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Critical success factors for post-disaster infrastructure recovery: Learning from the Canterbury (NZ) earthquake recovery

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Abstract

Purpose – The purpose of this paper is to synthesise critical success factors (CSFs) for advancing post-disaster infrastructure recovery and underpinning recovery authorities in decision making when facing future disasters.

Design/methodology/approach – The seismic recovery after the Canterbury (NZ) earthquake sequence in 2010-2011 was selected as a case study for identifying CSFs for an efficient recovery of infrastructure post-disaster. A combination of research approaches, including archival study, observations and semi-structured interviews were conducted for collecting data and evidences by engaging with participants involved at various tiers in the post-disaster recovery and reconstruction. The CSFs are evaluated and analysed by tracking the decision-making process, examining resultant consequences and foreseeing onwards challenges.

Findings – Six salient CSFs for strengthening infrastructure recovery management after disasters are identified. Furthermore, the study shows how each of these CSFs have been incorporated into the decision-making process in support of the post-disaster recovery and what difficulties encountered in the recovery process when implementing.

Practical implications – The proposed CSFs provide a future reference and guidance to be drawn on by decision makers when project-managing post-disaster recovery operations.

Originality/value – The value of the paper is that it bridges the gap between managerial contexts and technical aspects of post-disaster recovery process in an effort to rapidly and efficiently rebuild municipal infrastructure.

Keywords Decision making, Infrastructure, Critical success factor, Post-disaster recovery, Disaster management, Canterbury earthquake

Paper type Case study

Introduction

Natural hazards, like hydro-meteorological, geophysical and biological disasters, stem from single or multiple spontaneous movements of the Earth (United Nations International Strategy for Disaster Reduction, 2002). They are inevitable and, in many cases, disastrous. According to the United Nations International Strategy for Disaster Reduction (2004), natural hazards in 1994-2004 have cost the lives of 478,100 people worldwide, injured more than 2.5 billion people and caused US$690 billion of damage to engineered structures and infrastructure. Commonly infrastructure refers to water supply, sewerage, storm water, transportation, gas and telecommunication systems (Kameda, 2000).

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Damaged or functionally impaired infrastructure can create serious inconveniences for both residents and rescuers, and thereby prolong the post-event recovery process. On the other hand, reliable and functional infrastructure systems providing the basic living needs can boost the community's confidence, making the situation more bearable (Kameda, 1994). There is a manifest need for decision makers to seek informed and rational reactive operations for effectively managing post-disaster infrastructure rehabilitation and promptly recovering from disaster disruption in the face of natural hazards (Orallo, 2011).

Critical success factors (CSFs) might be a sound tool to satisfy the need. CSFs are the requisite elements that are crucially needed for achieving the success of an organisation or a project (Daniel, 1961; Rockart, 1978; Inayat *et al.*, 2014). Although the CSF approach was originally developed to serve in the field of business management and project management, an increasing number of researchers have adopted CSFs to identify significant factors and enhance pertinent performance of post-disaster recovery (Rockart and Bullen 1981; Pathirage *et al.*, 2012). A non-exhaustive literature review has been conducted by authors on the implementation of the CSF approach in disaster knowledge management (Seneviratne *et al.*, 2010), housing reconstruction (Comerio, 2005, 2014; Ophiyandri *et al.*, 2013), life cycle phases of public projects after disasters (Moe and Pathranarakul, 2006), disaster recovery planning of information system in Hong Kong (Chow, 2000), post-disaster development of concentrated rural settlement in China (Peng *et al.*, 2013), solid waste management after the Black Saturday bushfires in Australia (Brown *et al.*, 2011), building reconstruction after the Canterbury earthquakes (Taylor *et al.*, 2012), community recovery following earthquakes (Olshansky *et al.*, 2006, 2008) and national emergency management (Ozceylan and Coskun, 2008).

