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Quantifying organisational resilience: an integrated resource efficiency view

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ABSTRACT

Organisations are increasingly exposed to risks from globally disruptive events, triggering interest and new research into organisational resilience. Several levers to increase resilience are defined in the literature but organisations still find it challenging to prepare for the next disruption. This study contributes to the resilience literature by drawing on the integrated resource efficiency view (IREV) framework to measure four levers of organisational resilience and derive an organisational resilience index (ORI). Levers include resiliency management, business continuity and organisational learning capacity, which are related to the levels of preparedness of the organisation for potential disruptions, and operational flexibility, which relates to how quickly it can reconfigure resources in changing situations. Results show that a composite index encompassing the four levers is strongly associated with increased organisational resilience. The ORI provides leaders and decision makers with an approach to assess resilience at the level of the whole organisation and with sample groups, such as business type or geographical location, enabling structured multi-level comparisons and analysis. Furthermore the ORI helps managers target attention and resources to improve preparedness and take action to mitigate constraints on operational flexibility.

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Organisational resilience; resiliency management; business continuity; organisational learning capacity; operational flexibility; resource efficiency

1. Introduction

Organisations and societies are exposed to potentially disruptive risk categories that include incidents of malicious attacks, serious and organised crime, environmental hazards, human and animal health, and major accidents and societal risks (HM Government 2020). High-income and fast-growing middle-income countries lost an estimated $1.2 trillion from disruptive shocks such as storms and floods in a single decade (OECD 2019). Following unprecedented natural disasters in 2004/05 (Indonesian tsunami, Hurricanes Irene and Katrina), the US Homeland Security Council addressed the need for resilience of infrastructure systems and communities, with Presidential Policy Directive (PPD)-21: Critical Infrastructure Security and Resilience, signed in February 2013, defining resilience as 'the ability to prepare for and adapt to changing conditions and withstand and recover rapidly from disruptions' (PPD-21 2013). The COVID-19 pandemic disrupted organisation operations due to lockdowns, border closures, manufacturing reductions and transportation challenges (Allam, Bibri, and Sharpe 2022) and caused critical shortages of essential and medically critical goods (Sodhi, Tang, and Willenson 2023) and ripple effects on the supply chain (Dolgui and Ivanov 2021). Russia's escalation of the war in Ukraine in 2022 resulted in commodity price inflation in energy, metal supplies, food, wood and other raw material imports (Prohorovs 2022). Such operational disruptions force organisations to adjust order-fulfilment plans and can negatively impact delivery reliability (Cotta and Salvador 2020).

Resilience to disruptive events is an important managerial concern and is spoken of as an 'umbrella concept' with many factors, definitions and concepts (Vakilzadeh and Haase 2021). Resilience can mean any one of three outcomes: robustness or resilience, relating to an organisation's ability to absorb a disturbance and maintain its performance; stability or recovery, relating to its ability to recover and return to an original performance state; or adapting or benefiting, relating to its ability to adapt to the disturbance and move to a new equivalent or better state (Helfgott 2018). Dimensions of organisational resilience include relational resilience and operational resilience (Yilmaz Börekçi et al. 2021). Existing studies (Ambulkar, Blackhurst, and Grawe 2015; Lee, Vargo, and Seville 2013; McManus 2007; Verreynne et al., 2023) have examined antecedents and dimensions of resilience to operationalise organisational resilience.

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While organisational resilience is considered a capability that can be improved over time, however, there is no consensus over the elements that can improve it or how to assess it (Ruiz-Martin, Lopez-Paredes, and Wainer 2018; Vishwakarma et al. 2023). This study seeks to contribute to the resilience literature by examining the following research question: how can managers operationalise a measure of organisational resilience within their organisations that assists with the bespoke (Cohen et al. 2022) development of strategic planning, operational processes and resources allocation to increase resilience?

In the following sections we present the development of our hypotheses and the research methodology underpinning our calculation of organisational resilience. In section 2 we review micro and macro-level aspects of organisational resilience, consider the antecedents of organisational resilience and approaches to measure resilience, identify the research gap addressed by this paper and develop hypotheses and a construct model. In section 3 we describe our research methodology to implement the data collection and measurement protocols required to validate our hypotheses and construct model. We develop a scale to measure organisational resilience that focuses on 'observable processes, actions and practices that are thought to contribute to the organisation's resilience' (Lee, Vargo, and Seville 2013) and develop a composite index called the organisational resilience index (ORI). Following that, we present our findings in section 4. The key finding is that the ORI arrives at a similar mean to a simple measure of stated resilience based on a single question that asked respondents how resilient they felt their facility was, while decreasing the measured standard deviation. We then discuss how the results and findings contribute to resource efficiency debate and theory and their implications for managers and researchers in section 5, and conclude in section 6 with a summary of the research, limitations and suggestions for future work.

