

# Reassessing earthquake-induced downtime: a comparison of impeding factors between US and New Zealand

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## ABSTRACT

Post-earthquake downtime is increasingly recognised as a critical metric for assessing community resilience and is strongly influenced by impeding-factors that occur prior to repair initiation. Existing functional recovery frameworks quantify these delays, but their underlying assumptions are largely calibrated to conditions in the United States and may not adequately represent recovery processes in other regions.

This paper examines the transferability of commonly adopted impeding-factor models to the New Zealand context using the Canterbury Earthquake Sequence (CES) as a case study. A targeted synthesis of existing modelling approaches is undertaken to identify how impeding factors are defined, and updated within other frameworks. This is followed by a contextual analysis drawing on New Zealand-specific evidence, including government recovery reports, industry studies, and post-CES data, to assess differences in key impeding factors such as inspection, insurance settlement, access restrictions, and labour availability. Selected impeding factors are further illustrated using available empirical data and compared with REDi-based assumptions.

The results show that impeding-factors in New Zealand are often longer and governed by different mechanisms than those assumed in international models, reflecting differences in insurance structures, regulatory processes, workforce capacity, and recovery coordination. These findings highlight the limitations of directly transferring internationally developed assumptions without regional calibration.

The study provides a New Zealand-focused evaluation of impeding factors and demonstrates how locally informed representations can improve the realism of post-earthquake recovery assessment.

# 1 INTRODUCTION

The estimation of earthquake losses within the performance-based earthquake engineering (PBEE) framework is primarily tied to physical damage to buildings, with losses commonly quantified through repair or replacement costs derived from damage states (Moehle and Deierlein, 2004; Günay and Mosalam, 2013). However, experience from past earthquakes demonstrates that longer post-earthquake downtime can impose economic and social consequences that extend beyond the physical damage itself (Reinhorn and Cimellaro, 2014; Molina Hutt et al., 2016). For example, the 2011 Tohoku earthquake caused approximately \$319 billion in direct losses, while total costs increased to about \$619 billion when downtime was longer than expected (Kajitani et al., 2013).

Post-earthquake downtime refers to the time required for a damaged building to reach a defined recovery state through rehabilitation or reconstruction. Within functional recovery-based design frameworks developed by FEMA, downtime is interpreted as the duration needed to restore a building to its pre-earthquake level of functionality (FEMA, 2012). If the building is considered repairable, this period corresponds to the time required to complete repairs; if the building is deemed irreparable, downtime instead includes the time required for demolition and full reconstruction.

Downtime is not limited to the duration of physical repair or reconstruction. In practice, a substantial time gap frequently exists between the occurrence of damage and the start of repair activities. Comerio (2006) defines this gap as the “irrational factor” of downtime, which includes financing, relocation or temporary substitution of functions, availability of skilled workforce and contractors, regulatory and permitting processes, and broader economic uncertainty. REDI (Resilience-based Earthquake Design Initiative) developed by Arup in the United States, also formalised these pre-repair delays as impeding factors, and defined them as inspection time, engineering mobilisation, financing, contractor mobilisation, and permitting (Almufti and Willford, 2013).

Impeding factors play a critical role in governing post-earthquake downtime and, in many cases, dominate the overall recovery timeline. Previous studies have shown that delays associated with inspection, financing, and mobilisation can outweigh physical repair time, where structural damage may be limited but recovery is significantly delayed (Lessing et al., 2017; Marquis et al., 2017; Kourehpaz et al., 2025b). Impeding factors are often the primary drivers of downtime, even when damage severity is relatively low (Paul et al., 2018). Within performance-based seismic design, delays in repair initiation have been shown to contribute more to overall downtime than the repair process itself, thereby substantially increasing the time required to achieve any defined recovery state (Mayes et al., 2013). Longer pre-repair and organisational components of downtime have also been directly linked to increased business disruption and greater economic losses (FEMA, 2020).

