Developing a model and instrument to measure the resilience of critical infrastructure sector organisations

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Abstract

Societies are highly reliant on uninterrupted critical infrastructure services. Until recently, the focus has been on the physical resilience of hard assets such as pipes, cables and buildings. But attention is also turning to a systems approach, considering the capabilities of, and interconnections between, the organisations responsible for developing, maintaining and running those infrastructures. This paper draws on existing research into organisational resilience to develop a model and measurement instrument for whole of sector resilience for selected critical infrastructure sectors, in order to identify sector resilience strengths and weaknesses, and to develop and evaluate the effectiveness of their resilience strategies and investments. The model is intended as a 'conversation starter' to prompt further research on how critical infrastructure organisations can best address their significant co-dependencies to ensure the overall sector's ability to survive and thrive, even in times of crisis.

Keywords: model development; instrument development; measuring resilience; critical infrastructure resilience; organisational resilience; sector resilience; critical infrastructure organisations; resilience strategies.

Introduction

Resilient infrastructure serves as the 'backbone' for the continued function of communities (Bruneau et al., 2003) and requires resilient organisations to manage and respond appropriately to crises to ensure the ongoing function of critical services. From the perspective of government and wider society, macro-level socio-economic stability and political outcomes are highly dependent not on the continuity of any single critical infrastructure organisation per se, but on the broader resilience and sustainability of the critical infrastructure sectors. Given this, understanding and building sector-level resilience can be a critical factor for a country's domestic security, international competitiveness, and overall wellbeing.

In recent years many governments around the world have begun creating national disaster resilience strategies (Council of Australian Governments, 2011; The Critical Five, 2014). To this end, Canada, the UK, the US, Australia, and New Zealand have recently begun integrating resilience into plans built on earlier protection models which had an emphasis on readiness and response. This has been achieved through a consortium of government departments from these five countries working together to develop shared views on critical infrastructure, resilience, and security (The Critical Five, 2014). Key elements of these plans relating to critical infrastructure sector resilience are their emphasis on the importance of partnerships and information sharing, continuity, adaptability, and planning. Within Australia, critical infrastructure resilience has transitioned from a focus on the protection of physical assets, to a broader conversation about the ways to ensure critical service continuity in the face of any kind of adversity. Australia has developed a national Critical Infrastructure Resilience Strategy that prioritizes continuity of service provision from critical infrastructure, both public and private, through business-government partnerships, enhanced risk management, effective understanding and management of strategic issues, and understanding and application of organisational resilience (Council of Australian Governments, 2011). The approach taken by Australia is also being adopted overseas. Canada and the US, for example, both have a similar basis in public-private partnerships, information sharing, and risk management for the security, safety, and economic wellbeing of their citizens (The Critical Five, 2014). The United Kingdom's national critical infrastructure sector resilience plans cite similar attributes but have greater remnants of the protection past, with emphasis on information sharing for response rather than how it is more broadly utilised in the Australian strategy (Australian Government, 2015a; Cabinet Office (UK), 2011).

Critical infrastructure resilience is still very much an emerging concept. This is evident by the lack of consistency in the way the concept is used and in how it is assessed. While there are many tools for risk and vulnerability assessment, (Giannopoulos, Filippini, & Schimmer, 2012; Solano, 2010) methods to systematically assess critical infrastructure resilience are only slowly emerging (Bara & Bronnimann, 2011). While the importance of resilience has been well recognized within governments (Bach, Bouchon, Fekete, Birkmann, & Serre, 2013; The Critical

Five, 2014) the necessity of developing resilience assessment tools has only been recognized internationally very recently under the Sendai Framework for Disaster Risk Reduction (United Nations, 2015). One of the seven global targets is to "Substantially reduce disaster damage to critical infrastructure…through developing their resilience" (United Nations, 2015, p. 12), with a call for development of indicators to assess progress towards these global goals. A research and policy review at the regional scale in the United States came to a similar conclusion on the necessity of developing metrics for critical infrastructure sector resilience (Frye, 2014). The challenge then, is not only developing a method but also a model for sector resilience that accounts for the complexities and comprehensiveness of the critical infrastructure sector.

Recognising the importance of critical infrastructure sectors in ensuring a resilient nation, the Australian Attorney General's Office and the Australian Government's Resilience Expert Advisory Group, in conjunction with Resilient Organisations, has developed a model of Sector Resilience and an instrument to allow for assessment of the resilience of critical infrastructure sectors. This paper presents this model and measurement instrument, assesses the reliability of the measurement scale, and illustrates its use in assessing critical infrastructure sector resilience in Australia.

The next section sets out the development of an initial framework for sector resilience followed by a sector resilience model and method for assessment.

Conceptual framework: From organisational to sectoral resilience

While the literature on resilience goes back several decades, sector-level resilience is still an emerging phenomenon. Sector resilience development attempts to address the question:

"…how do [critical infrastructure] industries, consisting of networks of organizations, many with competing goals and interests, provide reliable services in the absence of conventional forms of command and control? " (DeBruijne & VanEeten, 2007, p. 19)

As the above suggests, sectors comprise a collection of organisations. So when developing a conceptual model, we draw on the significant body of work looking at aspects of organisational resilience (Bhamra, Dani, & Burnard, 2011; Boin & McConnell, 2007; McManus, Seville, Vargo, & Brunsdon, 2008; Stephenson, Vargo, & Seville, 2010), employee resilience (Britt, Shen, Sinclair, Grossman, & Klieger, 2016; Kuntz, Näswall, & Malinen, 2016; Paul & Garg, 2012) and resilience in small-medium size enterprises (Burnard & Bhamra, 2011; Wedawatta & Ingirige, 2016; Wedawatta, Ingirige, & Proverbs, 2013). Additionally, we examined current themes in the critical infrastructure resilience literature (Clavadetscher, 2010; Fisher et al., 2010; Laska, 2012; Petrenj, Lettieri, & Trucco, 2012; Vugrin & Camphouse, 2011).