2. Theoretical development

2.1. Theoretical and system-level aspects of organisational resilience

Micro-level theories of organisational resilience explain how individual behaviours, attitudes and actions contribute to organisational resilience. Connelly and Shi (2022) surveyed the theoretical landscape of general management for those that might explain organisational responses to threats. Theories aimed to explain managerial level perspectives (Chen 1996; Rogers 1975; Shi, Connelly, and Cirik 2018; Stephan and Stephan 2000; Tversky and Kahneman 1974), organisation and environment level perspectives (Bendoly et al. 2006; Cyert and March 1963; Hannan and Freeman 1977; Thomas, Clark, and Gioia 1993), and leadership and social capital perspectives (Adler and Kwon 2002; Hambrick and Mason 1984) are the most dominant. COVID-19 highlighted the intertwined nature of modern supply networks as complex adaptive systems, leading to operational responses such as jury-rigging (recombining components) by organisations to meet the resulting variety of demands on the system, conceptualised by Ashby's law of requisite variety, and the consequential effects on resilience (Feizabadi, Gligor, and Choi 2023). The nature of resources in the organisation, captured in the resource based view (RBV), coupled with its relationship to the natural environment, captured in Hart's (1995) natural resource based view (NRBV), has been used to study the impact of top-down directives on production operations in supply chains (Koh et al. 2013; Koh et al. 2016). DesJardine, Bansal, and Yang (2019) found that strategic practices requiring large resource commitments and significant organisational structural adjustments over a long time horizon contributed more to organisational resilience than tactical practices focused on short-term improvements that required few resources. The capability of managers to respond under conditions of rapid change may be explained by the NRBV complemented by the dynamic capabilities perspective, which emphasises the need for effective processes and routines to use resources (Barney et al., 2011).

System-level disruptions can stem from a variety of sources including: shocks such as Covid-19, natural disaster, terrorism, cyber attack, war or political-economic turmoil; fires or strikes at local or overseas suppliers; natural resource depletion; or operational risks such as quality defects (Gunasekaran, Subramanian, and Rahman 2015; Jin et al. 2023; Pu, Ma, and Yan 2023; Vann Yaroson et al. 2023). These sort of disruptions have become a new norm. They have direct consequences on operations stability and organisational performance, and hence have triggered a strong appetite in improving organisational resilience. Organisations with prior experience in managing disruptive events can significantly reduce disruption severity when faced with similar events again (Baghersad et al. 2022; Sajko et al. 2021). Managers need to proactively identify and manage resources such as material, energy, technology, environmental, social, economic, individual and socio-cultural capital that impact on the organisation as a system (Koh et al. 2016; Koh et al. 2017). Cohen et al. (2022) suggested that due to the interconnected complexity of real-world organisations a systems theory approach is required to take a tailored or bespoke assessment and allocate resources towards improving resilience.

Table 1. Organisational capabilities contributing to organisational and supply chain resilience.

Authors	Focus area	Organisational capabilities
Münch and Hartmann (2023)	Supply chain resilience	Agility, collaboration, digital preparedness, flexible redundancy, human resource management, contingency planning, transparency and visibility
Barasa, Mbau, and Gilson (2018)	Organisational resilience	Material resources, preparedness and planning, information management, collateral pathways and redundancy, governance process, leadership practices, organisational culture, human capital, social networks and collaboration
Nikookar and Yanadori (2022)	Supply chain resilience	Supply chain visibility, supply chain responsiveness, supply chain flexibility
Ivanov (2022)	Supply chain resilience	Viability, sustainability, agility, organisational, informational, process-functional, technological, and financial structures
Ivanov and Dolgui (2022)	Supply chain resilience	Viability, survivability
Polyviou, Croxton, and Knemeyer (2020)	Organisational resilience	Human resources and internal social capital
Vakilzadeh and Haase (2021)	Organisational resilience	Leadership, resources, organisation governance, culture and practice, business model and innovation, resilience plans, environmental scanning, learning, organisational change management
Morales Allende et al. (2017)	Organisational resilience	Organisational pathology
Vanpoucke and Ellis (2020)	Supply chain resilience	Risk propensity
Rubbio et al. (2020)	Organisational resilience	Individual practices, organisational routines
Wissuwa, Durach, and Choi (2022)	Supply chain resilience	Internal complexity, complex collaborations

2.2. Antecedents of organisational resilience

There is increasing interest in organisational resilience as a concept, with the number of papers published rising sharply from 2010 onwards (Ivanov and Dolgui 2022; MacDonald et al. 2018; Rahi 2019; Stevenson and Busby 2015). This paper follows the theoretical approach set out by Koh et al.'s (2016) integrated resource efficiency view (IREV), which is underpinned by the NRBV and systems theory, to operationalise measures of relevant variables and construct an organisational resilience index (ORI), with the aim of providing essential information in a transparent way to stakeholders. The IREV's two main premises are that participants evolve and adapt to resource challenges, and that environmental, social and economic capital reflect at a macro level aggregate characteristics of sub-systems within industrial ecosystems. Efficient organisational capabilities and practices to manage tangible and intangible resources under the IREV framework will 'diffuse' through into macro-level operations and results.