Despite their importance, impeding factors remain challenging to quantify and incorporate into recovery modelling, as the data required to characterise pre-repair delays are often incomplete, highly uncertain, and evolve rapidly following a seismic event (Molina Hutt et al., 2016; Hulse et al., 2018; Kammouh et al., 2018; De Iuliis et al., 2021b; Hulse et al., 2022). Evidence from the Canterbury Earthquake Sequence (CES) indicates that pre-repair delays in New Zealand, driven by insurance settlement, inspection requirements, labour constraints, access restrictions, and regulatory processes, can differ substantially in both duration and governing mechanisms from those assumed in widely used framework such as FEMA P-58 (Chang-Richards et al., 2015; Deloitte, 2015; Chang-Richards and Wilkinson, 2016; Ilan et al., 2016; Sipaseuth and van Heerden, 2022). Most existing impeding factors were identified using data, expert judgment, and institutional assumptions specific to their country of origin (Almufti and Willford, 2013), or are often applied in other contexts without explicit validation or recalibration (Li et al., 2025). To address this gap, this paper examines commonly adopted impeding factors, their underlying assumptions, and their transferability across regions by comparing selected impeding factor delays derived from New Zealand

recovery data with those assumed in the US such as FEMA P-58 and REDi. Evidence from the Canterbury Earthquake Sequence (CES) is used to highlight key differences in both the duration and governing mechanisms of pre-repair delays, including insurance settlement, and inspection requirements.

## 2 SYNTHESIS OF IMPEDING FACTOR MODELLING FRAMEWORKS

Early efforts to account for the irrational component of downtime can be traced to post-earthquake safety evaluation procedures such as ATC-20 (ATC, 2005). The ATC-20 methodology classifies buildings based on observed damage and assigns safety tags (green, yellow, or red), which implicitly govern access restrictions and mobilization timelines. Although not originally developed as a recovery model, ATC-20 provides a damage-state-based mechanism that influences total mobilization time by controlling when buildings can be reoccupied or repaired, thereby linking damage assessment to downtime outcomes. Building on ATC-20, Mitrani-Reiser applied this tagging framework to office buildings in the United States, focusing on post-earthquake recovery following the Northridge earthquake (Mitrani-Reiser, 2007). In this work, total mobilization times were proposed for green-, yellow-, and red-tagged buildings, with downtime due to irrational factors treated as a function of damage state alone. These delays were assumed to be unique and deterministic for each tag category, without explicitly accounting for variability arising from institutional, economic, or regional conditions.

Building on the conceptual distinction introduced by Comerio, REDi advanced this approach by formalizing and redefining these delays within a functional recovery framework (Almufti and Willford, 2013). REDi introduced the term impeding factors to describe the processes that impede the initiation of repair activities, based on data obtained from interviews with contractors and engineers involved in post-earthquake recovery following several earthquake and natural disasters in US and expanded the scope of these factors beyond earlier damage-state-based formulations. In REDi, impeding factors are represented probabilistically using lognormal cumulative distribution functions, commonly referred to as impeding curves, to capture the inherent uncertainty associated with pre-repair delays. Paul et al. (2018) later updated elements of REDi, particularly contractor mobilization time, by incorporating empirical evidence and expert judgments, highlighting limitations in transferring US-based assumptions to other contexts. These updates were subsequently incorporated into tools for recovery estimation and downtime simulation (TREADS), developed in UBC in Vancouver, Canada (Molina Hutt et al., 2022). A study by Cook and colleagues then proposed a comprehensive framework to operationalize post-earthquake functional recovery by integrating impeding factors within the FEMA P-58 architecture, which also forms the basis of ATC-138 project funded by FEMA (ATC, 2021; Cook et al., 2022). Building on REDi, this framework retains the conceptual structure of pre-repair delays while updating key assumptions due to upgrade in construction practice, technology, and empirical understanding gained since earlier events such as the Northridge earthquake, while still largely grounded in U.S. data and institutional settings.

Other studies have also sought to improve the treatment of impeding factors by explicitly addressing uncertainty and variability in pre-repair delays. De Iuliis et al. (2019) decomposed total downtime into a rational component (DT1) and an irrational component (DT2) and employed fuzzy logic to account for uncertainty and vagueness in recovery-related data and expert judgment for calculating DT2. In later studies, they further combined fuzzy logic and Bayesian networks to model uncertainty in impeding factors and estimate restoration times for infrastructure systems, including pipelines, power, and telecommunications (De Iuliis et al., 2021a; De Iuliis et al., 2021b). Kourehpaz et al. (2025b) demonstrated that post-earthquake recovery outcomes are strongly controlled by analyst-selected impeding factor and repair-time parameters, showing that epistemic uncertainty in recovery modelling can rival or exceed uncertainty arising from physical damage; to address this, impeding factor curves were incorporated within Monte Carlo simulations to better propagate uncertainty. Recently, Li and her colleagues used empirical data from the Earthquake

Commission (EQC) on residential buildings damaged during the Christchurch earthquake sequence and applied Bayesian networks and Markov Chain Monte Carlo methods to manage data uncertainty, providing probabilistic distributions for individual impeding factors specific to residential buildings in the Christchurch context (Li et al., 2025).