McManus et al describe organisational resilience as "a function of an organization's overall situation awareness, management of keystone vulnerabilities, and adaptive capacity in a complex, dynamic, and interconnected environment" (2008, p. 82). The outcome of these capabilities is an organisation that can "survive, and potentially even thrive, in times of crisis" (Seville et al., 2008, p. 2). Related to organisational resilience is the emerging field of work on employee resilience, which makes connections between individuals and the organisations they work in. Within this field of research, it is argued that a resilient workforce is dependent on the enabling conditions set by the organisations they work within, and is a process of adapting, coping, and thriving in response to changing workplace circumstances (Kuntz et al., 2016; Näswall, Kuntz, Hodliffe, & Malinen, 2013; Näswall, Kuntz, & Malinen, 2015).

Resilience is not a linear progression from employee, to organisation, to sector. The interactions *between* key elements within the system create dynamics that influence the resilience of the system as a whole (Senge, 2006). These key elements include not only the organisations within each sector and the sectors they rely on to provide service, but also their relationship with government authorities. The whole does not equal the sum of its parts.

In addition, each type of resilience has a unique orientation and aims. Organisational resilience is primarily singular – focusing on one entity, and looks inward, with one of its aims to maintain competitiveness with other organisations within the same industry. With sector resilience, for critical infrastructure sectors, the orientation is primarily outward and multi-faceted, with the aim of continuity of service during conditions of crisis or challenge.

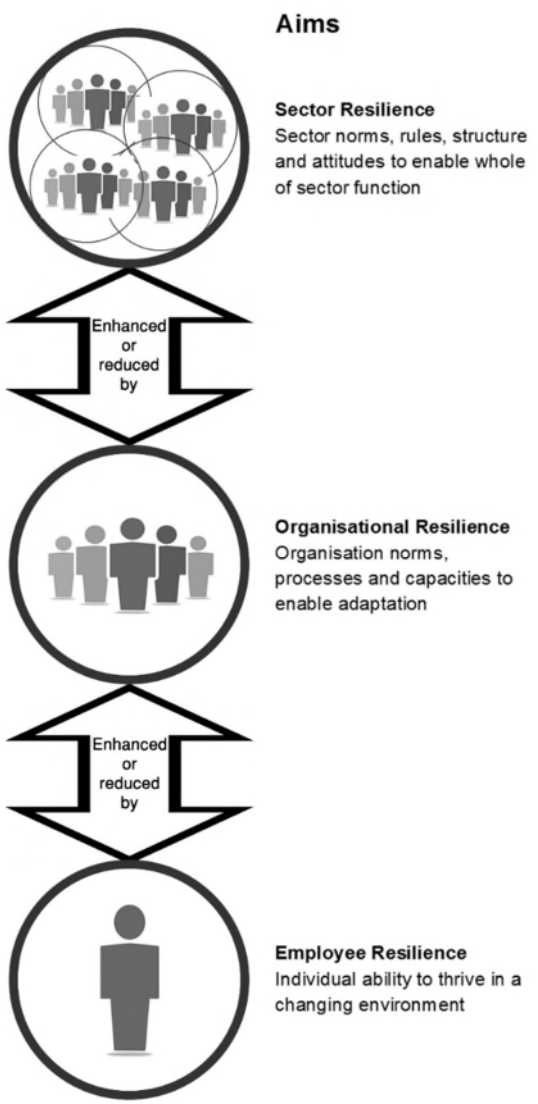
Earlier organisational resilience benchmarking systems were designed to help organisations make the business case for resilience investments, with the dual aims of ensuring competitiveness in both crisis and business as usual (Lee, Vargo, & Seville, 2013). The model for sector resilience presented in this article is built on a similar premise – to ensure continuity of critical services in a crisis, based on the government's responsibility to the community to provide for their social and economic wellbeing (Australian Government, 2010). In this case, competitiveness is framed as the country's competitiveness internationally, regardless of the crises they may face.

At the heart of the desire for resilient critical infrastructure sectors is the goal of ensuring functional social institutions in the face of adversity. Sector resilience also offers benefits to its member organisations. Operators within critical infrastructure sectors, whether they are public or privately owned, have an incentive to develop resilience and provide services, even in crisis, as their profitability and reputation depend on it (Australian Government, 2015b).

The case can also be made that the resilience of member organisations is enhanced by developing resilience within the sector as a whole. Sector resilience for critical infrastructure is based on partnerships, information sharing and collective understandings. This assumes that working together within and across sectors and with regional and national authorities will lead

to greater insights into vulnerabilities, risks, and resources than organisations developing their resilience independently (Australian Government, 2015a).