Table 1 outlines organisational capabilities and practices in the literature that contribute to resilience in organisations and their supply chains. We detail in Section 3.3 how we deduce four relevant dimensions of organisational resilience (resiliency management, business continuity, organisational learning capacity, and operational flexibility), beginning with a model from Ambulkar, Blackhurst, and Grawe (2015) that is then assessed through an expert judging process and the published literature. Organisational functions such as resiliency management (RM) address capabilities such as leadership, governance, scanning and planning for future disruptions, while business continuity (BC) develops agile, collaborative and practised responses to disruptive events. These functions are supported by learning (Wang et al. 2023) from and reflecting on previous responses to disruptions (Duchek 2020), and the integration of such learning onto operational processes and routines, referred to as organisational learning capacity (OLC). The range of responses is constrained by characteristics of the organisation such as resource redundancy, material availability, and process complexity that limit its ability to operate flexibly when experiencing a disruptive event, termed operational flexibility (OF). We identify for this study these four areas: RM; BC; OLC; and OF, as levers to enable the operationalisation of capabilities and practices that lead to organisational resilience. The following sections elaborate on the development of the measurement approach.

2.3. Measuring organisational resilience

Resilience can be measured across two dimensions: awareness and adaptive capacity. Indicators used to assess organisational awareness include efficiency of organisational networks, clarity of roles and responsibilities, alertness to the organisation's health, minimisation of organisational barriers and adoption of an innovation culture. Indicators assessing adaptive capacity include mobilisation of resources, employee engagement, leadership, access to information, decentralised decision-making and organisational analytical capabilities (Rahi 2019). Organisational resilience has also been inferred from organisational outcomes such as the rate of recovery in stock prices or sales following a shock (DesJardine, Bansal, and Yang 2019).

Extant measures in the literature use a range of factors to operationalise organisational resilience. McManus et al. (2007) defined resilience management as the planning that an organisation may have done, linking the relevant activities that may be carried out across the

organisation under one umbrella, and defined relative overall resilience (ROR) as a function of an organisation's situation awareness, management of keystone vulnerabilities and adaptive capacity. Lee, Vargo, and Seville (2013) chose ROR as the starting point to develop a survey tool to operationalise and measure organisational resilience as a function of adaptive capacity and planning but found that neither the original three-factor model or an adjusted four-factor model were supported by the data (33, 34). Ambulkar, Blackhurst, and Grawe (2015) developed, operationalised and validated a cross-sectional resilience measurement scale at the organisation level that considered three antecedents of resilience: the extent to which organisations recognise and are aware of pending disruptions and their approach to analysing and learning from prior disruptions; the risk management infrastructure they have in place; and their resource reconfiguration capabilities, and suggested that the future research should increase the number of respondents from each organisation and extend the research to encompass additional approaches. Although not an organisational resilience scale, Chowdhury and Quaddus (2017) developed a scale for measuring and validating three dimensions of supply chain resilience that predicted the operational vulnerability and performance of supply chains: the proactivity of organisations in scanning for environmental changes and being sufficiently flexible and adaptive; their reactive capabilities to reconfigure resources to recover from disruptions; and the density, complexity and criticality of their supply chain network. Verreynne et al. (2023) developed a scale of strategic organisational resilience that measures readiness, slack, problem-solving, flexibility, connectedness, adaptiveness and proactiveness, by applying a combination of six existing scales, with a focus on small-medium size enterprises in Australia.

As the ROR model was not supported by the data, Ambulkar, Blackhurst, and Grawe's (2015)' study has been chosen as the starting point for this study as it operationalises specific antecedents of resilience that can be tested and extended. In addition, it was carried out in the context of organisational resilience rather than supply chain resilience (Ivanov 2023b), making it a closer fit for our research question. It also provided a sound model for developing additional antecedents and addressed the limitations of the existing study, which only has one respondent from each company, by widening the results to include multiple respondents from the same organisations. Finally, other contemporaneous work focused on smaller organisations in a single country, while this paper focuses on large businesses operating in several countries.

2.4. Research gap addressed in this study

Industries are transitioning from shareholder value to viable stakeholder value based enterprises under the concept of Industry 5.0, which highlights emerging organisational principles and technologies that will lead to sustainable, human-centric and resilient organisations (Ivanov 2023a). Scholars have identified a need to move from studying definable risks to studying the capabilities and capacities that lead to organisational resilience (Van Der Vegt et al. 2015) and to consider threats that pose a risk to entire industries or countries, such as those posed during humanitarian logistics and disaster management (Kunz et al. 2017). In addition, an aspect that has hardly been investigated is how organisational resilience varies across industries and whether the characteristics of production systems influence the organisation's ability to be resilient (Dittfeld, van Donk, and van Huet 2022). Initial resilience strategies are designed to address the primary complexities faced by different supply chains (Saisridhar, Thürer, and Avittathur 2023) but can be enhanced by making bespoke or tailored adjustments to improve resilience capacity, supporting a shift from a one-size-fits-all approach to a bespoke or tailored one that addresses specific operational characteristics of a business, its individual environment and its supply chain (Cohen et al. 2022). In view of the increasing importance of resilience to organisations and in response to recent calls for methods to operationalise (Cerabona et al. 2023; Cohen et al. 2022; Münch and Hartmann 2023) measures of resilience, this study aims to develop an organisational resilience index (ORI).