### **3 COMPARATIVE ANALYSIS OF KEY IMPEDING FACTORS IN NEW ZEALAND AND THE UNITED STATES**

The section below draws on New Zealand-specific evidence, including NZ-focused studies, NZSEE publications since 2011, and selected recovery and insurance-sector documentation, to examine whether current IFs assumptions are transferable to the CES context. Section 3.1 focuses on the regional dependence of IFs by highlighting how construction capacity, labour availability, and access constraints can alter mobilisation processes and delay initiation of repairs. Section 3.2 then examines system-level differences in governing mechanisms to show how institutional settings and regulatory requirements can lead to materially different delay distributions than those embedded in commonly used international models. At the end, section 3.3 presents illustrative New Zealand-specific impeding factor representations for selected processes, using available post-CES data to demonstrate the implications of adopting locally informed assumptions in recovery modelling.

#### **3.1 Regional dependence of impeding factor models**

Current impeding factor models are strongly shaped by the institutional, economic, and construction-industry contexts in which they were developed, with most frameworks relying on empirical data, post-event surveys, and expert judgment from their country of origin. For example, REDi is largely based on recovery data and interviews from different earthquakes and natural hazards such as the 1994 Northridge earthquake, and TREADS and its subsequent applications draw on recovery simulations and empirical evidence from the United States and Canada. Developers of these models acknowledge that transferring impeding factor models to other regions without explicit recalibration or error assessment introduces uncertainty in their ability to represent post-event recovery accurately; consequently, these models should be updated as region-specific information becomes available (Almufti and Willford, 2013; Cook et al., 2022; Molina Hutt et al., 2022; Li et al., 2025; Kourehpaz et al., 2025a).

Another important aspect that requires explicit consideration is labour availability. Labour and human resource have been consistently identified as critical bottlenecks in NZ construction industry (Rotimi et al., 2019). Studies of CES show that shortages of skilled personnel including engineers, project managers, and specialist contractors, significantly constrained recovery capacity and prolonged mobilisation phases, affecting not only physical repair but also mobilisation time (Chang-Richards et al., 2017; Chang-Richards, 2019). In the New Zealand context, recent post-earthquake recovery studies demonstrate that workforce shortages interact with other recovery processes, such as inspection backlogs, redesign requirements, and contractor scheduling, creating feedback loops that amplify delays over time rather than acting as isolated constraints.

Evidence from CES further indicates that several important sources of delay are inadequately captured in current impeding factor frameworks when applied in the NZ context. Interviews with contractors in New Zealand identify access restriction as dominant role in delaying repair initiation in Christchurch (Lessing et al., 2017; Zhan et al., 2023) while most existing frameworks treat buildings as isolated units. In some cases, access restrictions to buildings delayed damage assessment and the initiation of repair works by up to 4 weeks in Christchurch CBD (Marquis, 2015). Also, in general, delays associated with reliance on imported construction materials, as well as delays in producing design documentation have been mentioned quite often in these interviews while these constraints are less prominently emphasized in current delay studies, where

permitting, inspections, and design approval processes are more frequently identified as the dominant contributors (Ahmed et al., 2003). Such contrasts suggest that impeding factor definitions and their relative importance differ substantially between regions and cannot be assumed to be universal. Moreover, impeding factor durations are sensitive to regional surges in material demand following major earthquakes, indicating that IFs are context-dependent processes rather than fixed parameters; an issue that is particularly relevant for New Zealand, where construction capacity were significantly constrained following CES (Chang-Richards et al., 2017; Zhan et al., 2023).