After a disaster event, government support at both national and regional levels is essential (Comerio, 1997; Ophiyandri *et al.*, 2013; Peng *et al.*, 2013). It is expected that government would provide any assistance that recovering the affected areas might necessitate after a disaster. The needs include, among others, organisational, financial and political, which can be achieved through creating new recovery-oriented organisations by national-level governance (Johnson and Olshansky, 2013). The government organisation could facilitate the horizontal and vertical coordination amongst all levels of stakeholders, organisations and residents and also expedite decision-making process (Johnson and Mamula-Seadon, 2014). However, not every recovery needs such a high level of government involvement and support. Whether there is a need for a recovery organisation after a disaster may depend on the scale and severity of the induced damage, but this has not been addressed. Economic and financial factors are considered vital in the post-disaster rebuilding because it guarantees the effective implementation of reinstatement (Comerio, 2005; Olshansky *et al.*, 2006; Seneviratne *et al.*, 2010; Brown *et al.*, 2011). The sufficiency of recovery funding and the availability of funding plan could further reinforce the confidence and certainty of decision makers, residents, investors in post-disaster rebuilding (Chow, 2000). The communication factor is highlighted, in particular the channels between all levels of government, stakeholders, technical professionals and community (Olshansky *et al.*, 2006; Brown *et al.*, 2011; Peng *et al.*, 2013). Modern technologies, such as information systems and decision support systems, can assist in the communication after natural disasters (Ozceylan and Coskun, 2008). However, limited research has been done with regard to data sharing mechanism which could largely speed up the decision making on recovery if applied adequately. Among the identified CSFs, technical factors are topic specific to different focusses. For instance, Brown *et al.* (2011) examine the decisions made in relation to solid waste management after the Black Saturday bushfires in Australia, finding key technical factors during the clean-up process, including waste classification and landfill site construction. Olshansky *et al.* (2006) find external funding and suitable local conditions are two key factors for the success of post-disaster housing programme in both short and long terms. However, a gap is recognised in terms of the identification of technical factors that look into practical operations in field for structural reconstruction and in particular, for infrastructure systems. This paper aims to contribute to bridging this gap by:

(1) reviewing and evaluating the post-earthquake infrastructure recovery process executed after the Canterbury earthquake sequence in 2010-2011; and

(2) identifying the CSFs that are considered as success determinants of the post-earthquake infrastructure recovery in Christchurch.

Here the post-earthquake infrastructure recovery after the Canterbury (NZ) earthquake sequence in 2010-2011 is selected for a case study. A combined method of archive study, observations and interviews are conducted. Six CSFs are identified and analysed by tracking the decision-making process, following up the decision implementation and examining resultant consequences. In particular, the difficulties that recovery organisations (e.g. Canterbury Earthquake Recovery Authority (CERA) and Stronger Christchurch Infrastructure Rebuild Team (SCIRT)) encountered when implementing those CSFs are investigated.

Background

Christchurch, the second largest city in New Zealand, and the nearby Waimakariri District were seriously affected by the Canterbury earthquake sequence in 2010-2011. The sequence started on 4 September 2010 earthquake ($M_w = 7.1$), and the subsequent major shocks, including the ones on 22 February 2011 ($M_w = 6.3$), 13 June 2011 ($M_w = 6.0$) and 23 December 2011 ($M_w = 5.8$) were each followed by thousands of aftershocks (Bannister and Gledhill, 2012; Cubrinovski *et al.*, 2011). The strong ground motion caused extensive soil liquefaction, resulting in widespread physical damage to and functional failure of lifeline utilities and facilities. After the earthquakes the initial assessments indicated that 1,021 kilometres or 52 per cent of the Christchurch urban sealed roads were in need of rebuilding operations (Canterbury Development Corporation (CDC), 2015). Approximately 348 km fresh water pipelines (almost 10 per cent of the water supply network) were damaged and the main reservoir (Huntsbury reservoir) was so severely damaged that it lost all stored water. The greater Christchurch region is served by 175 fresh water wells of which 22 lost all functionality and 64 more required repairs (Giovinazzi *et al.*, 2011). However, the Christchurch sewerage system sustained the most severe damage with 659 kilometres of wastewater pipelines, 41 per cent of the entire system, damaged (Liu *et al.*, 2015). Especially near waterways a large proportion of pipelines lost functionality and had to be replaced by more advanced pressurised sewerage systems. The storm water system in Christchurch was least affected and needed only a moderate amount of effort to restore the service and avoid flooding (CDC, 2015).

In view of the complexity and the quantity of the recovery activities in Christchurch, the central government of New Zealand established the CERA in April 2011 according to Canterbury Earthquake Recovery Act 2011 (Hartevelt, 2011). During the recovery CERA provided leadership, and coordinated other organisations involved in the recovery. CERA, in collaboration with the CCC and the New Zealand Transport Agency (NZTA), set up an alliance with contracting organisations, called the SCIRT. The SCIRT alliance was charged with the repair of 85 per cent of the damaged horizontal infrastructure in Christchurch (Botha and Scheepbouwer, 2015). The alliance

SCIRT consisted of three funding agencies (i.e. CERA, CCC and NZTA) as owners and five of New Zealand's largest contracting companies as non-owner participants. Figure 1 shows the inter-relationship of organisations involved in SCIRT.