This argument is more than theoretical - Porter (2000) makes the case for businesses having a "tangible and important stake" in the local business environment through what he calls "clusters" of businesses, customers, and suppliers. His argument is based on significant empirical evidence demonstrating strong linkages between the health of a cluster on the whole and the health of the businesses within it. Thereby, the businesses have a stake in the health of their cluster and not simply their own bottom-line. A sector could work in a similar way to a cluster. Porter does not consider the role of clusters in a crisis. However, the traits of clusters that Porter notes, would have significant benefits during a crisis response: enabling coordination, mutual aid and communication with key partners.



Recent work by Kachali (2013) found that the performance of organisations after the Canterbury earthquake sequence of 2010-2011 depended significantly on their sector. Kachali argues that discussing resilience at the sectoral level "enables the organisations in the sector to have a common language on the subject" enabling the sharing of knowledge and best practices and the development of sector-level resilience standards. Additionally, in the event of a crisis, formally organised sectors can leverage their existing connections. As Kachali found after the Canterbury earthquakes, collaboration and cooperation can occur - not simply for the good of the organisations but for the survival of the sector post-disaster. This case exemplifies the scenario where sector resilience is most likely to be exercised – wide scale disruptions which require the full and calculated interplay of the key elements of a sector.

The difference between employee, organisational, and sector resilience can be seen in Figure 1. The difference is found primarily in the orientation toward a particular outcome and in the relationship between employees, organisations, and sector members.

Figure 1 - Resilience types

A model of critical infrastructure sector resilience

To develop a conceptual model of sector-level resilience we first reviewed existing available resilience models and tools for applicability. Three models from the literature review stood out as good practical examples and were explored for potential adaptation: the Organisational Resilience Health Check (Australian Government, 2016), the UNISDR's Disaster Resilience Scorecard (United Nations Office for Disaster Risk Reduction, 2016), and the Rockefeller Foundation's City Resilience Framework (The Rockefeller Foundation, 2016). All three models use underlying attributes that contribute to resilience, and utilise a survey questionnaire for stakeholders to assess their own resilience.

A review panel of critical infrastructure resilience practitioners and researchers determined that the Organisational Resilience HealthCheck provided a suitable model to be used as the basis for developing a Sector Resilience assessment tool, given that it examines the resilience of organisations rather than models created to examine the elements of a city (law, justice, environment, social harmony, economic prosperity etc.). The theoretical foundations for the Healthcheck model were drawn from Seville et al. (2008) and Lee et al. (2013).

Analysing sector level resilience required refocusing the tool's orientation from exploring behaviours and attitudes within an organisation to being more outward oriented, by looking at behaviours and attitudes emerging between organisations within a sector and interactions between the sector and other groups. In line with the models used as its foundation, the sector resilience model proposed here focuses on leading indicators that aim to assess how resilient a sector will be in the future. As argued by Flin et al. (2000), leading indicators are of more practical benefit than any lagging indicators that look at retrospective performance. Similar to organisational resilience assessments, the survey is intended to "help translate a complex multidimensional sociotechnical phenomenon into something more tangible for organisations and to provide organisations with a starting point for addressing their resilience" (Lee et al., 2013, p. 30).

To create the theoretical model, the Australian Attorney General's Department engaged with critical infrastructure sector members, the Australian Government's Resilience Expert Advisory Group (Trusted Information Sharing Network (TISN), 2017), as well as input from academic researchers. Based on expert input and the desired objectives within the Australian Government's Critical Infrastructure Resilience Strategy and Plan (Australian Government, 2015a) a theoretical model was developed.

Attributes and Indicators

The Sector Resilience Benchmark model (**Error! Reference source not found.**) contains three attributes – Sector Culture and Cohesion, Sector Agility and Change Readiness, and Sector Dependencies and External Networks. Within those three attributes are 14 sector resilience indicators.

