate cascading and compounding risks, in which the failure of one element - such as power, communication, or transportation - triggers broader systemic disruptions (Pescaroli and Alexander 2016). While contemporary Disaster and Emergency Management (DEM) frameworks increasingly emphasise integration and whole-of-system approaches, coordination in practice remains undermined by fragmented interorganisational relationships, contested participation boundaries, and uneven collaboration across sectors and scales (Hodges and Larra 2021).

The DEM environment is best understood through a complexity lens, as a *complex adaptive system* (CAS): a web of interdependent actors and processes characterised by decentralised authority, emergent behaviours, and the interplay of formal and informal relationships (Hodges and Larra 2021; Miller et al. 2025a; Comfort et al. 2010). Effectiveness rests less on formal structures than on the dynamic, adaptive connections that enable collective action and resilience (Abbas et al. 2018), requiring systems to demonstrate coordination, decentralised decision-making, and sustained collaboration across sectors and jurisdictions (Burns and Eltham 2010; Comfort 2002). Yet many remain bound to command-and-control frameworks suited to more predictable scenarios (Hodges and Larra 2021). As the demands on DEM systems grow, so too must our understanding of how they are configured, how they function under stress, and how they might evolve to meet emergent challenges (Burger et al. 2021). This necessitates a critical enquiry not only into their structures but into their relational and networked dimensions (Miller et al. 2025a).

At the heart of DEM system performance lies the quality and configuration of its interorganisational networks. These networks - comprising the actors, relationships, and flows of information that connect the system - are foundational to how decisions are made, resources are mobilised, and collective action is sustained (Hodges and Larra 2021; Miller et al. 2025a). In complex and rapidly evolving environments, the formal design of a system is often less predictive of its functioning than the dynamic relationships that underpin it (Comfort et al. 2010). For example, following the 2023 Türkiye - Syria earthquakes, collaboration between international NGOs, local volunteer groups, and transnational community networks facilitated rapid aid distribution in areas where formal state coordination was delayed or disrupted (Bozkurt and ÇİÇEKDAĞI 2025).

These relational dynamics can also be examined structurally through network mechanisms such as brokerage, density, and modularity. Brokerage - the structural position of an actor who bridges otherwise disconnected parts of a network - highlights how information and resources traverse organisational boundaries; density reflects the robustness of coordination pathways; and modularity reveals patterns of clustering that may enable or constrain inclusion. Social network analysis is therefore used as an integrated analytic lens that links participants' experiences of coordination with the underlying configuration of the DEM network.

Within such networks, hubs and brokers play a crucial role. Hubs are highly connected organisations that can quickly disseminate information and resources, while brokers occupy bridging positions that link otherwise disconnected clusters. Both functions enable rapid coordination by ensuring information and resources move efficiently across the system (Abbasi and Kapucu 2012). However, structural holes – gaps in connectivity between parts of the network - create risks of fragmentation and exclusion. When these gaps are present, critical information or resources may not reach all actors, weakening coordination and reducing overall system performance (Abbasi and Kapucu 2012; Kim-Chung et al. 2014). Informal ties often prove decisive when formal mechanisms falter (Nowell et al. 2018). Thus, in CAS such as DEM, adaptive capacity is embedded not only in design but in the quality of relationships across the network (Hodges and Larra 2021; Miller et al. 2025a; Burger et al. 2021).

Persistent barriers such as silos, role ambiguity, and strained inter-agency relationships undermine collaboration across DEM systems globally (Davidson et al. 2025). Conversely, enablers such as shared expectations, pre-existing relationships, and joint training can be critical but often remain invisible in formal plans. Understanding how such barriers and enablers operate in practice requires an approach that attends to both structure and meaning, connection and context. This broader context sets the stage for examining how these dynamics play out within Aotearoa New Zealand's DEM system.

This study examines how the DEM environment functions as a complex adaptive system in Aotearoa New Zealand, with particular focus on boundaries, relational enablers, and systemic frictions. While international scholarship has documented the growing importance of interorganisational networks and adaptive coordination in complex disasters (Hodges and Larra 2021; Comfort and Resodihardjo 2013; Balaram and Dhananjay 2025), there remains a limited empirical understanding of how relational dynamics and structural network configurations interact in practice within national DEM systems. This interaction shapes coordination quality, inclusion, and system adaptability. This gap is particularly prominent in the New Zealand context, where statutory decentralisation, reliance on informal coordination, and Treaty-based partnerships with iwi[1] collectively shape how collaboration is enacted. The analysis therefore focuses on the networked relationships, barriers, and enablers that shape its performance. Accordingly, this study is guided by three interrelated research objectives. First, it examines how coordination and collaboration are experienced and enacted within Aotearoa New Zealand's DEM system, with particular attention to how system boundaries, participation, and legitimacy are constructed and negotiated in practice. Second, it seeks to identify how relational dynamics - including trust, learning, and brokerage – interact with the configuration of interorganisational networks to enable or constrain coordination across the system. Third, it explores how the interplay between meaning-making and structural network configuration shapes the adaptive capacities and systemic vulnerabilities of the DEM environment over time.

1.1 | Case Context: Aotearoa New Zealand

Aotearoa New Zealand provides a theoretically informative case through which to examine coordination and collaboration within a complex DEM system. Its DEM framework follows an *all-hazards, all-risks* approach that spans risk-reduction, readiness, response, and recovery (4Rs) (Civil Defence Emergency Management Act 2002). Responsibility is devolved to 16 regional Civil Defence Emergency Management (CDEM) Groups - and their local Territorial Authorities, supported by national policy, guidance, and surge capacity through the National Emergency Management Agency (NEMA). This enables context-responsive action, but also introduces complexity in terms of alignment, interoperability, and the translation of strategy into practice across varied settings (Saunders et al. 2020).

Beyond its formal architecture, the New Zealand context is analytically significant due to the centrality of Treaty-based partnerships with iwi, which position legitimacy, participation, and authority as relationally negotiated rather than solely organisationally prescribed. The system extends beyond mandated agencies. Iwi, emergency services, lifeline utilities, civil society organisations (CSOs) (Clayton et al. 2000), private sector, and community networks play shifting roles depending on the hazard context (Ministry of Civil Defence and Emergency Management 2019; Flecha et al. 2023). As a result, system boundaries are neither fixed nor uniform, but are continuously shaped through relationships, trust, and local leadership. Relationships, rather than roles alone, drive system performance (Kapucu et al. 2024). These relationships form both institutionalised pathways and informal networks of trust, reciprocity, and shared understanding - for example, during Cyclone Hale, which struck Tairāwhiti in 2023, freight operators rerouted deliveries due to roading failures, ensuring essential goods reached isolated communities before formal logistics plans were activated. Such dynamics illustrate how

legitimacy and network connectivity can mobilise adaptive responses when formal arrangements lag behind operational realities. Recognising DEM as a system thus demands an appreciation of its relational network: constantly adapting connections that shape collective action in the face of complexity (Comfort and Resodihardjo 2013).