### 3.2 Fundamental system-level differences in Impeding factors

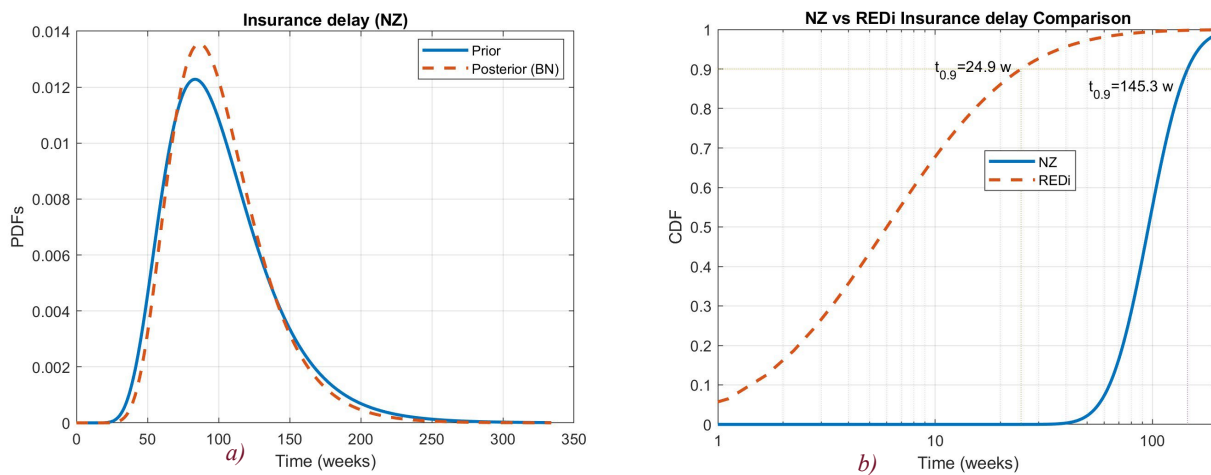
Beyond the regional differences in recovery drivers discussed above, IFs also differ fundamentally in their underlying nature and governing mechanisms, further limiting the direct transferability of existing frameworks to the New Zealand context. One key IF is financing delays that are modeled using the Performance Assessment Calculation Tool (PACT) of the FEMA P-58, which is grounded in US-based documentation of post-disaster financing mechanisms. These assumptions reflect financing pathways commonly observed in the United States, where insurance coverage following natural disasters has been reported to be as low as approximately 13%, and recovery often relies on combinations of private or public loans and insurance-based mechanisms derived from historical events (FEMA, 2012; Almufti and Willford, 2013). Following CES, however, New Zealand's recovery was characterized by a substantially higher penetration of natural hazard insurance, with nearly 80% of affected buildings insured, supported by a differentiated claims and funding structure in which residential recovery was managed through the Natural Hazards Commission (NHC, formerly EQC), horizontal infrastructure through the Stronger Christchurch Infrastructure Rebuild Team (SCIRT), and commercial buildings within the central business district were coordinated by the Christchurch Central Development Unit (CCDU) and insured by private insurers (Chang-Richards and Wilkinson, 2016; Marquis et al., 2017).

Another example of this difference is inspection-related delays in recovery timelines in New Zealand. Level 1 and Level 2 rapid building assessments were intended to provide an immediate evaluation of building safety and occupancy following an earthquake by assigning placards (green, yellow, or red), in accordance with the NZSEE post-earthquake building assessment guidelines (NZSEE, 2009). These assessments are designed to support rapid decision-making regarding building access and use in the immediate aftermath of an event. For buildings assigned yellow or red placards, a more detailed engineering evaluation (DEE) is subsequently undertaken to provide a comprehensive assessment of both structural and non-structural performance. Detailed engineering evaluations are required to establish the extent of damage and to assess compliance with seismic performance requirements, including the calculation of New Building Standard (%NBS) where applicable. Under current MBIE guidance for earthquake-prone buildings affected commercial buildings may be required to demonstrate seismic performance of at least 67% NBS prior to repair or reoccupation (MBIE, 2025). Reports documenting post-earthquake recovery following the CES indicate that the duration, sequencing, and decision-making associated with these detailed evaluations differ substantially from the assumptions embedded in current recovery frameworks, particularly color-tagging procedure defined in the FEMA P-58 methodology.

### 3.3 Implications of Impeding Factors for earthquake recovery

This section provides a limited, data-informed illustration of how selected impeding factors may be characterised using New Zealand recovery data and compared with assumptions adopted in international functional recovery frameworks. To present the results, lognormal probability and cumulative distribution functions (PDFs & CDFs), similar to REDi, were used. Bayesian Network (BN) framework is also adopted, enabling prior data to be updated using New Zealand-specific evidence, thereby yielding posterior distributions that better reflect observed recovery behaviour. As an illustrative example of an impeding

factor, insurance-related delay is examined using insurance settlement timeline data for commercial buildings that were formally tagged as repairable by CERA. These data were compiled from available published sources, reports from the Reserve Bank of New Zealand, and ICNZ online information, (Deloitte, 2015; ICNZ, 2015; Marquis, 2015; Ilan et al., 2016; Poontirakul et al., 2017) and were analyzed to form the IFs specific to commercial building and presented in Figure 2. Published data include six commercial buildings with explicitly reported insurance claim initiation and settlement dates, alongside aggregated insurance and media reporting used to contextualize and support the estimation of settlement timelines, cited above. For comparison, the REDi impeding curves shown in Figure 2b and Figure 3b are taken directly from the official published outputs of the Resilience-based Earthquake Design Initiative, developed by Arup and collaborators, and represent the delay assumptions adopted within that framework (Almufti and Willford, 2013).