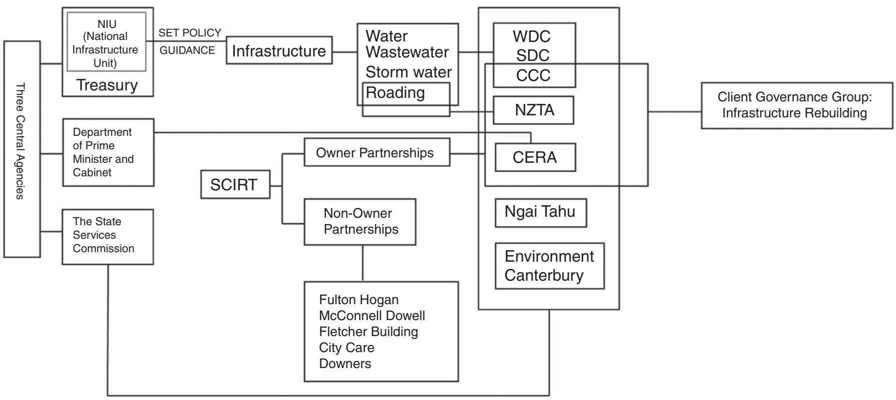
Research methods

The research is framed by the research questions which determine the methods, and drive all activities and strategies (Yin, 2013). They also identify the theory and phenomena to be studied (Eisenhardt and Graebner, 2007), and guide the data collection process. Data collection often combines archive, interviews, observations and questionnaires (Yin, 2013). The combined method could better substantiate conceptions and hypotheses (Meyer, 2001). In terms of interviews, it is useful to capture views from multiple interviewees for providing a pluralist view regarding the research questions (Glick *et al.*, 1990). Any replicated or contrast information provided is of value in that they could enhance findings or disclose research breakthroughs (Hartley, 1994). In the preparation for decision-related interview questions, Schramm (1971) suggests to delineate each factor/decision by answering why it was taken, how it was implemented and with what results. Examples of applying the abovementioned combined case study method to draw CSFs for ensuing the success of the disaster-related projects can be found in Brown *et al.* (2011), Moe and Pathranarakul (2006), Ophiyandri *et al.* (2013), Pathirage *et al.* (2012), Seneviratne *et al.* (2010) and Taylor *et al.* (2012).

In this research, the core research question is how to enhance post-disaster infrastructure recovery. In other words:

RQ1. Which critical factors/decisions contribute to an efficient and informed infrastructure recovery and reconstruction after disasters?

Towards that, authors first carried out archive study and observational work. The archive study was conducted on national and international documentations referring to disaster recovery specifically for urban infrastructure recovery, for seeking relevant answers to the identified research question. In particular, the documents related to the Canterbury infrastructure recovery were scrutinised for identifying lesson-learnt which might be of value to the question. Additionally, authors have participated in regional, national and international technical meetings/conferences in



Source: Liu *et al.* (2013)

Figure 1.
Inter-relationship between organisations involved in the Canterbury earthquake recovery

relation to post-disaster rebuild and, in most cases, Canterbury infrastructure recovery and thereby obtained first-handed observational evidences.

Based on the nature of the research question, interview questions were formulated, in line with Schramm (1971), such that decision-making process, decision implementation and resultant consequences were examined.

In order to gather a pluralistic viewpoint of the infrastructure recovery following the Canterbury earthquakes, semi-structured interviews were conducted with a total of 17 interviewees selected from professionals working in the key organisations listed in Figure 1, such as CERA, SCIRT, CCC, WDC and Fulton Hogan. Their positions pertain to either management level (e.g. general manager, technical manager and project delivery manager) or technical level (e.g. geographic information system (GIS) consultant, project estimator and site engineer), covering decision making, decision implementation and reconstruction delivery of the infrastructure recovery process in Christchurch. At least two key personnel were chosen from each of the involved organisations/companies in the abovementioned phases for ensuring the representativeness and information richness. Since interviewee's expertise covers the whole process of the Canterbury infrastructure recovery, it is believed that the collected information by means of interviews is sufficient and reliable.