While existing studies address specific antecedents of resilience and develop frameworks for measuring resilience, this study aims to (a) develop a methodological tool for managers to carry out a top-down assessment of organisational resilience that reflects the aggregate routines and practices across the organisation and (b) enable managers to use four levers of organisational resilience to proactively design bespoke strategic and operational interventions to increase resilience in their organisations.

2.5. Hypothesis development

In this study, we postulate that organisations with resiliency management (RM) can enhance organisational resilience. Organisational resilience is further improved through the application of business continuity (BC) procedures and the capability of the organisation to learn and share lessons, termed organisational learning capacity (OLC). The characteristics of operational flexibility (OF) enhance or limit organisational resilience.

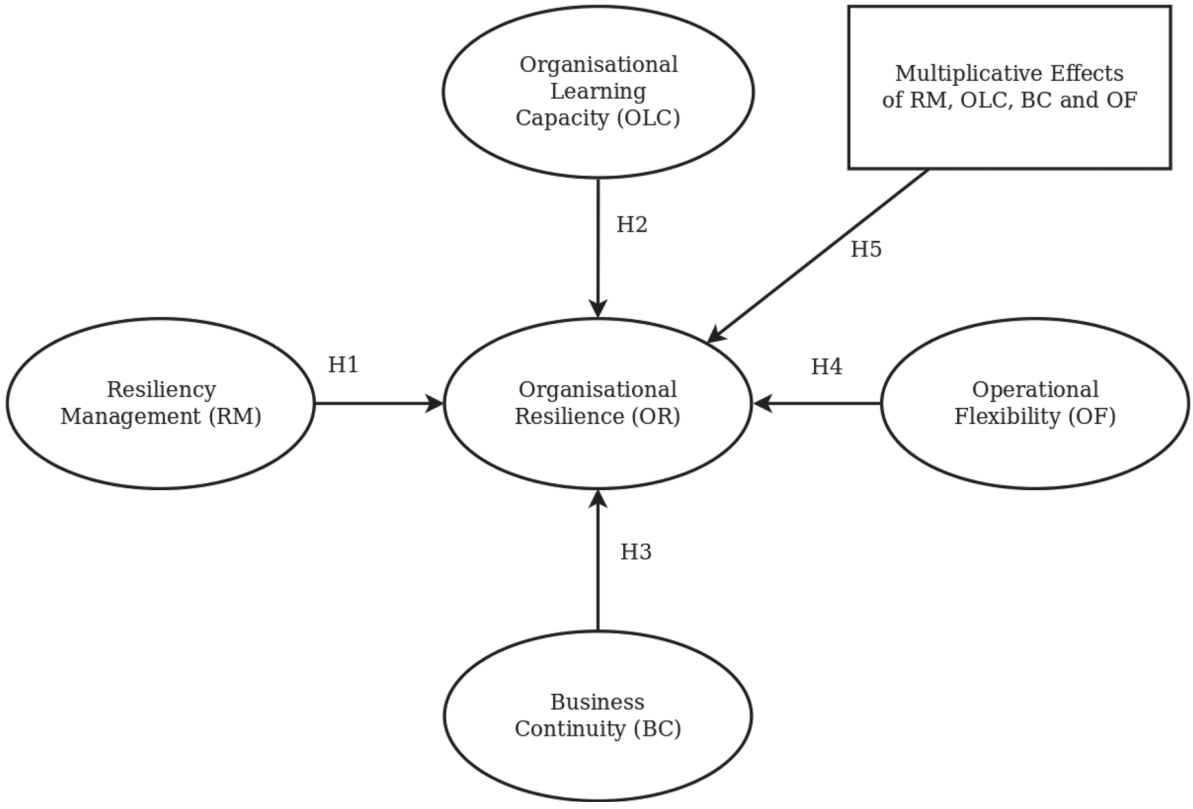

Figure 1. Proposed organisational resilience construct model.

Resilience can be calculated as a composite function of these factors, allowing for the limitations and interrelationships between them, building on the IREV that takes a systems perspective to construct measures, which provide essential information in a transparent way to stakeholders (Koh et al. 2016). Building from these theoretical frameworks and viewpoints, we develop five hypotheses that form the foundation of the measurement of organisational resilience as shown in Figure 1.

2.5.1. Resiliency management (RM)

RM is a subset of risk management within organisations in this study, as risk management was defined by participating stakeholders as a wider end-to-end assessment of risks to an organisation, while RM addresses the elements of risk that managers within organisations need to consider that affect organisational resilience. Resilient organisations are thought to maintain high performance levels in even complex and competitive environments (Rodríguez-Sánchez et al. 2021). Organisational routines shape institutional responses to environmental uncertainty (Lengnick-Hall and Beck 2005). Operational resilience, an aspect of organisational resilience, is defined as the survival and sustainability of an organisation's operations including task completion, work performance and product delivery (Yilmaz Börekçi et al. 2021). RM has four cornerstones: responding, monitoring, anticipating and learning (Hollnagel 2009) and responses can be restorative, adaptive or transformative (Yilmaz Börekçi et al. 2021). Based on the above, our first hypothesis (H1) links RM with organisational resilience.