Despite the intention of a unified, all-of-nation approach, interorganisational coordination and collaboration remain enduring challenges (Miller et al. 2025a; Drabek and McEntire 2002; Curnin and O'Hara 2019; Abbas and Miller 2025). Reviews of recent events, including the Government Enquiry into the North Island Severe Weather Event (New Zealand Government 2024), and the Auckland Flood Response Review (Bush 2023) have highlighted fragmentation, institutional silos, and boundary tensions that undermine system coherence. These challenges underscore the analytical value of the New Zealand case: its combination of governance, reliance on informal coordination, and Treaty-based partnership obligations renders boundary formation and legitimacy visible as active processes shaping system performance, rather than background conditions.

Lessons from COVID-19, the 2016 Kaikōura earthquake, and 2023 Cyclone Gabrielle each revealed both the strengths and limitations of coordination in practice (Herbert et al. 2018; Carter and Kenney 2018; Moyle et al. 2025). In many cases, formal structures were complemented – or bypassed – by informal relational workarounds, such as iwi networks providing rapid welfare support during Cyclone Gabrielle (New Zealand Government 2024) or lifeline utility managers relying on long-standing personal ties to restore essential services (Herbert et al. 2018). These examples illustrate both the resilience and the fragility of New Zealand's DEM system. Understanding the barriers and enablers of coordination within this complex landscape requires more than procedural fixes. It necessitates a systemic enquiry into how interorganisational relationships are formed, maintained, and mobilised. Exploring these relational dynamics offers a pathway to identify leverage points for improving collaboration, fostering adaptive capacity, and ultimately, enhancing the system's ability to function as a cohesive whole.

2 | Methods

This study uses CNGT (Miller et al. 2025b) to explore coordination and collaboration within Aotearoa New Zealand's DEM system through a complexity lens. Data was gathered between August 2024 and June 2025. CNGT extends Charmaz (Charmaz 2014) constructivist grounded theory by integrating social network analysis, enabling examination of how meaning-making and relational structure co-evolve within complex systems. It is grounded in the assumption that DEM systems operate as CAS. Within this view, coordination emerges through decentralised decision-making, feedback processes, and interdependencies among diverse actors, rather than through formal structures alone.

Within this framework, networks are understood not as static representations but as socially constructed and dynamically enacted through participants' interpretations, practices, and positionality. To clarify how CNGT was operationalised in practice, Table 1 outlines the sequential, yet iterative phases of analysis used in this study, illustrating the integration of grounded coding, network construction, and constant comparative analysis across the research lifecycle. Ethical approval was granted by the Auckland University of Technology Ethics Committee (24/37).

Participants were purposively recruited to reflect the diversity of the DEM environment with invitations disseminated via national forums, working groups and targeted organisational approaches. Inclusion required participants to be over eighteen,

TABLE 1 | Overview of phases of CNGT (Miller et al. 2025b).

	Phase	Description
1	Research question	Establishes the initial focus, framing the enquiry.
2	Recruitment and sampling of participants	Iteratively identify participants whose positions and relationships within the system can illuminate emerging categories and network dynamics.
3	Data collection	Semi structured interviews generating rich, interpretive accounts of practice and interaction, capturing both meaning-making and relational context.
4	Initial coding	Breaks down the data to identify actions, processes, and meaning without imposing predefined structures.
5	Node and edge categorisation	Translates qualitative accounts into categorised actors and relationships.
6	Focused coding and categorisation	Consolidates initial codes into coherent categories that reflect recurring systemic patterns.
7	Network analysis and development	Examines how relational configurations shape coordination, influence, and boundary formation across the system.
8	Theory building	Integrates categories and network structures to explain how system-level behaviours and capacities emerge over time.
9	Write up	Write up and disseminate the research.

organisational consent, and engagement in the DEM continuum. As analysis progressed, theoretical sampling guided ongoing recruitment to elaborate emerging categories and to test their explanatory adequacy across organisational roles and sectors. Recruitment continued until conceptual saturation was reached, defined as the point at which additional interviews no longer generated substantively new properties of core categories, nor altered the structure or interpretation of the emerging network patterns (Braun and Clarke 2021). This process resulted in a total of 40 participants with 38 semi-structured interviews conducted (22 virtual, 18 in-person), lasting between 43 and 96 min. Nine identified as Māori, ensuring representation of Treaty[2] partners' perspectives. Interviews focused on how coordination and collaboration were experienced, emphasising relational enablers and constraints. Participants identified 67 organisations, subsequently de-identified and grouped into broad categories: Central Government ($n = 26$), Local Government ($n = 8$), Māori ($n = 4$), Community ($n = 4$), Private Sector ($n = 9$), Education ($n = 3$), CSO ($n = 6$), Emergency Service ($n = 5$), and International ($n = 3$). Analytic rigour was supported through iterative constant comparison, reflexive memo-writing, and participant verification.

2.1 | Network Analysis Methods

Within CNGT, network analysis was used to identify relational structures embedded within participants' accounts, rather than as a predictive or statistical model. Network data were derived from interview transcripts by coding organisations named by participants as nodes and the reported presence of a working relationship as edges. Relationships were treated as binary and undirected, reflecting whether a connection was described as present rather than its intensity.

Network development was undertaken using Gephi (v0.10). The resulting network comprised 73 nodes and 129 edges. Descriptive network statistics are summarised in Table 2 to provide an overview of the structural characteristics of the interview-derived DEM network. Network density was calculated as the ratio of observed ties to all possible ties, indicating overall system connectivity. Degree centrality (Freeman et al. 1979) was used to identify highly connected actors, while betweenness centrality (Barthélemy 2004) captured brokerage roles by measuring the extent to which actors lay on shortest paths between others. Structural differentiation was examined using modularity (Blondel et al. 2008) to identify clustering patterns, interpreted descriptively rather than as statistically discrete communities. Network visualisations employed the ForceAtlas2 (Jacomy et al. 2014) layout to enhance interpretive readability.

Thresholds and cut-off decisions were applied conservatively for analytic clarity. Node sizes were scaled proportionally using degree centrality. No inferential statistics (Hanushek and Jackson 2013) (e.g. *p*-values or confidence intervals) are reported, as network metrics were not treated as independent variables but were triangulated with qualitative coding through constant comparison. This approach positions the network analysis as interpretive-descriptive, where analytic rigour is assessed through triangulation with qualitative coding rather than statistical significance testing.

3 | Results

Analysis of participants' accounts revealed three interconnected themes shaping the operation of the DEM system. The first concerns the challenge of defining what the system is. The second highlights the factors that strengthen collaboration and adaptability. The third captures the structural, cultural, and operational constraints that inhibit coordination and collective action. Together, these themes provide a layered view of both the strengths and the tensions that shape DEM system performance.