The interviews were carried out in 2013, approximately three years after the first earthquake in 2010. This allows for the evaluation of the recovery decisions from a retrospective viewpoint, thereby effectively synthesising CSFs of the Canterbury infrastructure recovery. In particular, how each CSF has evolved along with the dynamic process of the post-earthquake recovery is scrutinised. Furthermore, the effectiveness and usefulness of the identified CSFs are evaluated and re-considered during the case study research.

Identification of CSFs for post-disaster infrastructure recovery

The six identified CSFs cover organisation, finance, communication and technical aspects of the Canterbury infrastructure recovery. CSFs 1, 2 and 3 entail managerial and organisational aspects of the post-earthquake infrastructure recovery from a policy-makers' viewpoint, whereas the remainder deal with the restoration from a technical perspective.

In this analysis, we focus on the operational involvement of each CSF in decision making and decision implementation process, the discrepancy between resulting consequences and expected effects and on latent challenges onwards.

CSF 1: establishment of a recovery vehicle

The 4 September 2010 earthquake ($M_w = 7.1$) caused "moderate" damage to infrastructure systems in Christchurch city. In the aftermath of the quake, CCC established an Infrastructure Rebuild Management Office (IRMO) to rebuild its damaged infrastructure. IRMO comprised of 20-30 council staff that were responsible for design, construction management, finance, communication, programming, procurement and project administration (Controller and Auditor-General, 2012). IRMO entered into four design-build contracts with five construction companies to reinstate the impaired infrastructure. The division of work was based on geographical location and six weeks after this seismic event, almost 480 repairs to water supply and wastewater pipelines had been initiated by IRMO.

After the devastating 22 February 2011 earthquake, more damage was caused to the city and it became clear that the infrastructure rebuild would require significant support from central government, beyond funding alone. Hence, CERA was established to lead, direct and coordinate the massive recovery activities to be undertaken following the Canterbury earthquake sequence. Upon CERA's establishment the government, CCC and NZTA examined various contracting models through which a large-scale infrastructure rebuild could be undertaken. There were reservations about a traditional contracting model being able to cope with the need for an end-to-end investigation, design and construction process, especially as the procurement and contract management of hundreds of projects would be logistically challenging and expensive. The volume of rebuilding projects was expected to be tenfold the annual maintenance programme conducted by CCC (Liu *et al.*, 2013). The three partners finally selected an alliance-contracting model to establish SCIRT with five contracting companies in June 2011, nine months after the September earthquake in 2010. After three months of pre-operation period, it officially took over from IRMO one year after the first seismic event. At that time, SCIRT took over 148 projects that were in the design, construction and handover phases to IRMO and 125 projects in the early design stages. Using wastewater catchments as spatial units, SCIRT has been reinstating the aforementioned systems according to Infrastructure Recovery Technical Standards and Guidelines (Christchurch City Council, 2012a), in conjunction with CCC Infrastructure Design Standard (Christchurch City Council, 2013a) and CCC Construction Standards Specification (Christchurch City Council, 2012b). By November 2015, 80 per cent of reconstruction tasks had been completed at a total value of NZ$1,379.9 million (Stronger Christchurch Infrastructure Rebuild Team (SCIRT), 2015).

The establishment of one recovery vehicle is of benefit in interpreting recovery decisions, developing innovative techniques and achieving rapid post-disaster recovery. However, whether to form a recovery-oriented vehicle depends on, among others: the magnitude of the disaster, the severity of the disaster-induced damage, the flexibility of the government and the resilience of society and community. SCIRT was established after the occurrence of a series of intervening earthquakes, which led to a realisation of local government that IRMO is not managerially and organisationally capable of coping with this large-scale post-earthquake recovery. Subsequently, the establishment of SCIRT is a well-recognised success in the post-earthquake infrastructure rebuilding in Christchurch within time and budget constraints. However, the responsibility shift from IRMO to SCIRT and the long deliberation period of this shift might have resulted in a delay of overall rebuilding process and inconsistency of recovery guidelines. Potential future risks lie in the managerial and technical morph of all recovery projects back to CCC after SCIRT will be disbanded in 2016.

CSF 2: formulation of a flexible funding plan

Following a number of intervening seismic events in 2010 and 2011, the severity and quantity of the damage to infrastructure highlighted that extensive funding support from central government was needed. The central government of New Zealand through CERA pays 60 per cent of the costs for three waters infrastructure (Christchurch City Council (CCC), 2013b).