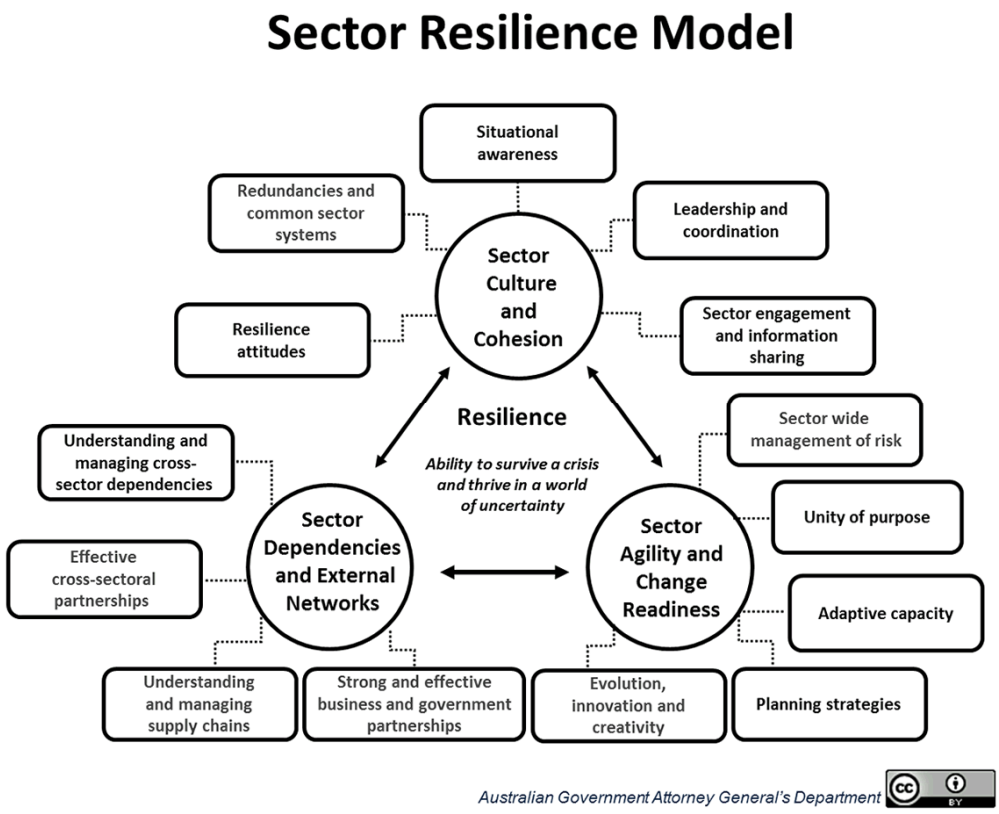


Figure 2 – Sector Resilience Model

Sector culture and cohesion consists of five indicators focused on leadership, attitudes, awareness and collective understandings (Table 1).

Table 1 - Sector culture and cohesion indicator description

Sector Culture and Cohesion	
Leadership and Co-ordination	The extent to which effective leadership exists across the sector to support good sector management and decision making during times of challenge or periods of adversity.
Resilience Attitudes	The extent to which resilience is understood and embraced within the sector.
Situational Awareness	The extent to which organisations within the sector understand potential threats or trends that may affect security or resilience.
Engagement and Sharing of Information	The degree to which knowledge is captured and shared effectively within the sector, with a strong focus on ensuring critical information is always available, an openness to learning, and drawing on internal and external expertise.
Redundancy of Sector Essential Functions and Common Sector Systems	The extent to which the sector understands its essential functions and shared dependency on common systems, networks, suppliers, and other organisations within the sector to deliver its services. The degree to which appropriate redundancy arrangements are in place.

Leadership is a key driver of organisational resilience (Seville, 2016; Stephenson, 2010; Stephenson et al., 2010; Westrum, 2006) with leaders playing a significant role in terms of strategic focus and decision making, as well as the 'how' of getting things done. In the context of sector resilience, the focus of leadership is on protocols for, and attitudes towards, co-operative and collaborative mechanisms within the sector, in particular mechanisms for response and recovery function between government and critical infrastructure sectors. Resilience Attitudes is similar to Weick and Sutcliffe's (2001) description of a 'culture of resilience'. This indicator focuses on how the concept of resilience is understood and whether attention is paid to it. This also draws from Pearson and Clair's (1998) work which talks of executive perceptions of risk. Situational Awareness within an organisation relates to how aware organisations are of what is happening around them, along with an ability to translate that into future implications (Lee et al., 2013). In the sector resilience context, this awareness of what is happening relates to the overall understanding of both the internal and external environments impacting on sector performance, along with considerations of the extent that understanding is shared. While Situational Awareness focuses on the openness and understanding of information, Engagement and Sharing of Information focuses on the mechanisms for sharing relevant knowledge across sector members, as well as learning from that information and crisis events. Redundancy of

essential functions and systems focuses specifically on the nature of interdependencies between organisations within a sector and the level of redundancy arrangements to ensure continuity of service. As argued by McManus (2008, p. 15) “much of the risk that organisations face is tied up in their intrinsic interconnectedness”.

Sector Dependencies and external networks has four indicators which focus on partnerships and dependencies across the sectors, and with suppliers and government (Table 2).

Table 1 - Sector dependencies and external networks indicator description

Sector Dependencies and External Networks	
Managing Cross-Sector Dependencies	The extent to which the sector understands its dependencies on other sectors and the impact of a disruption occurring outside of the sector. The degree to which effective communication and coordination processes are in place to address any disruption in the sector.
Effective Cross-Sectoral Partnerships	The extent to which the sector can leverage relationships with other interdependent sectors during challenges and times of adversity. The degree to which the sector plans and manages these relationships.
Management of Supply Chains	The extent to which the sector has a comprehensive and shared understanding of its dependencies on supply chains.
Strong and Effective Business & Government Partnerships	The extent to which the sector has strong and effective engagement with state, territory and commonwealth government agencies for: information exchange, escalating requests for support to minimise impacts of disruptions, and facilitating resilience building initiatives.

The importance of the first indicator, managing cross sector dependencies, for sector resilience is grounded in a systems approach and based on the idea of coupling discussed in (Perrow, 1999, 2011). Tightly coupled organisations, or in this case sectors, where a change in one organisation or sector has an immediate impact on the other, is a key aspect of critical infrastructure. For example, telecommunication and energy sectors are highly dependent on the transportation sector to access physical components of their systems. As stated by Hopkins et al. (1993, p. 217) “new and important factors come to light” when infrastructure providers discuss their assessments with other infrastructure sectors. The first indicator focuses on understanding those dependencies. The focus of the next two indicators is tangible actions to address those dependencies. This includes both the relationships to enable the collective sense-making necessary to create a shared understanding of events and the appropriate actions to take (Weick, 2006). It also includes the communication, coordination and process aspects to enable effective and efficient prioritisation of actions. These initial two indicators are focused internally within the broader critical infrastructure network i.e. the dependence of critical infrastructure sectors on other critical infrastructure sectors. The next indicator, management of

supply chains, looks externally at the broader environment. It examines the extent to which supply chains are shared across the sector along with their vulnerabilities. The importance of supply chain issues at the sector level was illustrated by the flow on impacts of the Thailand floods in 2011 (Abe, 2014). Business and Government partnerships focus on partnerships external to each sector with local, regional and central government. Crisis responses require intensive collaboration across critical infrastructure and governments, both with regards to sharing information and efficiently planning and prioritising responses and external communications. This indicator challenges respondents to assess current multi-government and multi-sector arrangements to coordinate a response. Reviews of problems in crisis responses commonly cite a failure of effective communication and collaboration between organisations and various governmental layers (Farazmand, 2007).