*Figure 1 : Insurance settlement delay. (a) prior and posterior Probability Distribution functions (PDFs) for New Zealand; (b) comparison of New Zealand-specific insurance delay CDF with the REDi impeding curve.*

According to Figure 2a, there is approximately a 90% probability that insurance settlement occurs within about 150 weeks (about 3 years). For comparison, the impeding curve adopted in the REDi framework in Figure 2b suggests substantially shorter insurance-related delays, with a reported 90th-percentile value of approximately 25 weeks. This difference reflects contrasting recovery financing structures, as insurance represented the primary source of repair funding for many commercial buildings in Christchurch, whereas in the United States a smaller proportion of buildings rely on insurance coverage, with recovery more commonly supported through combinations of public and private loans. The figures therefore illustrate a clear divergence between insurance settlement behaviour observed in New Zealand and in internationally adopted recovery frameworks. In TREADS, insurance-related impeding curves are weighted using financing coefficients derived from U.S. data, assuming approximately 16% of realizations are funded through earthquake insurance, 12% through public loans, and the remaining 72% through private loans, based on census and state-level insurance coverage statistics.

Inspection-related delay data following CES were compiled for three assessment stages: Level 1 and Level 2 rapid building assessments, detailed engineering evaluations (DEE), and the corresponding inspection delay assumptions adopted in the REDi framework. For New Zealand, Level 2 and DEE inspection timelines were obtained from published post-earthquake assessments and building-specific reports (Galloway and Hare, 2012; Marquis, 2015). These data were used to construct probability density and cumulative distribution functions representing inspection-related delays across different stages of post-earthquake assessment. Figure 3a presents the prior and Bayesian-updated distributions for Level 2 rapid inspection in New Zealand, illustrating the uncertainty associated with inspection timelines. Figure 3b compares cumulative distribution

functions for inspection-related delays, showing that Level 2 rapid assessments in New Zealand progress more slowly than REDi inspection assumptions for non-essential facilities, while DEE exhibits substantially longer delays, and reflects that the increased analytical and regulatory requirements associated with detailed performance evaluation. Together, the figure illustrates clear differences in both the magnitude and distribution of inspection-related delays between New Zealand practice and internationally adopted recovery frameworks.

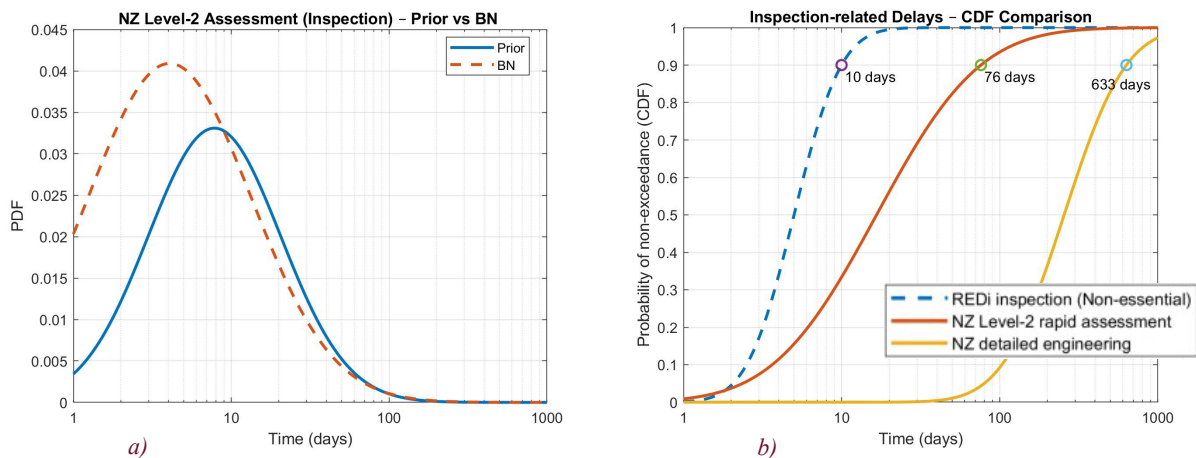


Figure 2 : Inspection delay comparison, NZ vs REDi. a) Level 2 inspection delay in NZ, b) Comparison of L-2, DEE, and REDi inspection and assessment