Multiple informants stated that since the September earthquake, cost sharing between CCC and central government has been a hot topic. In 2011, a Canterbury Earthquake Recovery Fund of NZ$5.5 billion was set up by the central government for the purpose of supporting and subsidising the infrastructure rebuilding in Canterbury region. Of this, NZ$1.65 billion had been allocated to the infrastructure rebuild.

In 2013, another NZ$4.8 billion agreement was formulated between CCC and central government on the cost sharing of NZ$1.9 billion and NZ$2.9 billion to the rebuild, respectively (CCC, 2013b).

The recovery would have benefited from any pre-defined funding plans. For instance, a funding division plan formulated prior to a disaster may shorten the time taken for applying for financial support from central government, expedite infrastructure recovery post-disaster and thus facilitate functional recovery of society and community. However, it is important to envisage that there will be underlying risks in exclusively setting up post-disaster funding plans, especially when the severity of a disaster is unknown. Therefore, a flexible funding plan might be an ideal solution.

CSF 3: community engagement

SCIRT actively communicates all rebuilding operations to the community, it strives to clear up any uncertainties of locals and thereby build up their confidence. Extensive work has been done to promote community engagement in the Canterbury recovery. Until November 2015, approximately 6,047 work notes have been specifically produced and delivered to 1,409,083 residents/businesses. In total, 34,921 face-to-face meetings were organised with locals who were living/working in SCIRT rebuilding areas. In addition to this, 160 visits to local schools were acted to engage with students in relation with SCIRT's (2015) work. A SCIRT webpage had been set up as an interface with public for updating work progress, informing the upcoming tasks and answering people's inquiries. The communication team conducts surveys and interviews to collect people's ideas and satisfaction levels with regard to SCIRT's rebuilding operations on a six-month interval. The results of a survey conducted in November 2013 by Opinions Market Research Ltd. are presented in Table I (Stronger Christchurch Infrastructure Rebuild Team (SCIRT), 2014). All of the surveyed subjects receive more than half of support level. The high (90 and 86 per cent) support levels shows the community feel informed and satisfied regarding the construction work.

The high satisfaction levels represented from the conducted surveys reflect the well-recognised performance of SCIRT and in turn facilitate the implementation of the infrastructure rebuilding. However, the implementation of community communication could be improved. The community communication efforts have

Subject area of survey questions	Support level (%)
Acknowledged impact on road travel (approximately)	90
Satisfaction with communications	86
Tolerance of traffic impacts in central city	79
Tidiness of sites	77
Very satisfied or satisfied with local works	75
Clarity of information received	73
Ease of navigation past works	66
Residents with works in their neighbourhood	66
Acceptable standards and time frames (approximate sum)	66
Priorities believed appropriate	64
Awareness of SCIRT	59

Source: SCIRT (2014), used with permission

Table I. Sample of survey reports conducted in November 2013 been only concentrated on the rebuild projects executed by SCIRT. The information has been only related to upcoming and on-going projects without the overall viewpoint of the recovery scheme included.

CSF 4: selection of a rebuild driver

SCIRT chose the repair of the sewerage system as the rebuild driver when it planned the infrastructure rebuilding programme. First, SCIRT planners determined recovery plans depending on the priority and severity of the impaired sewerage assets. Then the need of repairing other underground infrastructure in the same location was identified. This way, the recovery operations are carried out without unnecessary duplication of digging and traffic blocking.

There are three reasons for the choice of the wastewater system. First, the Christchurch sewerage system suffered the most extensive physical damage as a result of the earthquakes. Second, it is the deepest infrastructure for the purpose of making better use of gravitational force to deliver the sewage as a gravity-fed system. Lastly, the Christchurch rebuilding projects are zoned using wastewater catchments as common spatial units. The implementation of the rebuild driver in Christchurch has helped in expediting recovery, maximising the efficiency of resource and reducing extra expense.

It should be noted that the selection of the rebuild driver may vary along with the post-disaster recovery process. The main focus of the emergency response phase is on the provision of rescue service and basic living needs for community. The functionality of infrastructure systems is crucial to guarantee the accomplishment of these goals. In the emergency response period, the elemental human needs which include clean water and stable electricity are the first priorities. Therefore, water supply and electricity power systems can be designated as rebuild drivers in this phase. As for long-term recovery plans, the choice of a rebuild driver is not that straightforward in that it yields many other factors, for example, damage level of infrastructure facilities, community expectation as well as service standards.