> **H1.** Enhanced resiliency management (RM) increases organisational resilience.

2.5.2. Organisational learning capacity

Resilience capabilities depend on the availability of knowledge (Lichte, Torres, and Engler 2022). The capacity of an organisation to emerge stronger from a crisis is linked with the idea of learning (Boin and van Eeten 2013). Organisational learning capacity (OLC) is defined as the organisational and managerial characteristics that facilitate the organisational learning process or allow an organisation to learn (Goh and Richards 1997). Five essential dimensions of OLC are experimentation, risk-taking, interaction with the external environment, dialogue and participative decision-making (Chiva, Alegre, and Lapiedra 2007). OLC has a beneficial effect on organisational performance (Rodríguez-Sánchez et al. 2021) and is a strategic means to achieve long-term organisational success (Liao and Wu 2010). The ability to learn is one of five core capabilities (the others are the ability to anticipate, adapt, respond and recover) that

affect organisational resilience (Ali, Mahfouz, and Arisha 2017). For these reasons, we predict that OLC supports RM in enhancing organisational resilience (H2).

H2. Enhanced organisational learning capacity (OLC) increases organisational resilience.

2.5.3. Business continuity (BC)

Business continuity (BC) planning is the practice of developing appropriate plans to resume key business operations immediately after a disruptive event (ISO 22301, 2019) and is an important strategic steering instrument for senior management (Lindström and Hägerfors 2009). Effective and efficient BC plans must address the key measures that matter for an organisation in order to maximise resilience (Rezaei Soufi, Torabi, and Sahebjamnia 2019). BC planning contributes to organisational resilience by enabling the resumption of operations to a minimum acceptable level within a minimum acceptable time (Losada, Scaparra, and O'Hanley 2012; Sahebjamnia et al. 2015). Measures of BC are motivated by existing assessments of resilience that identify critical processes and activities to construct metrics that are used for organisational communication and the effective use of resource allocation for efficient recovery (Namdar et al. 2021). Based on this we predict that BC planning supports RM and OLC in enhancing organisational resilience (H3).

H3. Enhanced business continuity (BC) increases organisational resilience.

2.5.4. Operational flexibility

The ongoing success of organisations has been studied under the theory of dynamic capability, ambidexterity, absorptive capacity and agility (Thomas and Douglas 2022). An organisation's ability to reconfigure resources in changing situations and uncertain environments swiftly and effectively determines whether or not it can maintain its competitive advantage (Parker and Ameen 2018). Flexibility and redundancy are capabilities that increase organisational resilience but which can also be associated with significant additional costs (Sheffi and Rice 2005). The ability to manage and reconfigure resources enables the development of adaptive capabilities that bolster organisational resilience (Ambulkar, Blackhurst, and Grawe 2015). Strategies for improving resilience include increasing flexibility, creating redundancy, constructing collaborative supply chain relationships and improving supply chain agility (Tukamuhabwa et al. 2015). Conversely, operational constraints on the flexible deployment of resources can limit an organisation's ability to respond. Based on the above we predict that operational flexibility will enhance organisational resilience (H4).

H4. Improved operational flexibility (OF) increases organisational resilience.

2.5.5. Multiplicative effects

Traditional approaches to preparing for potential adverse events may include using historical data, probability distributions and sophisticated modelling to identify risks and predict future disruptive events, although in several cases these practices have provided insufficient protection when adverse events materialised (Van Der Vegt et al. 2015). A disruptive event progresses in a typical profile, beginning with preparation before the event for a range of potential disruptions, and then with the crystallisation of a specific event initiating a chain reaction of first response, initial impact, full impact, recovery preparations, recovery and long-term impact (Sheffi and Rice 2005). This profile is compressed in the antecedents, disruption and outcomes (ADO) model to consider a resilience process that considers three phases: pre-adversity; adversity; and post-adversity (Su and Junge 2023). Our first four hypotheses consider relevant antecedents of organisational resilience. Three of these antecedents are related to organisation specific preparatory activities and capability building that take place before a disruptive event (RM, BC and OLC) in the pre-adversity phase, and may form a supporting group of antecedents which may complement or have an impact on an organisation's OF, the fourth antecedent that may enhance or limit the ability for an organisation to respond to the impact of a disruption during the adversity and post-adversity phases. This leads to our fifth hypothesis that OF and the group of RM, BC and OLC may form two complementing groups of constructs that interact in a non-linear manner to affect organisational resilience. Based on the above, we predict non-linear multiplicative effects of RM, BC and OLC with OF on organisational resilience (H5).

H5: The block of levers RM, BC and OLC have a multiplicative relationship with OF that enhances or diminishes organisational resilience.

3. Research methodology

The current research aims to extend the empirical development of the measurement of organisational resilience. We developed a survey with new multi-item scales for resilience management, organisational learning capacity, business continuity and operational flexibility. Figure 2 shows our research methods and the steps taken in the research.