#### 4 FUTURE DIRECTIONS FOR IMPEDING FACTOR FRAMEWORKS

While existing impeding factor models are largely calibrated using post-earthquake observations, evidence from the New Zealand context demonstrates that systemic labour constraints can significantly influence mobilisation and pre-repair delays due to impact on inspectors, engineers, and contractors. This indicates that workforce capacity should be treated as an explicit and dynamic driver of impeding factors, rather than an implicit background condition, and should be incorporated into future recovery frameworks.

Additional sources of delay observed in the New Zealand recovery context also warrant explicit consideration. In particular, access-related delays require more detailed representation, as recovery literature shows that restricted access to damaged buildings often arises from multiple interrelated conditions, including the presence of hazardous materials, instability of adjacent structures, and the imposition of safety cordons. These constraints can delay repair initiation independently of building damage state.

Uncertainty representation and data availability remain central challenges for advancing impeding factor models. As highlighted in recent recovery modelling studies, uncertainty can be better managed by incorporating larger and more diverse datasets and by adopting probabilistic updating techniques as additional recovery data become available (Kourehpaz et al., 2025a; Kourehpaz et al., 2025b).

In the New Zealand context, several impeding factors, such as contractor mobilisation, and decision-making delays, are widely recognised in practice but remain poorly quantified due to limited empirical data. Addressing these gaps will require systematic data collection efforts and collaboration with industry and recovery agencies.

Future frameworks should move toward generating building-specific impeding factors, rather than relying on aggregate distributions derived largely from commercial building recovery data, as is common in REDi. Differences observed between residential and commercial financing timelines following CES suggest that impeding factors can vary substantially by building type, ownership, and recovery pathway, and the need for

disaggregated, building-specific representations of impeding factors in future New Zealand-oriented recovery models.

For disaster recovery policymakers in New Zealand, these findings highlight the need to explicitly incorporate workforce capacity, access constraints, and regulatory processes into recovery planning and policy frameworks, including improved coordination mechanisms and data-sharing systems across agencies and insurers. For practitioners, including engineers, contractors, and project managers, the results emphasise the importance of anticipating delays related to inspections, access restrictions, and resource availability, and adapting planning and mobilisation strategies accordingly. Together, these insights support the development of more realistic, locally calibrated recovery timelines and decision-making processes.

## 5 CONCLUSION

This paper examined how impeding factors influence post-earthquake downtime and assessed whether assumptions commonly adopted in international recovery frameworks are representative of recovery conditions in New Zealand. By synthesising key developments in impeding factor modelling and drawing on evidence from the Canterbury Earthquake Sequence, the study showed that pre-repair delays in New Zealand are often longer and governed by different mechanisms than those assumed in U.S.-based frameworks such as REDi and FEMA P-58.

The synthesis highlighted that many existing impeding factor models are grounded in institutional arrangements, insurance coverage levels, workforce capacity, and regulatory processes that differ substantially from those observed in New Zealand. Evidence from Christchurch indicates that insurance settlement, inspection and detailed engineering evaluation, labour availability, access restrictions, and regulatory requirements frequently dominate recovery timelines and cannot be adequately represented using imported assumptions alone.

Using available post-CES data, the paper provided illustrative New Zealand-specific representations of selected impeding factors, focusing on insurance settlement and inspection-related delays. Comparison with REDi assumptions demonstrated clear differences in both the magnitude and distribution of delays, reinforcing the sensitivity of recovery outcomes to local financing structures, regulatory settings, and market capacity. These examples are not intended as a comprehensive New Zealand impeding factor model, but rather to demonstrate how locally informed assumptions can materially change recovery estimates.

Overall, the findings underline the need for New Zealand-specific impeding factor representations that are grounded in local data and explicitly account for uncertainty, building type, and system-level interactions. The targeted synthesis and illustrative analyses presented here provide a practical foundation for adapting functional recovery frameworks to better reflect real post-earthquake recovery conditions in New Zealand and for guiding future data collection and model development efforts.

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