Sector Agility and Change Readiness has five indicators assessing the planning abilities, understanding of core priorities, understanding of risks that the sector faces, and the sector's ability to innovate and adapt when needed (Table 3).

Table 3 - Sector agility and change readiness indicator descriptions

Sector Agility and Change Readiness	
Sector-Wide Management of Risk	The extent to which the sector: understands its operating environment, has identified and rated the potential impact of threats to the sector, and has developed appropriate mitigation strategies.
Evolution, Innovation and Creativity	The extent to which the sector uses knowledge in novel ways to solve new and existing problems, and the degree to which it utilises innovative and creative approaches for developing solutions.
Unity of Purpose	The extent of the sector's awareness of what its priorities are during business as usual and during and following a challenging or adverse event.
Adaptive Capacity	The extent of the sector's strategic and behavioural readiness to respond to changing circumstances.
Planning Strategies	The extent to which the sector continuously monitors and reviews its plans and strategic capability. The degree to which the sector can manage vulnerabilities.

In line with current trends in critical infrastructure strategy, this attribute group incorporates many aspects of traditional critical infrastructure protection approaches. Sector Wide management of risk is in line with the embedded risk management principles present in many countries with comprehensive CIR strategies (The Critical Five, 2014). Evolution, innovation and creativity is grounded in organisational resilience concepts such as 'bricolage' (Weick, 1993) as well as more recent work looking at the response to the September 11 terrorist attacks (Kendra & Wachtendorf, 2003). Unity of Purpose, sharing a common goal or guiding principles, underpins many of the response and protection aspects of national governments (The Critical Five, 2014) but also crosses over with resilience as a factor for managing vulnerability (Lee et al.,

2013). Adaptive Capacity is a key part of both organisational resilience and national CIR plans. The United Kingdom, for example, includes this trait as part of the process of learning and understanding risks and uncertainties and doing better than "bouncing back" (Cabinet Office (UK), 2011). The United States also include adaptive capacity in their definition of infrastructure resilience as the ability to function outside of normal circumstances (National Infrastructure Advisory Council, 2010). Starr et al. (2003) suggest an organisation's ability to adapt is at the heart of their ability to display resilient characteristics. We believe this applies equally to a whole of sector resilience measurement. Planning strategies (which includes monitoring and reviews) and managing vulnerabilities were identified by McManus et al (2008) as a critical component of resilience when performed with co-dependent organisations.

The model holds true to the definitions of resilience given earlier, with inclusion of attributes and indicators for identifying vulnerabilities, adaptability, and connection pathways, and was developed specifically for the complex environments critical infrastructure sectors work in.

An instrument to indicatively measure sector resilience

Based on this sector resilience model, items were developed for each indicator following the processes outlined by Hinkin (1998). The model and indicator definitions described above provided a clear theoretical foundation where each component of the definitions was used to deductively develop between 3-11 items, depending upon the complexity of the item. A 5 point Likert scale was used with responses ranging from Strongly Disagree to Strongly Agree. A 'don't know' option was also included to ensure that completion rates were not hindered by respondents exiting the survey if sections were not within their area of expertise. Once the survey tool was drafted, a pilot study was conducted with selected representatives to check the usability of the survey tool and face validity of the items. The survey was then sent to the Australian Statistical Clearing House, a mandatory step in Australia to ensure that Government surveys conducted of businesses in Australia are fit for purpose and not too onerous on business. Table 4 gives an example illustrating the survey questions for the indicator "*Sector wide management of risk*". The questions can be reframed to provide a checklist to assist in formulating a future work plan to improve sector resilience.

Table 4 - Survey questions for Sector Wide management of risk

	Strongly Disagree ← → Strongly Agree					Don't Know
Sector members share information about threats and risks that impact across the sector						
Our sector has a comprehensive understanding of shared threats and risks						
Our sector collaboratively and effectively manages and mitigates sector level risks						
Sector members understand the business continuity capabilities of other sector members						

Our sector is effectively governed by an independent industry regulator including statutory requirements and obligations regarding business continuity and crisis management						
Our sector effectively manages strategic risks						
Our sector has the capacity to effectively manage unforeseen risks						

The question structure differed for two indicators – *Cross-sectoral relationships* and *External networks*. For these indicators, organisations were first asked about the extent of their dependency on other sectors. Skip logic was then applied to ask dependency questions only in relation to sectors with a moderate or high dependence. For example, "*Our sector has developed crisis arrangements with*" or "*For sectors dependent on our sector, to test planning arrangements, our sector participates in joint exercises and cross sector activities with*", followed by a list of the other sectors and a rating scale.