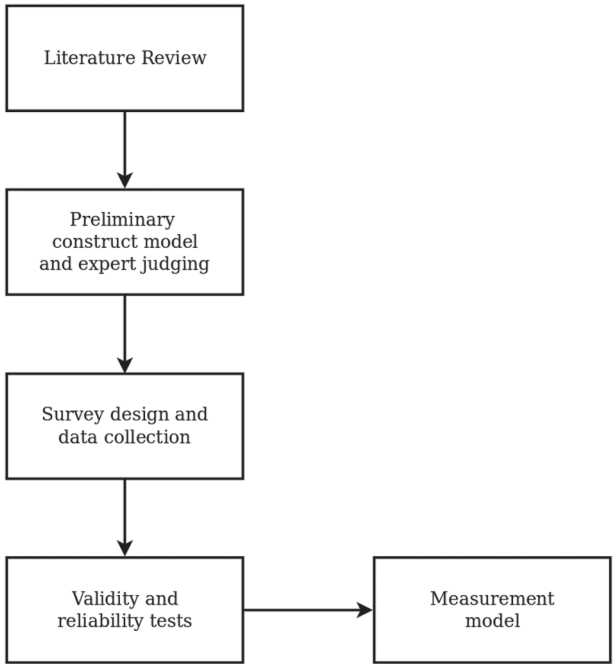

Figure 2. Research methods flow chart.

3.1. Context of the research

The study was carried out in four businesses operating in the civil aerospace, defence, power systems, and electrical sectors. The businesses operate in 49 countries and employ over 44,000 employees. The businesses had been working to simplify their approach to managing resilience within their internal supply chain and recognised that they needed an approach that enabled them to measure resilience. The aim of the study was to establish whether it was possible to measure in a quantifiable manner the concept of resilience within an organisation and, in doing so, carry out the following: define resilience; establish its elements, establish consensus on the relative importance of different areas; assess whether measurements could be carried out without overburdening the organisation; and codify the approach into a repeatable solution.

3.2. Overview of research steps

We began with a review of the relevant literature to understand extant methods of measuring organisational resilience, as described in Section 2, following which the research activity was carried out over five phases. We selected an existing work on resiliency by Ambulkar, Blackhurst, and Grawe (2015) which followed Gilliam and Voss's (2013) procedure for reviewing existing literature and developing a construct definition. Gilliam and Voss (2013) stress the importance of conceptualising and defining constructs in developing measurement models and propose an iterative six-step process for developing definitions of latent constructs as follows: write a preliminary definition; build a nomological network from the literature; assess the value added; refine the definition; expert judging process; and adjust definition and iterate.

In the first phase, from December 2021 to March 2022, seven working sessions were conducted lasting an hour each with core members of organisational security and resilience teams that were nominated to be part of the expert group supporting the research. The first session was an in-person introductory meeting followed by six working sessions held remotely using Microsoft Teams. A preliminary definition was taken from Presidential Policy Directive (PPD)−21: Critical Infrastructure Security and Resilience, which defined resilience as 'the ability to prepare for and adapt to changing conditions and withstand and recover rapidly from disruptions' (PPD-21 2013). This PPD-21 definition of resilience was adapted in this study, which led to the stakeholders agreed definition for organisational resilience as 'the ability to quickly adapt to disruptions while maintaining delivery to customer, business operations, whilst safeguarding people, assets and protecting overall reputation.' We then developed a construct model (nomological network) from the literature and went through a process of review and discussion with the expert group, which enabled us to assess the value added by the model, refine the construct definitions with further reference to literature and build the final model that could be used as the basis of a question set.

The data collection then moved into the second phase where a questionnaire was designed that used a 1–5 Likert scale to measure items that enhance organisational resilience. Ethics approval for the questionnaire and data collection protocols were approved by the ethics reviewers at the University of Sheffield (ref no 045927). No personal data was provided to researchers and organisations participating in the study took responsibility for ensuring appropriate informed consent was provided from participants as the researchers did not have access to participant information.

In the third phase, the questionnaire was piloted in four online meetings. Received data was used to carry out validity and reliability analyses. Results from these analyses were used to refine the organisational resilience construct model and its 4 variables: Resiliency management (RM), organisational learning capacity (OLC), business continuity (BC) and operational flexibility (OF). Five questions were removed that did not effectively measure exclusively one of the four variables. The final question set is provided in Appendix 1. The variables were combined to create a proposed measurement model of calculated resilience (CR) and create a combined measure termed the organisational resilience index (ORI) which

Table 2. Demographic characteristics of respondents ($n = 170$).

	Percent (%)		Percent (%)
Business type		**Area of operations**	
Civil Aerospace	25.9	Manufacturing	25.3
Defence	46.5	Office Based	45.9
Electrical	0.6	Research, Development & Testing	14.1
GBS / Head Office	4.7	Services	14.7
Power Systems	22.4		
Responsibility			
Accountable Person	34.7		
Responsible Person	41.8		
Security & Resilience	13.5		
Other	10.0		

was refined and finalised with the working group and operationalised into a final construct model, shown in Figure 1.