3.1 | Defining the System and Its Network Boundaries

Participants described the DEM system not as a single entity but as a complex web of actors and relationships whose boundaries remain fluid and contested. Some framed it in formal statutory terms - national, regional, and local arrangements under the CDEM framework - while others saw it as a broader social and operational network shaped by relationships, roles, and lived experience. This diversity of perspectives highlights that system boundaries are both permeable and negotiated, a feature that both enables flexibility and generates coordination challenges. One participant summarised this breadth:

TABLE 2 | Network descriptive statistics.

Indicator	Value	Interpretation
Nodes	73	Distinct orgs identified through interviews
Edges	129	Interview-derived working relationships
Network type	Undirected, binary	Presence of tie rather than strength or direction
Density	0.050	Low overall connectivity across the system
Average degree	2.70	Average number of connections per actor
Diameter	5	Maximum distance between any two actors
Average path length	2.60	Av. coordination distance across the network
Modularity	0.379	Moderate clustering into sub-groups
Highest degree actor	A01 (value)	Most connected actor
Highest betweenness actor	A12 (value)	Primary brokerage position

> *I see it as every agency that has a role, whether it's statutory or not... It only works well if we actually talk to each other before we need to.*
>
> P08

From a systems perspective, participants offered contrasting views on the scope of the DEM system. Some described it as encompassing all New Zealanders, reflecting the reality that disaster response and recovery often depend on households, communities, CSOs, and the private sector (amongst others), as much as formal agencies. Others preferred a more bounded view, distinguishing between the sector (CDEM organisations and people involved) and the system (the broader mechanisms and structures). For some, this distinction was critical for accountability, as collapsing the two risked blurring responsibilities and creating confusion about who was expected to act:

> *The system is everyone in the country, but the sector is those of us who work in it day-to-day. Sometimes we talk past each other because we're not clear which we mean.*
>
> P07

This observation reflects a recurring tension in how the DEM environment is conceptualised. For some ($n = 15$), the *system* referred to the whole-of-nation network of people and organisations contributing to resilience, while the *sector* described the professional community formally employed within CDEM and related agencies. Ambiguous boundaries made it harder to allocate resources, design inclusive plans, and establish clarity in decision-making. Some ($n = 5$) iwi and CSO representatives noted that they were sometimes treated as peripheral – "invited in" only when convenient – while in other regions they were considered indispensable partners. Private sector organisations also highlighted that their operational contributions were often essential in practice but absent from formal planning discussions.

The network analysis suggests a structural pattern consistent with these contested boundaries. It reveals a diverse relational structure characterised by a core-periphery configuration (see Figure 1). At the centre, several highly connected organisations - A01 [Central Govt], A12 [Local Govt], and A15 [Central Govt] - exhibited elevated degree centrality, functioning as hubs that maintained multiple ties across the system. These hubs were supported by bridging actors, such as A06 [Emergency Service], A13 [CSO], A03 [Central Govt] and A17 [Local Govt], whose high betweenness centrality enabled them to connect otherwise discrete clusters. The overall density of the network was low (0.050), meaning that only about five percent of all possible ties between actors were present [Nodes = 73, Edges = 129]. Connections existed across the system but were unevenly distributed with concentrated clusters of interaction coexisting alongside sparsely connected nodes. This structural pattern appears consistent with participant accounts of ambiguity. While statutory agencies formed a dense and influential core, iwi, CSOs, private-sector, and community actors occupied the

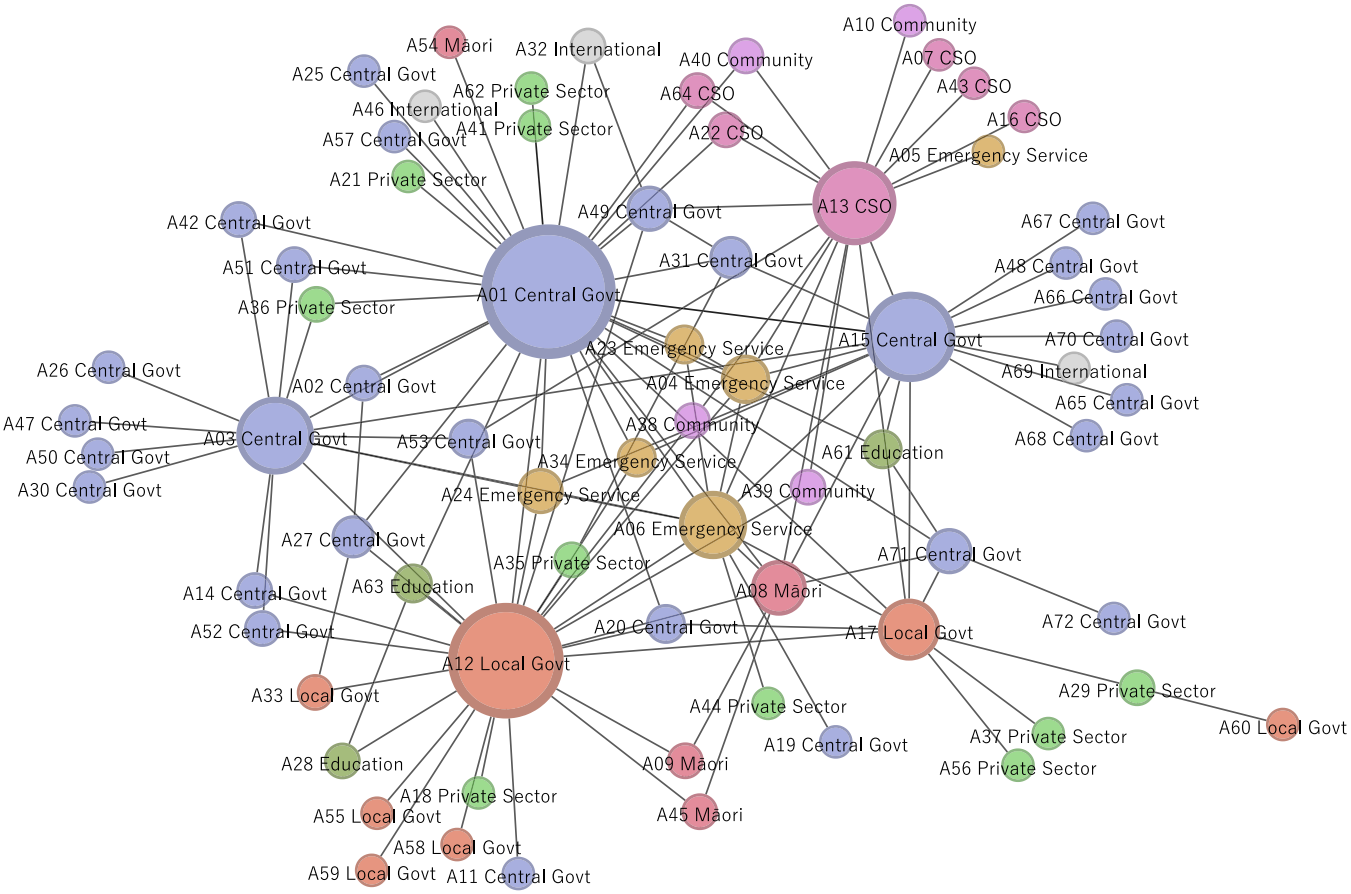

FIGURE 1 | Interorganisational network of Aotearoa New Zealand's DEM system. Network is undirected and unweighted; Ties are derived from interview-based relational mentions and visualised using Gephi (v0.10).

periphery. Their weaker connectivity may have contributed to experiences of marginalisation, especially in areas of planning and decision-making, unless supported by trusted brokers. In this way, the system's boundaries appeared both porous and contested – adaptive in some situations, yet fragile when bridging actors or key hubs were absent.