CSF 5: determination of rebuild project prioritisation methodology

SCIRT developed a spatial prioritisation methodology to underpin the decision-making process of post-earthquake reinstatement for horizontal infrastructure systems (Figure 2). The prioritisation methodology aims to prioritise rebuilding projects of infrastructure facilities and the sequence in which those projects are carried out. It is run in a platform Feature Manipulation Engine, by where GIS data and non-GIS data are incorporated and integrated to rank infrastructure facilities of interest.

The methodology allows for the global evaluation of asset condition, criticality, residual serviceability and future maintenance cost of individual assets. Based on that, and accounting for geographical dependency and priorities of critical facilities, along with any resource constraints and external factors, rebuilding schedules are formulated. The results require further verification by use of common sense check. The project prioritisation analysis is run on a three monthly interval based on latest data upgraded. This method separately considers and analyses individual structures (such as bridges, pump stations) as stand-alone projects.

The prioritisation methodology is considered a success by the majority of interviewees as it produced an integrated combination of technical factors and societal influences on infrastructure rebuilding. It allows for a multi-criteria assessment of the damaged infrastructure at both component and system levels in a step-wise manner,

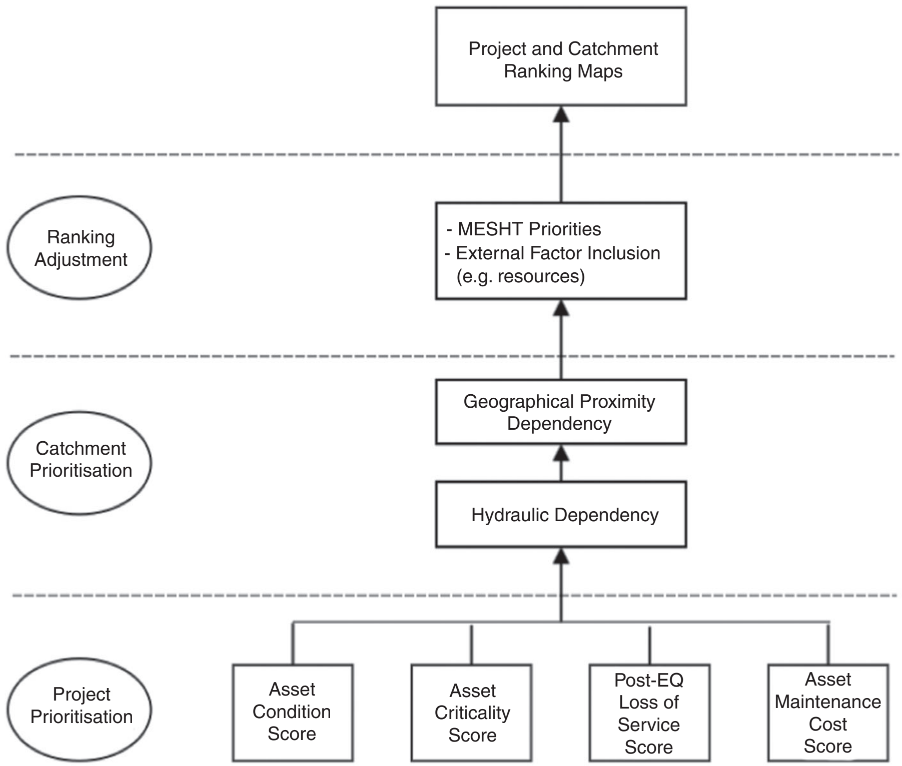


Figure 2. Flowchart of rebuild project prioritisation methodology

with particular emphasis on critical structures. The regular operational check and information upgraded ensure the appropriateness and effectiveness of the identified priorities. A rebuild project prioritisation methodology is capable to provide policy makers with solid information upon which recovery plans could be built.

Possible improvements could be made by adding more generic attributes of assets (e.g. length, depth) and by assigning weights to each factor. These may increase the accuracy and reliability of the prioritisation outcomes. However, the trade-offs of doing so, such as added time and expense, could create a problem for decision makers.

CSF 6: standardisation of data management mechanism

After the Canterbury earthquakes, assessment teams were summoned nationally and internationally to investigate the earthquake-induced physical and functional damage to local infrastructure systems. For example, three types of damage assessment teams were assigned to investigate the Christchurch wastewater reticulation system, namely: manhole-level survey team, closed circuit television inspection team and pipe profilometer assessment team, for the purpose of gaining a comprehensive understanding of the level of the physical damage to the sewerage system pipelines in Christchurch.