In the fourth phase, the finalised questionnaire was subsequently issued to a pool of participants. Responses were received from 170 individuals at four businesses in the civil aerospace, defence, power systems, and electrical sectors. Completed questionnaires were also received from individuals that operated at group level or head offices. Table 2 summarises the demographic characteristics of the respondents.

3.3. Construct model development

The development of the construct model was supported by an expert judging process carried out over six working sessions. We began with a model from Ambulkar, Blackhurst, and Grawe (2015) that operationalised three variables: supply chain disruption orientation (SCDO); risk management infrastructure and resource reconfiguration. These variables were assessed through expert judging sessions with a working group of group security and resilience teams, with 2–5 members in attendance at each session. A follow up session was held with a smaller team of senior risk specialists. These discussions highlighted that the conceptualisation of SCDO and risk management infrastructure did not align with organisational views at the participating companies and also led to the inclusion of organisational learning capacity (OLC) as a construct within our study. The risk specialists, in particular, were keen to emphasize that risk management was viewed as more than just completing and maintaining 'shiny registers' in their organisations. 'Shiny registers' are likened to risk registers, which can often be used as a tick box exercise. They characterised the typical activity of risk management that involves identifying hazards, creating a register and noting mitigating actions as having little real impact, dismissing it as a form of 'risk admiration'. Therefore, instead they argued that a risk management system should take a broader and deeper system view, encompassing the entire value chain beginning from an understanding of root causes to the impact on facilities and beyond, and assessing both the cost of risk and the price to the customer.

The set of activities relating to environmental scanning captured in 'SCDO' and the subset of risk management activities in 'risk management infrastructure' could be more usefully encapsulated in the construct of 'resiliency management', expressly articulating the importance of managing resilience within an overall framework of managing risk. Resiliency management was supported by business continuity and bolstered by the development of organisational learning capacity. An organisation's ability to respond was constrained by its operating characteristics, an aspect that we looked at initially using the construct of 'resource reconfiguration'. We chose to rename this, however, to 'operational flexibility' to widen the focus from resources, which can be viewed as limited to supply chain assets, to encompass actions, relationships, expertise, ability and capacity. The insights from the expert judging sessions also informed the development of the hypotheses underpinned by the literature articulated in Section 2.5 and the design of a survey as set out in Section 3.4.

3.4. Survey design and data collection

Operationalising the survey and carrying out validation and robustness tests were done in five steps. First, a long list of 99 questions that aimed to measure the four variables set out in Figure 1 that comprised resilience was subjected to an expert judging process and reduced to 33 questions adapted and enhanced from constructs and question sets in the literature (Ambulkar, Blackhurst, and Grawe 2015; Wei and Wang 2010). Second, this list of questions was tested with a validation group from the participating companies, consisting of managers with responsibility for risk management and reduced to 24 questions. A single question was added as a check measure that asked participants how resilient they felt their facility was, termed stated resilience (SR). In addition, participants were also asked to provide demographic

Table 3. Indicator factor loading and cross-loading assessment for the pilot ($n = 73$).

Indicators	Resilience management (RM)	Operational Flexibility (OF)	Organisational learning capacity (OLC)	Business Continuity (BC)
RM1	0.76			
RM2	0.70			
RM3	0.76			
RM4	0.66			
RM5	0.75			
RM6	0.72			
RM7	0.74			
OF1		0.69		
OF2		0.75		
OF3		0.77		
OF4		0.59		
OF5		0.68		
OF6		0.69		
OLC1			0.78	
OLC2			0.76	
OLC3			0.60	
BC1				0.71
BC2				0.73
BC3				0.56

Appendix 1 contains the question set.

data such as job role, responsibility level, business, country, facility and area to support with multi-level analysis and the development of a resilience measurement tool for managers. Third, the revised question set was then piloted in online meetings attended by participants who held the roles of accountable or responsible persons, a level considered suitable to respond to the questionnaire, according to the participating companies. The data received at the pilot ($n = 73$) was subjected to exploratory factor analysis (EFA) and confirmatory factor analysis (CFA). Using results from the analysis five questions were discarded, leaving a final list of 19 questions split across four variables forming the final questionnaire. Fourth, the questionnaire was also made available to participants who were unable to attend the online meetings. Fifth, a total of 170 responses were received and analysed. The data was anonymised before being provided to researchers at each stage of the process.

3.5. Validity and reliability tests

Each of the four variables: resiliency management; lessons learned; business continuity; and operational flexibility was operationalised using a five-point Likert scale (1 = strongly disagree, 5 = strongly agree). Factor loading and cross-loading analyses were used to assess the validity of the indicators. An indicator was considered valid if the factor loading was greater than 0.5 and the cross-loading was less than the factor loading. Exploratory factor analysis was carried out using the open source statistics package GNU PSPP on responses to the initial 24 item survey. Principal components analysis was used to extract factors and the extracted solution was rotated using VARIMAX. Variables were sorted in descending order of significance and coefficients with an absolute value of less than 0.5 were not printed. Five items were removed and remaining 19 questions were reorganised, and showed that the revised question set and responses resolved into four factors. Table 3 shows the assessment of factor loading and cross-loading and demonstrates convergent validity.