3.2 | Network Enablers of Collaboration and Adaptation

Alongside differing views of system scope, participants identified a series of relational and organisational factors that enhanced the DEM network's ability to function adaptively. These enablers – spanning learning, trust, partnerships, and innovation – demonstrate how the system's performance emerges less from formal structures and more from the density, quality, and resilience of its connections.

3.2.1 | Relational Enablers

Relational factors were consistently described as the foundation of system performance. Participants noted that collaboration, iwi partnerships, and interpersonal trust functioned as the connective tissue of the DEM network. Formal structures provided a framework, but it was the quality of relationships across actors that determined whether coordination was effective in practice.

Collaboration was sustained through regular contact and shared forums, which not only aligned priorities but also reinforced existing ties and created new ones. As one participant noted:

> *We meet quarterly with our key partners to map out who's doing what... it helps make sure we're not all chasing the same problem in isolation.*
>
> P15

Such interactions strengthened the density of ties across clusters, reducing duplication and improving situational awareness.

Partnerships with iwi and Māori were described as both a Treaty obligation and an operational necessity. Where these relationships were strong, they provided access to communities, resources, and decision-making pathways that statutory agencies could not replicate alone. Importantly, participants stressed that these partnerships needed to be built before the emergency, so that collaboration was grounded in trust rather than transactional engagement during crises:

> *If you start talking to them [Māori] based on 'we need to tick a box', it's pretty much going to fail... meet in peace time to talk about the roles you will play, because if you do get an event... you're prepared together.*
>
> P22

Strong iwi connections thickened the periphery of the network, helping to bridge gaps between the statutory core and local communities.

Trust was seen as the most critical enabler. Figure 2 illustrates how brokerage positions such as A03 [Govt Agency], A06 [Emergency Service], and A13 [CSO] serve as pivotal connectors, linking otherwise weakly connected clusters and enabling information flow and coordination across boundaries. These brokers maintained coherence across the system by transferring information and coordinating action. For example, one chief executive described how years of collaboration and shared challenges with a neighbouring council had built a foundation of trust that allowed them to coordinate seamlessly during emergencies, bypassing procedural delays and aligning priorities in real time.

Such trust often made the difference between plans on paper and coordination in practice. The presence of brokers created resilience by ensuring that knowledge and resources could flow across boundaries. Participants described relationships as multi-layered, extending across sectors and organisational levels. While personal trust between senior leaders often facilitated open communication, formal organisation-to-organisation ties were increasingly limited by information-sharing constraints. Participants agreed that relationships were not always about complete agreement but about knowing that partners could be relied upon to act in good faith, even when perspectives differed.

3.2.2 | Process Enablers

Beyond relationships, participants highlighted learning, the exchange of knowledge, and readiness activities as critical enablers of collaboration. These processes reinforced the connective fabric of the DEM network by building shared understanding, aligning expectations, and strengthening trust across organisational boundaries. Learning was often described as emerging through repeated interaction. Working together in non-crisis contexts allowed agencies to develop a clearer sense of each other's capacities and constraints, creating confidence in how partners would act under pressure. One participant noted:

> *The more time we spend together, the more we understand how each other works... it's about building that muscle before you need to use it.*
>
> P06

Such relational learning expanded the range of effective ties in the network and created feedback loops that supported adaptive decision-making.

Readiness activities - including joint planning and exercises – further enhanced the network by making connections more reliable and predictable. Participants stressed that planning needed to be inclusive and ongoing, not simply a written document. Exercises, in particular, were valued for creating "first-hand" experience of collaboration, so that when crises occurred, actors were not meeting for the first time but reactivating established ties. As another participant explained:

> *Running exercises together means when the real thing happens, we've already worked through the 'how'... it's not the first time we've met.*
>
> P18