The collected information was logged in the GIS database that is jointly owned by the CCC and SCIRT. A suite of geospatial databases created by the SCIRT GIS team include, among others, system inventory, physical damage, repair operations, renewal activities of all types of horizontal infrastructure systems (water supply, wastewater, storm water and road networks).

A web spatial platform was conceived and developed by SCIRT to facilitate data sharing between planners, designers, operators and decision makers involved in the recovery process. It has basic data manipulation functions and map interface for users to operate based on their own purposes. The information contains descriptive spatial GIS layers, photos, evaluative statements, covering all projects conduced or being conducted in Christchurch. A dedicated GIS team within SCIRT updates the database with the latest data.

It is recognised by respondents that data collection and data sharing amongst distinct shareholders, authorities, agencies and operators has been effective. The databases and web platform developed by SCIRT enable effective data exchange and distinct usage of information available. However, there are two issues that have incurred during data collection and data transference process in Christchurch. The first is the lack of an integrated information documentation mechanism such that inconsistent format and incomplete data can be found in the databases. The second one is the incompatibility and inconsistency of different data sources due to a variation of data management systems deployed by different users. In particular, the misunderstanding and information discrepancy have arisen from data transference between different organisations. This severely limits the use of the recorded data/information for guiding and assisting in recovery operations.

Discussion

The infrastructure recovery in Christchurch provides an exemplary case study for others that could come to face a similar situation. The CSFs identified in the previous sections disclose the opportunities for improvements in the field of post-disaster disaster management specifically for infrastructure systems.

Establish a recovery vehicle in charge of infrastructure rebuilding

A recovery vehicle has the potential to holistically organise and manage the post-disaster reinstatement operations. Unlike recovery authorities that predominantly handle the institutional matters (e.g. Victorian Bushfire Recovery and Reconstruction Authority after the Australia Victorian Bushfire in 2009, Centre of Direction for Command and Control after the Italian L'Aquila Earthquake in 2009 and CERA in Christchurch), recovery vehicles mainly focus on the implementation of the decisions released by recovery authorities, design and engineering of the recovery works in field and on delivery of the post-event reconstruction to community. The scale of the recovery vehicle is dependent on the severity and quantity of the damage (physical and functional) caused by the disasters. The challenges with recovery vehicles are first, how to determine at what disaster or damage level a recovery vehicle is necessary. The threshold must take into account the type of disaster, damage level and the availability of resources (e.g. staff and finance). The deliberation period after a disaster should be kept as short as possible. How to shorten the deliberation period of setting up a recovery vehicle to save time and expense and also expedite post-disaster recovery, while minimising the risk that uncertainties lead to changes, will incur along the way. This is what influenced the choice of recovery vehicle in Christchurch. Then, it is imperative to clearly define the roles and responsibilities of the involved parties. Post-disaster sentiments change and have the ability to influence standpoints. Lastly, when the post-disaster recovery period comes to an end, all unfinished recovery projects will be transferred to local government agencies. The local agencies will then finish the projects as part of daily maintenance practice. This may lead to risks relating to administration, budget, data management and technical support.

A pre-established funding plan for post-disaster infrastructure recovery is necessary
In line with the findings from previous studies, funding is crucial and a pre-established funding plan for post-disaster infrastructure recovery that can be tailored depending on the actual situation is necessary. In particular, rational regulations regarding funding division among relative parties (e.g. central government and local authority) should be well defined, taking into account likelihood of future events. The findings also underscore the importance of insurance that could become a challenge for policy makers if not settled beforehand.

Recovery needs community involvement
The core role of post-disaster infrastructure recovery is to regain services and serve the community. Therefore, the satisfaction of the local community is one of the key criteria of recovery operations and consequently determines whether the whole recovery programme is successful (National Infrastructure Unit, 2012). Effective communication with local community will not only create a pleasant working environment but, to a certain extent, speed up the recovery process. It is, for example, very useful to inform locals about upcoming inconveniences that the rebuild work might cause. Further to the current community engagement plans, information on the infrastructure recovery in general terms should be available to people for providing a thorough overview. As community involvement has a cost, the extent of community involvement in post-disaster recovery is determined by the quantity of government input and the assistance of non-government organisations if available.