Application of the Tool to Critical Infrastructure Sectors in Australia

As part of the Australian Government's Critical Infrastructure Resilience (CIR) Strategy a benchmarking survey was conducted with participation from members of the Trusted Information Sharing Network (TISN) and non-member critical infrastructure providers. The TISN was formed by the Australian Government in 2003 and is the "primary national engagement mechanism for business-government information sharing and resilience building initiatives" (Australian Government, 2015a, p. 2). The aim of the TISN is to provide a forum for business owners from seven sectors (Banking and Finance, Health, Food and Grocery, Transport, Water Services, Communications, and Energy) and the Government to share non-commercial information, cooperate across sectors, and to address business continuity and security issues. The TISN has special provisions to allow discussions between competitors that might otherwise breach the Australian competition and consumer regulations.

In total, 527 respondents holding senior positions within critical infrastructure organisations were invited to participate in the survey over a three-week period. A total of 209 valid responses were received across the seven sectors of the survey population, a 40% response rate. Scores were generated for each indicator and attribute and for overall resilience for each sector by calculating the average response to each statement.

The aim of the survey was to provide organisations within each sector, and the government, an opportunity to consider and assess each sector's resilience capabilities against the resilience model, prompting them to assess existing arrangements for multi sector and multi government responses. This was accomplished by establishing an indicative benchmark sector resilience measure for each of the sectors and sharing the benchmark information with sector groups. Reports were compiled for each sector providing overall summary results as well as analysis at

question level to support stakeholders in identifying strengths to leverage and opportunities to improve the resilience of each sector. Reports were highly visual and designed to be able to be easily digested by a broad range of end users, from the C-suite to operational managers.

It is important to note that the results of the survey were intended to be used as a basis for relative comparison rather than as an absolute measure of resilience. For example, the survey revealed gaps in perception of upstream and downstream dependencies, indicating an area where attention could be paid to better understand potential deficiencies and to enhance risk management – the latter being one of the intended outcomes of the critical infrastructure sector strategy. A higher score achieved by a given sector over another sector in a particular area would serve as a focal point for analysis, reflection, and discussion of why those scores were generated, rather than as an indicator of a failing sector.

Results

Sector Resilience Model Reliability

To validate the theoretically derived Sector Resilience Model and measurement instrument, a series of statistical analyses were carried out using 209 responses from across 7 critical infrastructure sectors in Australia. The results of these analyses allow us to determine whether the questions, indicators and attributes that comprise the Sector Resilience Model are appropriately grouped and that they all measure the same underlying theoretical concept.

First, a scale reliability test (Cronbach's Alpha) was carried out to ensure that the questions within each indicator are internally consistent. The results showed that the questions within each indicator were internally consistent with a Cronbach's Alpha >0.7 (Hinkin 1998) and, therefore, measuring the same concept (Table 5).

Table 5 - Scale reliability results

Indicator	Cronbach's Alpha
Leadership and Co-ordination	.935
Resilience Attitudes	.910
Situational Awareness	.866
Engagement and Sharing of Information	.890
Managing Cross-Sector Dependencies	.908
Effective Cross-Sectoral Partnerships	.922
Management of Supply Chains	.937
Strong and Effective Business & Government Partnerships	.881

Redundancy of Sector Essential Functions and Common Sector Systems	.825
Sector-Wide Management of Risk	.937
Evolution, Innovation and Creativity	.921
Unity of Purpose	.949
Adaptive Capacity	.921
Planning Strategies	.954

Next, an exploratory factor analysis, at the indicator level, was carried out. The factor analysis looks at the indicators and determines whether there is an underlying theoretical construct. That is, whether the three-attribute model shown in Figure 2, is a suitable way to group the indicators. The analysis showed that the indicators fall into just two theoretical constructs (see Table 6), but the constructs largely align with the theoretical model.

Table 2 – Two Factor Sector Resilience Model

Sector Culture and Cohesion and Sector Agility and Change Readiness	Sector Dependencies and External Networks
• Leadership and coordination • Resilience attitude • Situational awareness • Sector engagement and information sharing • Redundancies and common sector functions • Sector-wide management of risks • Unity of purpose • Adaptive capacity • Planning strategies	• Understanding and Managing Cross-Sector Dependencies • Effective Cross-Sectoral Partnerships • Managing Supply Chains • Strong and Effective Business and Government Partnerships*
*Groups with both constructs	

All indicators in the *Culture and Cohesion* attribute and the *Change Ready* attribute group together. Three of the four network indicators (*Understanding and Managing Cross-Sector Dependencies*; *Effective Cross-Sectoral Partnerships*; and *Understanding and Managing Supply Chains*) grouped together in a separate construct. The fourth network indicator, *Strong and Effective Business and Government Partnerships*, groups with the first construct; however, there is also a weak association with the second factor. Given the theoretical links between the four network indicators, it is reasonable to group these together, as per the original model, and so the three-attribute model was retained. A scale reliability test at attribute level showed a high degree of consistency with the three-factor model (Table 7).

Table 7 - Scale reliability attributes test result 3 factor model

Attribute	Cronbachs Alpha
Sector Culture and Cohesion	.911
Sector Dependencies and External Networks	.774
Sector Agility and Change Readiness	.954

It should also be noted that in the second construct, *Understanding and Managing Cross-Sector Dependencies* and *Effective Cross-Sectoral Partnerships* grouped more strongly together than with *Managing Supply Chains*. This may have been due to the different format of these questions (respondents answered questions relative to specific sectors). Further analysis into the format of these questions should be considered for future surveys.