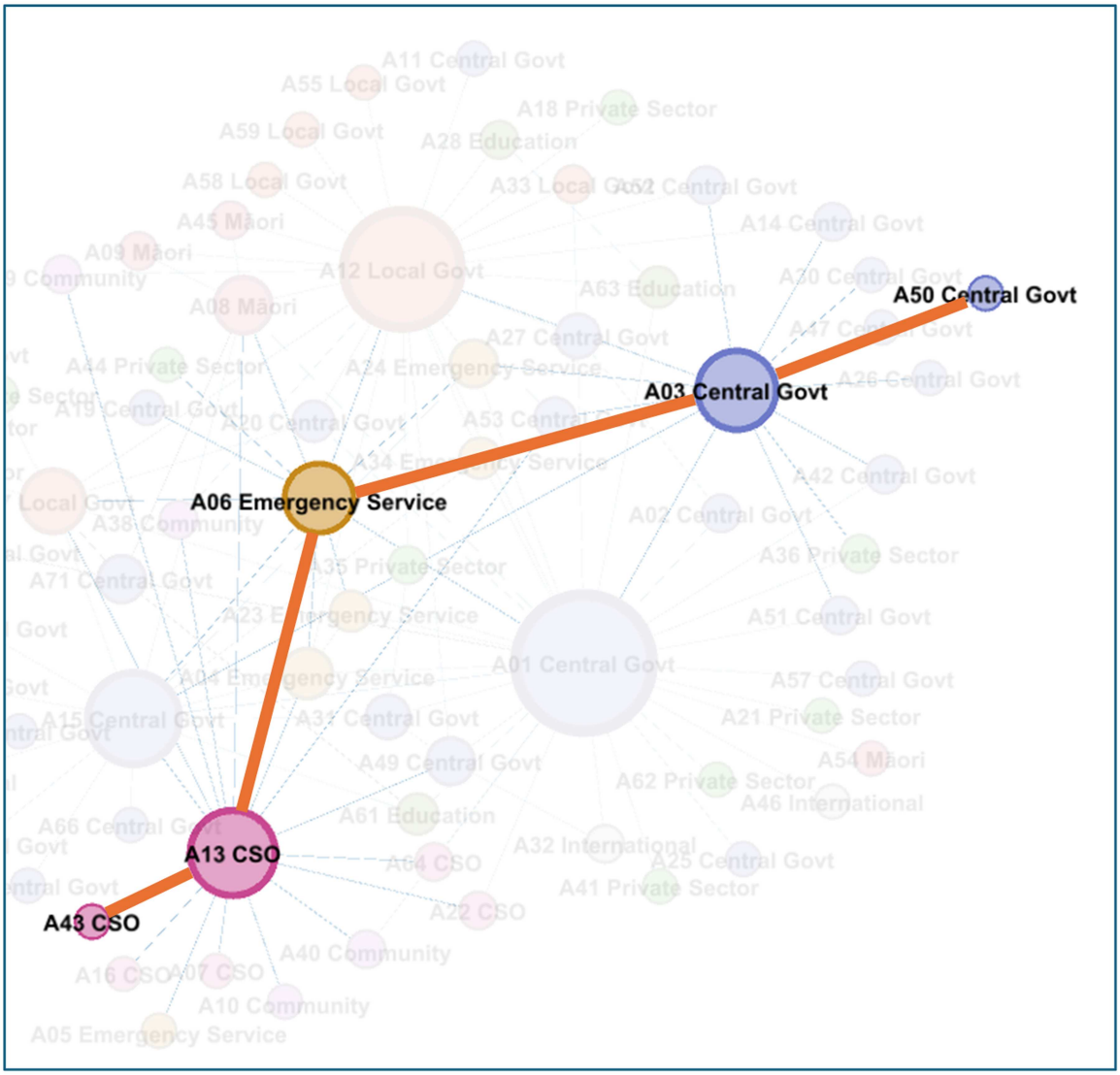

FIGURE 2 | Key brokerage positions within Aotearoa New Zealand's DEM network. Network is undirected and unweighted; ties are derived from interview-based relational mentions and visualised using Gephi (v0.10).

3.2.3 | *Adaptive Enablers*

Participants also identified innovation, leadership support for experimentation, and partnerships beyond the statutory core as key enablers of adaptability within the DEM network. These factors expanded the system's capacity by introducing new resources, perspectives, and practices that could be diffused across existing ties.

Participants described "workarounds" that became institutionalised once they proved more effective than established approaches. Leadership played a decisive role in shaping these dynamics: when leaders signalled openness to experimentation, staff felt authorised to test new solutions. As one participant explained:

> *If the boss is open to trying something new, it sends a message... that we're allowed to push boundaries to get a better result.*
>
> P21

Such openness fostered adaptive capacity by ensuring that novel practices could spread through the network rather than remain isolated. For instance, one CDEM leader described developing an in-house solution to long-standing welfare needs assessment challenges. Through cross-agency collaboration, creative funding approaches, and supportive leadership, the initiative illustrated how local innovation can overcome systemic barriers.

Partnerships with private-sector and external organisations were also described as vital to strengthening the system. These ties extended the network beyond its statutory core, adding specialised expertise, logistics capacity, and operational flexibility. Pre-existing agreements with transport and utilities companies, for instance, ensured that critical services could be mobilised quickly under stress, reducing dependence on ad hoc arrangements. As one participant reflected:

> *We've been collaborating with utilities on infrastructure resilience... now, when something happens,*

we already know who to talk to and how to work together.

P14

Such ties increased redundancy in the network, creating alternative pathways for resources and information to flow when demand was high. These adaptive enablers allowed the DEM system to evolve in response to shifting pressures. By supporting innovation and extending partnerships beyond traditional boundaries, they strengthened both the reach and the flexibility of the network. This adaptability ensured that the system was not locked into rigid patterns but could reorganise itself to meet emergent challenges.

Considered as a whole, these relational, process, and adaptive enablers strengthened the DEM system not by altering its formal architecture but by enhancing and diversifying the ties that held it together. Trust, cultural partnerships, and collaboration reinforced connectivity across clusters; shared learning and readiness activities created reliable pathways for mobilisation; and innovation and external partnerships expanded the network's reach and flexibility. In combination, these enablers increased density, redundancy, and adaptability, giving the system resilience that was often absent from formal plans. Yet participants also stressed that such enablers were fragile – dependent on sustained investment in relationships, leadership support, and political will. Their presence demonstrated how systemic performance emerged from the quality of connections, setting the stage for understanding the constraints that weakened them.

Just as differing definitions of the system revealed a tension between flexibility and cohesion, the presence of enablers was counterbalanced by persistent constraints that fragmented relationships, narrowed participation, and weakened the network's adaptive capacity.

3.3 | Network Barriers and Systemic Frictions

While participants identified numerous factors that enabled collaboration, they also described persistent constraints that undermined the DEM system's performance. These barriers arose from structural silos, leadership and resource gaps, and cultural or psychosocial frictions that weakened relationships and reduced inclusivity. Network analysis reinforced these accounts, showing how uneven connectivity and reliance on a limited number of brokers left the system vulnerable to fragmentation. Viewed through a systems lens, these constraints appear consistent with vulnerabilities associated with this