A type of infrastructure system should be selected as a rebuild driver
How to cope with the large number of projects to repair the damaged infrastructure networks becomes a big concern for decision makers after disasters (Kameda, 2000). To aid in post-disaster rebuild, it is useful to select one infrastructure asset type as a rebuild driver around which other infrastructure systems can then be planned. This infrastructure asset type is considered as a baseline and is planned first, followed by the design and engineering of remaining infrastructure systems. For example, in a recovery area, the water supply system can be chosen as a baseline and decision makers should then formulate rebuild plans based on the rebuilding sequences of the water supply network. According to this sequence, the working schedule of other infrastructure systems can be determined such that infrastructure assets in the same geographical locations could be restored altogether. This could be helped by centralising logistics and labour at times of high demand, avoiding difficulties associated with simultaneously adjusting working schedule of all infrastructures. Furthermore, it avoids duplicating construction of the same location for different underground networks which exacerbates the inconvenience for road users and residents by, for instance, blocking/limiting the traffic. Therefore, a rebuild driver should be selected for facilitating the post-event infrastructure recovery, so components can be systematically and efficiently restored. It should be noted that the selection of the rebuild driver may vary along with the post-disaster recovery process as the recovery objectives and focus may morph at different recovery stages.

A prioritisation methodology is of use

The post-disaster recovery process involves a wide range of stakeholders with different interests and intentions regarding rebuilding projects (Olshansky *et al.*, 2006). Because of that, a transparent and robust methodology to prioritise numerous repair/reconstruction tasks is of importance. In particular, the methodology needs to pay special attention on critical facilities (e.g. hospitals, schools). A prioritisation methodology accounting for relevant factors involved in post-event infrastructure reconstruction is of value. Increasing factors pertinent to infrastructure can improve the accuracy and efficiency of the prioritisation outcomes. However, the associated added resources (e.g. expense and time) could prove to be a challenge.

An integrated data collection and management mechanism is needed

A holistic understanding and interpretation of the damage (physical and functional) to infrastructure components will assist in the formulation of recovery plans, the implementation of the informed plans and ultimately expedite post-disaster infrastructure recovery. Therefore, it is valuable to systematically document data and information regarding the impaired infrastructure networks.

Recent research shows that data collection and data sharing are important to both the post-event recovery and pre-event disruption reduction (Moe and Pathranarakul, 2006; Younis, 2010). At the same time, previous international case studies indicate that large amounts of data were not properly recorded or documented (Hsu *et al.*, 2005; Da Silva *et al.*, 2010). Even when information was logged, however, due to inconsistent data management systems and different data formats, the usage of the documented data can still be challenging for recovery organisations (Kameda, 2000; Liu *et al.*, 2015). Therefore an integrated data collection and management mechanism is needed. In addition, asset taxonomy, data format, damage classification should be standardised and identified in advance of information documentation process. Data documentation mechanism and management procedures should be defined and clarified to avoid inconsistent logging and input of incomplete data. It is desirable to carry out staff training with regard to the proposed data management procedures. Once again, decision makers need to balance the efficacy of the mechanism and budget.

Conclusion

Natural hazards can severely damage urban infrastructure services such as water, wastewater, storm water, gas, electricity, and transportation and telecommunication systems. Damaged infrastructure systems need comprehensive rebuilding programmes which involve inspection, assessment, design, construction of the networks. How to cope with the complexity, number and size of these projects and how to systematically plan the rebuilding projects becomes a challenge to decision makers responsible for the infrastructure rebuild.

Available post-event recovery frameworks could assist in managing recovery operations, quickly reinstating the impaired infrastructure, using any built in system resilience. However, a paucity is disclosed in terms of technical factors that look into practical operations in field for structural reconstruction and in particular, for infrastructure systems. Towards that, CSFs are useful tools to bridge the gap between managerial and technical contexts by identifying significant factors in post-disaster infrastructure recovery.

In this study, six CSFs that were crucial in the Christchurch post-disaster infrastructure recovery were identified. After reviewing international and national documentation regarding infrastructure rebuild, semi-structured interviews were held with various participants involved in the various tiers of the Canterbury earthquake recovery. This provided information on the identification of the six CSFs, and how these were incorporated into the infrastructure recovery process in Christchurch. The six identified CSFs include: establishment of a recovery vehicle, formulation of a flexible funding plan, community engagement, selection of a rebuild driver, determination of rebuild project prioritisation methodology and standardisation of data management mechanism. The identified CSFs could feed into recovery frameworks, with particular concentration on key aspects of recovery process after disasters. Furthermore, CSFs might allow for a proactive plan to be built for mitigating potential loss that future disaster may induce.

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