Australian Critical Infrastructure Sector Resilience

Unfortunately, for reasons of confidentiality, the specific results for each sector are unable to be shared, but we are able to present results at an aggregate level (Figure 3).

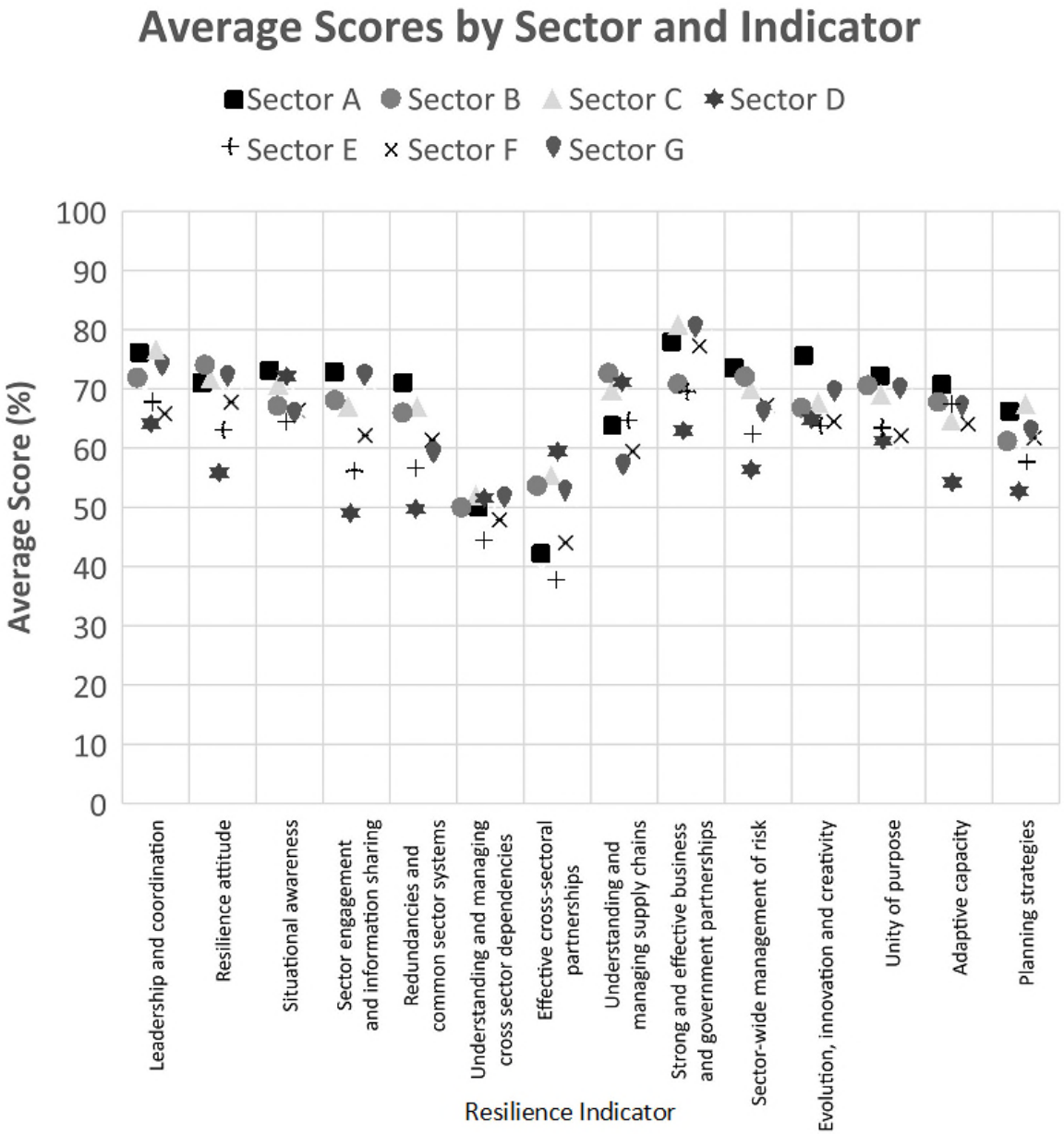


Figure 3 - Sector results by resilience indicator

Across the seven Australian critical infrastructure sectors (Banking and Finance, Communications, Energy, Food and Grocery, Health, Transport, and Water Services), an area of perceived common strength was *Strong and Effective Business and Government Partnerships*, followed closely by *Understanding and Managing Supply Chains* and *Situational Awareness.* These positive results indicate that the existence of the TISN network is a key enabler of information sharing both across sectors and with the government.

In general, the weakest indicators for the Australian critical infrastructure sectors were *Effective Cross-Sectoral Partnerships* and *Cross-Sector Dependencies*. The survey revealed significant gaps between the perceived and actual dependencies of sectors. In other words, the sectors did not agree with each other as to their relative dependence on one another. This is a strong indication

of an area needing further exploration and discussion within and between sectors as to where their dependencies exist, as this is a critical element for identifying vulnerabilities and preparedness plans.