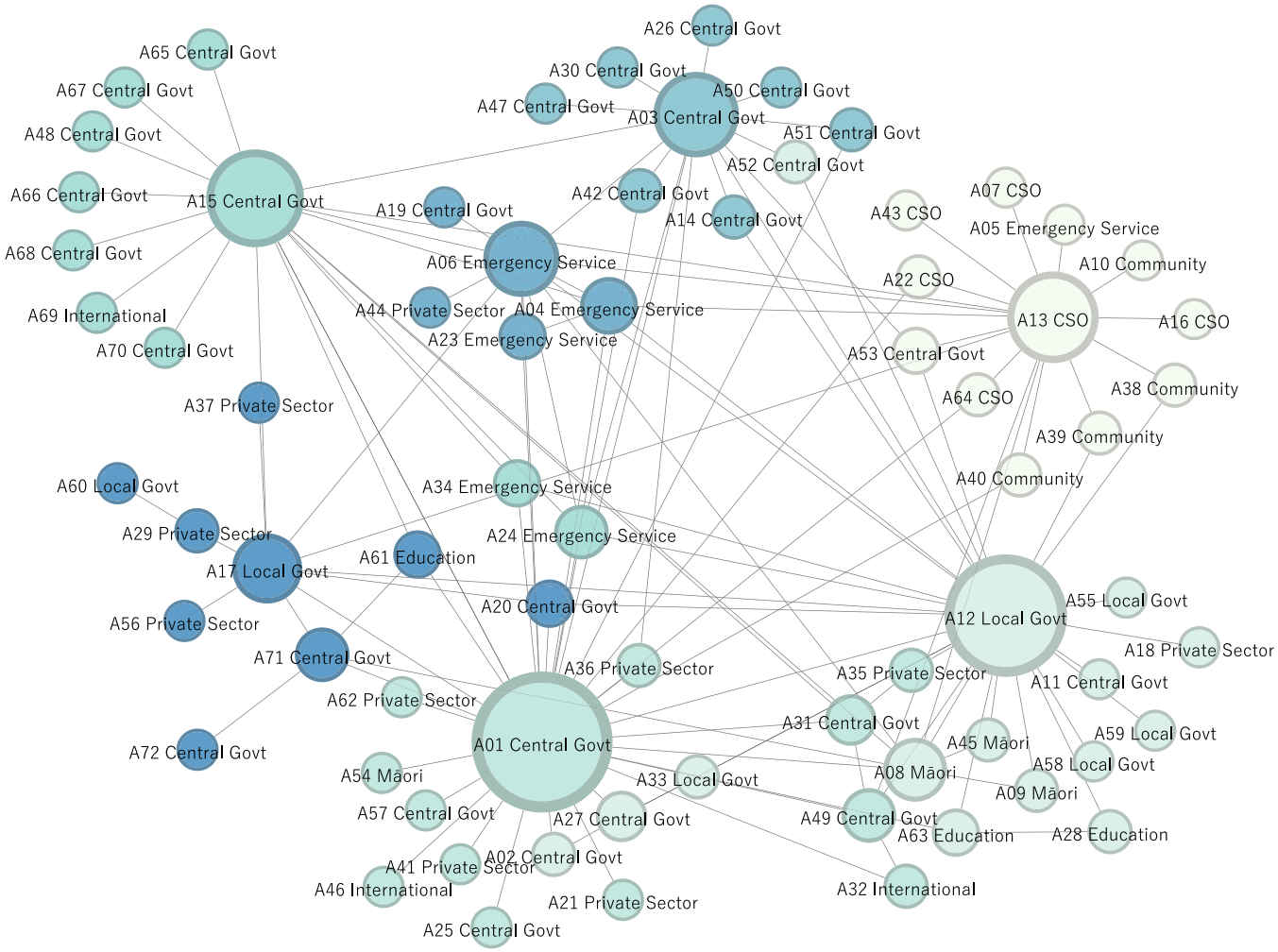

FIGURE 3 | Modularity-based clusters within the Aotearoa New Zealand DEM network. Network is undirected and unweighted; ties are derived from interview-based relational mentions and visualised using Gephi (v0.10).

network configuration, limiting its capacity to act collectively and adapt under pressure.

3.3.1 | *Structural and Engagement Constraints*

Structural features of the network created persistent barriers to collaboration. Figure 3 illustrates how the DEM system was organised into a series of dense sub-groups, each containing tightly interconnected organisations. While these clusters reflected cohesion within domains, connections across them were comparatively sparse, leaving the wider system reliant on a limited number of bridging actors to sustain coordination. This structural pattern mirrored participant accounts of siloed practice, where collaboration within clusters was effective but cross-cluster engagement was fragile and often dependent on specific individuals.

Engagement challenges were a recurring theme. Several participants noted that organisational commitment to interagency coordination tended to fluctuate depending on the recency of events, with some regions deprioritising engagement in the absence of recent crises. This reactive rather than sustained engagement undermined the stability of ties across the network, weakening the system's capacity to mobilise collectively. Political and organisational dynamics could also undermine collaboration. Several ($n = 6$) participants noted that the prevailing political climate sometimes discouraged deeper engagement with iwi or community groups, leading some agencies to approach partnership as a procedural formality rather than a genuine collaboration:

> *The current political environment gives support, so you don't have to deal with Māori if you don't want to... but some are taking it further, saying, 'Well, no, we're going to do it.'*
>
> P22

Internal focus further compounded these issues. Participants observed that staff with limited exposure to the wider DEM environment often assumed others operated in the same way, leading to mismatched expectations and missed opportunities for integration. Inconsistent terminology within the CDEM sector reinforced these silos, making it harder to communicate across organisations and to align perspectives during planning or response.

Representation gaps also weakened inclusivity and legitimacy within decision-making. In some regions, iwi participation remained limited due to historical disengagement or competing commitments, leaving their perspectives absent from formal structures:

> *Some iwi are well connected into CDEM, but others just don't have the capacity right now... and that means their voice is missing.*
>
> P05

Participants also noted that entire sectors were at times absent from coordination forums, reducing diversity of perspective and leaving critical capabilities outside the decision-making process – for example, private-sector logistics providers and community-based organisations whose networks were essential for welfare delivery.

3.3.2 | *Leadership and Capability/Resource Constraints*

Leadership capability and workforce capacity were repeatedly identified as critical to the coherence of the DEM network. Where leadership was absent, inconsistent, or overly directive, connections across the system weakened, leaving collaboration reliant on individual effort rather than institutionalised practice. Participants described how gaps in leadership created bottlenecks for decision-making and undermined the flow of information through the network. Leadership styles also shaped the quality of ties. Approaches influenced by police or military traditions were described as overly hierarchical, limiting dialogue and discouraging the horizontal relationships that underpin effective interorganisational networks. As one participant reflected:

> *It can get very top-down, especially when [A24] take the lead... it becomes about following orders instead of actually talking through options together.*
>
> P01

A further barrier was the limited diversity of professional experience among leaders, which constrained their ability to adapt to unfamiliar or complex challenges. Participants noted that those who had worked across multiple sectors tended to bring more options and broader perspectives to collaborative problem-solving. Without this, leadership remained narrow in scope and less able to foster cross-system integration.

Resource and operational constraints reinforced these leadership gaps. Smaller councils and rural agencies often operated with very limited staff, leaving individuals to cover multiple roles. Even in larger organisations, competing day-to-day demands limited the ability to allocate staff or equipment for readiness activities. As one participant put it:

> *The urgent wins over the important.*
>
> P31

These pressures reduced the system's capacity to sustain long-term collaboration and readiness, leaving networks vulnerable to fatigue and overstretch during extended events.

3.3.3 | *Cultural and Psychosocial Constraints*

Cultural and psychosocial dynamics shaped how relationships formed and endured across the DEM network. Participants described how differences in decision-making styles, organisational cultures, and individual wellbeing affected the ability of actors to collaborate and sustain trust.

Cultural approaches to leadership and communication sometimes clashed with more hierarchical or time-pressured practices. For iwi partners, tikanga[3] emphasised deliberation and consensus, ensuring that commitments are embedded in relationships rather than rushed through procedure. As one participant explained:

> *Our tikanga means we take the time to discuss and agree... that can feel slow to others, but it's how we build commitment.*
>
> P05

Such differences occasionally frustrated other organisations, but when respected, they deepened engagement and reinforced legitimacy by anchoring decisions in shared values.

Psychosocial pressures were also seen as a limiting factor. Fatigue, workload, and the emotional demands of response work could erode collaboration by reducing patience and narrowing communication. As one participant noted:

> *When people are tired or stressed, they can get defensive or stop listening... that's when relationships suffer.*
>
> P03

These pressures strained interpersonal ties and made the network more brittle, particularly during prolonged events when reserves of goodwill were exhausted.

These constraints reveal how systemic frictions limited the DEM network's capacity to function as a cohesive whole. Structural silos and representation gaps fragmented the network, leadership and resource shortages created points of dependency, and cultural or psychosocial pressures weakened the quality of ties under stress. Rather than isolated failings, these barriers were embedded in the configuration of the network itself, reducing density, narrowing participation, and eroding trust. Their persistence underscores that systemic resilience cannot be achieved through structural design alone; it requires sustained investment in relationships, capability, and cultural competence to prevent the network from fracturing when demands intensify.

4 | Discussion

This discussion interprets the findings through the lens of complexity and network theory, positioning Aotearoa New Zealand's DEM environment as a complex adaptive system (CAS) composed of interdependent actors, relationships, and feedback processes. Rather than a fixed structure, the DEM system functions as a dynamic network whose performance emerges from the quality of its connections and the capacity of actors to adapt to changing conditions. Because these configurations are derived from participants' accounts of operationally meaningful relationships, the network reflects experienced connectivity at the time of data collection rather than a complete institutional mapping; interpretations should therefore be understood within this constructivist frame.

4.1 | What Is the System

This study shows that Aotearoa New Zealand's DEM is an adaptive, multi-actor network. Participants expressed contrasting views of the system: some saw it as encompassing "everyone in the country," while others limited it to the formal CDEM sector. These differing perspectives reveal ongoing tensions around inclusion and coherence. Similar ambiguities are evident internationally. In the USA, the Federal Emergency Management Agency's *Whole-of-Community* approach likewise blurs boundaries between government, civil society, and private actors (Mix et al. 2024), while in the United Kingdom the Local Resilience Forum structure institutionalises multi-agency participation but often excludes community and business networks (Fagan-Watson and Burchell 2016). Aotearoa's devolved model sits between these extremes - formally decentralised but reliant on informal relationships to maintain connectivity.

This fluidity of boundaries reflects a defining feature of complex adaptive systems, where membership and influence shift as conditions change. Boundaries are not fixed but negotiated zones of interaction, continually redrawn through engagement, trust, and power dynamics (Vangen and Huxham 2005). For instance, several participants described how iwi and community organisations were sometimes included as equal partners in planning, yet at other times only "invited in" once a response was underway - illustrating how participation depends as much on relational trust and local leadership as on formal mandate. From a practical standpoint, this boundary work constitutes both the system's adaptive mechanism and its vulnerability. On one hand, permeability allows rapid mobilisation of non-traditional actors – such as iwi networks, schools, CSOs, or local businesses – during crises, echoing examples from Japan's community-based disaster response (Okada et al. 2013) or the Philippines' barangay networks (Bankoff 2007; Nacaya et al. 2023). On the other hand, ambiguity over who is "in" or "out" can diffuse accountability and fragment coordination, particularly when actors operate under differing assumptions of authority or mandate.

Defining the DEM system as "everyone" raises questions about responsibility, legitimacy, and resourcefulness. A broad conception encourages inclusivity and recognises the distributed nature of resilience, yet it risks creating an expectation gap between community autonomy and government accountability. Conversely, a narrow, sector-based view provides clarity but can marginalise key partners whose legitimacy stems from social, cultural, or economic influence rather than statutory authority. For example, iwi and Māori organisations occupy both positions – embedded within communities yet often peripheral to formal structures – illustrating how systemic legitimacy in Aotearoa is simultaneously institutional and relational. This duality reflects the system's adaptive boundaries, which change in response to political and relational dynamics and shape who is able to participate in coordination at any given time.

Understanding the DEM system as a networked CAS thus reframes boundary ambiguity not as failure but as an emergent property of a living system. Boundaries flex and re-form in response to changing hazards, politics, and relationships, shaping who participates and how coordination occurs. Managing these adaptive boundaries – through inclusive governance, shared situational awareness, and respect for Treaty partnerships – is therefore central to strengthening the system's coherence and legitimacy.

4.2 | Network Enablers

The enablers identified in this study highlight how coordination and adaptability within the system emerge from relational architecture rather than its formal hierarchy. Whereas the

statutory framework provides necessary structure, effective performance depends on the density, quality, and reciprocity of ties among diverse actors. This reinforces arguments from international research that governance in complex disaster systems is sustained through relational capacity – the ability of networks to align, learn, and adapt under uncertainty (Nowell et al. 2018; Kapucu et al. 2023).

Trust was consistently presented as the medium through which information, authority, and legitimacy flowed across the network, operating as a form of social capital that enabled coordination under conditions of uncertainty. Internationally, similar dynamics have been observed where pre-existing trust relationships shape coordination quality more strongly than formal structural design (Aldrich 2012; Kapucu 2006; Curnin and Owen 2014). In Aotearoa New Zealand, this mechanism was closely associated with Māori partnerships, where whakawhanaungatanga[4] functioned as a relational process through which legitimacy and authority were established (Moyle et al. 2025). Rather than operating through formal mandate, Māori engagement strengthened coordination by embedding trust within ongoing relationships, enabling information flow and collective action across institutional and community boundaries. Structurally, this dynamic was reflected in the network through Māori organisations occupying peripheral yet strategically significant positions, with connectivity mediated through a limited number of high-trust brokerage ties (Figure 2 – Section 3.2.1). Where such ties were present, relational trust translated into functional connectivity; where they were weak or absent, coordination became fragmented. This pattern demonstrates that Māori partnerships operate as a system-level enabler that materially shapes network performance.

Learning and knowledge exchange operate as feedback mechanisms within the network. Repeated interaction – through joint exercises, shared planning, or informal collaboration – produces collective memory and anticipatory capacity. This aligns with Comfort's (COMFORT et al. 1999) notion of shared cognition, where iterative experience allows a system to self-correct. Internationally, similar processes underpin adaptive emergency governance in the Netherlands (Van Buuren et al. 2015) and South Korea (Kim 2017), demonstrating that relational learning, rather than structural reform, sustains long-term improvement. In this study, these feedback loops often occurred through recurring partnerships and secondments between local councils, government agencies, and emergency services. Such relational learning widened mutual understanding of roles and constraints, enhancing interagency relationships and improving preparedness.

Innovation appeared as both an outcome and a driver of network adaptability. Participants described "workarounds" that became embedded when they out-performed official procedures – an example of emergent adaptation common to complex systems (Preiser et al. 2018). Leadership that legitimised experimentation fostered safe-to-fail environments where novel practices diffused across the network. Comparable dynamics have been documented in Australia's shared-responsibility approach (McLennan et al. 2019), the U.K.'s voluntary sector collaborations (Owen and Currie 2022), the U.S.'s Wildfire and emergency governance (Weichselgartner and Kelman 2015), and Scandinavia's civil contingencies agency's adaptive governance exercising (Nilsson et al. 2010; De Winter et al. 2009). In Aotearoa, innovation was frequently relational: iwi and private partners co-developed logistics solutions during Cyclone Gabrielle, illustrating how cross-sector collaboration can generate new operational norms. These examples show that creativity arises not from top-down directives but from boundary-spanning relationships that link diverse knowledge domains.

International literature has long emphasised collaboration, trust, and learning as cornerstones of effective disaster governance (Kapucu and Garayev 2011; Nohrstedt et al. 2018; McNaught 2024). What this study adds is empirical evidence of how these relational mechanisms are structured and enacted within a national system, combining grounded narratives with social-network analysis. The SNA visualisations make tangible the otherwise invisible architecture of trust, brokerage, and redundancy that sustains coordination. Moreover, by situating these relationships within a Treaty-based context, the study demonstrates that cultural legitimacy and adaptive capacity are intertwined: the system's strength lies in its ability to integrate institutional, community, and iwi networks into a single, if uneven, adaptive whole.