There were significant differences between the resilience profiles of each of the sectors, suggesting that there are few 'cookie cutter' solutions for how to improve critical infrastructure sector resilience. The regulatory and competitive environment appears to provide a powerful context from which resilience behaviours (both positive and negative) emerge. For example, the highly regulated and monitored sectors scored very high for *Sector Engagement and Information Sharing*, whereas a less regulated sector achieved a much lower score in this indicator. Conversely, the lesser regulated sectors performed better on the externally focused *effective cross-sector partnerships.*

Overall feedback from users of the survey results suggest that this is a useful tool for effectively prioritising and focusing efforts to build resilience. It enables the tailoring of advice, targeted to the context of each sector.

Limitations and Future research

The first development, and use of a model and associated measurement tool provides an important opportunity to reflect on its efficacy and identify areas for improvement. In this section, we reflect on its limitations and further development work needed.

By their nature, self-assessment tools are limited by the degree of participation from the sample population and their ability to self-reflect and respond to the survey. The survey also relied on self-reporting which assumes sufficiently accurate knowledge of the organisation and sector. Other research on organisational resilience noted a similar limitation when surveying a single respondent from an organisation and recommended multiple respondents per organisation (Lee et al., 2013). While there were multiple respondents from within each sector (thereby presenting a meaningful representation for a sector), having input from multiple respondents within a single organisation may have given a richer dataset although with greater complexity. However, care needed to be taken for practical considerations when deploying the survey and not overburdening organisations with a lengthy survey for multiple personnel to complete. On that note, the overall dropout rate for respondents was 25%, indicating the length of the survey instrument is an issue. Should the survey be redeployed, in particular if more respondents from single organisations are involved, a shorter version may be necessary. Overall, the results of the case study were enough to be representative for the population identified as the critical infrastructure sector overall even though some sub-sectors were not as strongly represented as others.

In terms of the model itself, in the written responses, several respondents noted potential limitations of the approach taken to sector resilience. For example, one respondent noted that

during a crisis, organisations within a sector will respond but it is not the sector on the whole that is acting (i.e. not all geographies). It is the sector members within the geographic areas affected by the crisis. Therefore, the responses may be skewed by geography based on their exposure to hazards and certain sectors may have greater resilience in certain locations than others. This is the nature of a broad survey, so for a more nuanced understanding of a sector, or a geographical area (a business precinct or a city), smaller scale studies could be conducted.

Similarly, the survey format offered limited insights into organisational resilience. As discussed earlier, sectoral resilience comprises both individual organisations and the environment and systems that allow the sector to survive and thrive. There may be strengths (or weaknesses) within organisations that could contribute to (or detract from) sector resilience but were not revealed by the survey. Organisations may also have different objectives or aims that would lead them to act in isolation to the sector. They also may have a limited 'outward-looking' perspective on the resilience of the sector if they are not actively engaged with the sector. This might make it difficult for individual organisations to give accurate responses to the sector-level resilience questions. This is further evidenced by the 104 respondents who indicated 'don't know' at some point in the survey. A supplement to the sector resilience measure would be an organisational resilience measure. This would allow us to better analyse and understand the interplay, and mutual beneficence (or not), between organisational resilience and sectoral level resilience.

Currently the model gives equal weight to all Attribute categories and all Indicators but they may not all be equally important to all sectors. Resilience by its nature is not a static concept but a dynamic and fluid construct (Australian Government, 2015a). The nature of a sector at a given time can make certain attributes more important to the sector's health than others. That is not to say some are irrelevant, but they may simply be constrained by context – either the characteristics of the organisation itself, the turbidity of the market it operates in, or other external contextual factors. One of the major attributes for resilience is collaboration, but certain industries are prohibited from many types of collaboration for legal reasons. Some sectors face anti-collusion laws which may either limit their forms of interaction or cause a degree of wariness about collaboration from both regulators and sector organisations. In Australia, the TISN is an effective means to limit this barrier, however this many not exist in many other contexts. On the other hand, survey respondents noted a strict regulatory environment can be an enabler for unity of purpose and creating common values and understanding. Additionally, many government agencies that may benefit from collaboration, either with other public sector organisations or with the private sector, may find it difficult given the limits of their statutory mandate. These differing contexts must be considered when comparing scores across sectors.

This benchmarking survey was conducted qualitatively at one point in time providing a snapshot. Repeated use of the tool would give a richer measure of changes and trends over time. The survey also relies on leading indicators, which are only as accurate as the self-

assessments that provide them. Further assessment, post-crisis, would allow some 'lagging' indicators or metrics to be used to assess the robustness of the 'leading' indicator approach. This would potentially provide a rich dataset for comparison and would help to identify trends that could be fed back into the model.

Conclusions

This paper presented the development of an initial conceptual model of sector resilience. Building from this conceptual model, a survey instrument was created for qualitatively evaluating perceptions of sector resilience. This survey was then used in a case study to benchmark the resilience of 7 critical infrastructure sectors in Australia, to evaluate its ability to offer insights into resilience strengths and weaknesses that different sectors exhibit. Overall, the survey process and results provided an effective basis for engendering discussion among the critical infrastructure sector stakeholders about the most appropriate places for investing resources to build resilience, and for reflection on how and why certain resilience indicators fared as they did.

Sector resilience is a relatively new construct, and this was the first deployment of the sector resilience benchmarking tool. Additional uses of the tool in different contexts, at smaller scales, in comparison to other measures of resilience such as organisational resilience, or utilising post-crisis reflections and assessments would help to further validate the model.

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