4.3 | Network Barriers

While the previous section illustrated how relational enablers generate adaptive capacity, this section examines the counterposing forces that constrain it. From a complexity perspective, these barriers act as negative feedback loops that stabilise the system but also limit its evolution. They manifest through structural silos, leadership and resource dependencies, and cultural or psychosocial frictions that collectively erode connectivity and trust. Understanding these frictions as systemic – rather than isolated organisational weaknesses – helps explain why similar issues persist across events and reforms.

Network analysis indicated that the DEM system comprises multiple dense clusters connected by only a handful of bridging

TABLE 3 | Structural sensitivity to sequential broker removal.

Condition	Nodes	Density	Connected components	Modularity
Original	73	0.050	(baseline)	0.379
– A01 removed	72	0.039	8	0.460
– A12 removed	71	0.029	15	0.567
– A15 removed	70	0.023	23	0.620
– A13 removed	69	0.016	34	0.667

actors. Such modular fragmentation is common in DEM networks internationally (Comfort et al. 2010; Kapucu and Hu 2016). In this study, strong cohesion within sectors – such as emergency services, local councils, or central government – was offset by limited cross-cluster ties. This structural pattern mirrors what Moynihan (Moynihan 2009) calls collaborative inertia: coordination relies on interpersonal goodwill rather than institutionalised connection. Sequential removal of high-betweenness actors (A01, A12, A15, A13) revealed progressive fragmentation (Table 3), with density declining from 0.050 to 0.016, connected components increasing to 34 discrete sub-networks, and modularity rising from 0.379 to 0.667. These shifts indicate low redundancy and high dependency on a narrow set of brokerage positions, confirming that cross-cluster connectivity is concentrated rather than distributed across the system. Similar fragility has been observed in Australia's state-centric arrangements (Eburn 2014) and the U.K.'s Local Resilience Forums, where cross-sector coordination often collapses outside of major incidents (Owen and Currie 2022).

Leadership gaps further weakened adaptive capacity. Participants described how the absence or over centralisation of authority delayed decisions and narrowed participation. Comparable findings from the U.S. FEMA system show that hierarchical command cultures can suppress local initiative and slow collective sense-making (Kapucu and Hu 2022). In New Zealand, limited cross-sector exposure and high staff turnover compounded this problem, producing what Comfort and Resodihardjo (Comfort and Resodihardjo 2013) term *adaptive drift* – a gradual loss of institutional memory and learning. Resource scarcity reinforced these leadership pressures. Smaller councils and community organisations operated with minimal staff and short-term funding, reducing redundancy and deepening dependence on a few over-extended actors. This pattern reflects what Kharrazi, Yu (Kharrazi et al. 2020) describe as low system resilience arising from insufficient diversity and limited substitution capacity.

Cultural dynamics added an additional layer of complexity. Differences in leadership styles, decision-making tempo and communication norms between iwi partners and government agencies often created tension (Mistry et al. 2026). While *tikanga* emphasises consensus and relationship-building, Government agencies frequently operate under time-compressed, command-oriented expectations. When these logics clash, coordination slows, and trust can erode. Comparable cross-cultural frictions have been documented in Indigenous disaster management partnerships internationally – including in Canada (Kaiser et al. 2022) and Australia (Spurway 2018) – as well as in Aotearoa New Zealand, where similar tensions were observed during iwi-agency coordination in Cyclone Gabrielle (Moyle et al. 2025). Psychosocial stressors – including fatigue, workload, and the emotional demands of DEM work – further eroded relational quality. As Hu, Knox (Hu et al. 2014) and da Gama Batista, Bouchaud (da Gama Batista et al. 2015) discuss, the social fabric of response networks is vulnerable to exhaustion; when trust is depleted, cooperation gives way to defensiveness. These findings underline that emotional and cultural competence are not ancillary skills but core capacities for maintaining network integrity under pressure.

Together, these network barriers reveal that resilience cannot be legislated; it must be cultivated through connectivity, diversity, and trust. Without deliberate efforts to broaden participation and reduce dependency on a narrow set of actors, the DEM network risks reproducing the very silos it seeks to transcend.

4.4 | Limitations

Several limitations should be considered when interpreting the findings of this study. The network analysis resulted from accounts of working or meaningful relationships that were identified by participants, rather than a complete mapping of all prescribed associations. As a result, some latent connections may be under-represented. In addition, the relational structures identified are shaped by timing and context, as the network adapts across phases of the disaster lifecycle and in response to hazard-specific demands.

A further limitation concerns representation. While the study sought to include a broad range of organisational perspectives, participation was uneven across actor types, as some organisations chose not to participate. As a result, certain relationships and coordination pathways may not be fully captured in the network. The decision to model the network as undirected and unweighted was deliberate to support clarity in mapping the system; however, this approach does not capture variation in relationship strength, directionality of influence, or uneven authority and resourcing, all which shape coordination outcomes.

Finally, the study is situated within the institutional, cultural, and Treaty-based context of Aotearoa New Zealand; while the relational mechanisms identified resonate with international disaster governance literature, their configuration reflects local governance arrangements and Indigenous partnership obligations, requiring caution when transferring insights to other jurisdictions.

5 | Conclusion

This study examined Aotearoa New Zealand's DEM system and demonstrated that system performance emerges from the configuration and quality of relationships, with coordination shaped by fluid boundaries, relational enablers, and persistent systemic frictions.

Key Contributions of This Study Are

- The study demonstrates the value of understanding DEM as a complex adaptive system in which coordination and legitimacy emerge through relational architecture, rather than formal hierarchy alone. Fluid boundaries, information flow, and brokerage appear as defining features of system behaviour.
- By applying CNGT, this research integrates interpretive meaning-making with social network analysis, enabling simultaneous examination of how actors experience coordination and how relational structures underpinning systemic performance. This approach provides a robust pathway for studying complex, networked environments.

- Practically, the finding highlights the importance of shifting from controlling the system to stewarding its conditions. Strengthening performance requires sustained investment in relational capacity, trust, learning, and culturally legitimate partnerships, alongside institutionalised feedback mechanisms that support adaptation over time.

The study shows that Aotearoa New Zealand's DEM system possesses significant relational capacity but remains constrained by structural and cultural frictions that limit coherence and adaptability. Addressing these challenges requires approaches that scaffold coordination through relationships, if the system is to remain effective in an increasingly uncertain and interdependent risk environment.

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Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

Endnotes

[1]Iwi are Māori tribal groups, recognised as Indigenous communities and Treaty partners in Aotearoa New Zealand, with enduring governance and cultural roles.

[2]The Treaty of Waitangi (Te Tiriti o Waitangi) is Aotearoa New Zealand's founding document, signed in 1840 between representatives of the British Crown and many Māori chiefs. It establishes the principles of partnership, protection, and participation that guide Crown–Māori relationships.

[3]Tikanga refers to Māori customary values, practices, and protocols that guide appropriate behaviour and decision-making.

[4]Relationship-building.

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