Table 4. Reliability test results.

Research variable	Cronbach's alpha
Resilience management (RM)	0.91
Organisational learning capacity (OLC)	0.74
Business continuity (BC)	0.80
Operational flexibility (OF)	0.81

Confirmatory factor analysis (CFA) was used to further assess the reliability, validity and dimensionality of constructs on the revised 19-item set of data using lavaan, a free open-source structural equation modelling R package (Rosseel 2012). This showed a good fit with a comparative fit index (CFI) of 0.895, a Tucker-Lewis index (TLI) of 0.877 and root mean square error approximation (RMSEA) of 0.081 with $p < 0.005$. The Kaiser-Meyer-Olkin (KMO) measure is 0.85, which suggests that the samples for each factor are adequate and reliable (Black and Porter 1996), and Bartlett's test of sphericity has $p < 0.001$. Cronbach's alpha for each scale ranges between 0.74 and 0.91, demonstrating acceptable levels of reliability, and are shown in Table 4.

3.6. Organisational resilience index (ORI)

The construction of the organisational resilience index (ORI) draws on the methodology set out in Koh et al. (2016), which advances an integrated resource efficiency

Table 5. Pearson Correlation analysis ($p < 0.001$).

	RM	OLC	BC	OF
RM	1	0.467	0.653	0.356
OLC	0.467	1	0.368	0.433
BC	0.653	0.368	1	0.272
OF	0.356	0.433	0.272	1

Note: All figures are statistically significant at the 0.001 level.

view (IREV) and derives a composite 'integrated resource efficiency index' (IRE-index). This begins with ensuring the variables comprising the index are sufficiently independent with correlation coefficients $|r| < 0.7$ as demonstrated in Table 5.

Likert scales for each item in a survey are ordinal in nature, necessitating the use of non-parametric procedures such as rank, median or range to analyse such data but sets of Likert-scale items can be combined and analysed as interval values if the combination of sets measures an underlying construct or variable, demonstrated by an adequate Cronbach's alpha, which allows the use of parametric analysis such as means and standard deviations (Allen and Seaman, 2007). The items in the survey were organised such that seven measured resiliency management (RM), six measured operational flexibility (OF), three measured organisational learning capacity (OLC) and three measured business continuity (BC), each four variables calculated as an average of the relevant responses.

Combining sets of Likert-scale items that measure an underlying construct into a composite index can be carried out using two approaches: a regression model can be used to construct weights; or an average of the variables can be used directly (Angeon and Bates, 2015). Most composite indicators use equal weights for all variables (OECD, 2008, 31). Averages can be computed using arithmetic or geometric means, but geometric means have been shown to provide more meaningful indexes (Ebert and Welsch, 2004) and have been used in Koh et al. (2016). As a result, this study uses an equally weighted geometric mean approach to calculate resilience and construct the ORI composite index for further analysis. We tested the robustness of the geometric mean approach by computing and comparing means using different methods of calculating resilience and analysing the results. We tested 23 calculation variants, with different combinations of variables as well as comparing arithmetic and geometric means for each combination. Geometric means performed slightly better than arithmetic means. The three best performing calculation variants were the square root of OLC and OF, with a mean of 3.16, the cube root of OLC, OF and BC, with a mean of 3.15 and the fourth root of OLC, OF, BC and RM with a mean of 3.17, compared to a mean for stated resilience (the response to a single question that asked respondents how resilient they felt their facility was) of 3.15. Using all four factors resulted in a similar standard deviation to the other two approaches (0.84 versus 0.85). A full set of calculation variants is provided in Appendix 2.

We proceeded to operationalise an approach using the geometric mean of all four factors, by first computing the calculated resilience (CR) as shown in Equation (1).

$$CR = \sqrt[4]{RM \times BC \times OLC \times OF} \tag{1}$$

Equation (1): Calculated resilience for each response.

We then computed an ORI by taking the average of calculated responses based on total CR divided by the number of responses (R_n), as shown in Equation (2), for the organisation as a whole and for subsets of the data based on demographic splits.

$$ORI = \frac{\sum CR}{R_n} \tag{2}$$

Equation (2): Calculation of the Organisational Resi lience Index (ORI).

In the following section we set out the results from operationalising CR and ORI and findings from the survey responses.

4. Results and findings

4.1. Regression analysis

Respondents to the questionnaire were asked a single check question on whether the facility being considered was resilient. The responses to this question, termed stated resilience (SR), were used to carry out three ordinary least squares (OLS) regression analyses considering independent variables singly and in combination. First, we considered each independent variable (RM, OLC, BC and OF) against the dependent variable SR using linear regression. Second, we expanded the results using multiple regression. Third, we tested the multiplicative relationship between groups of resilience levers, specifically OF versus (RM + BC + OLC) with a multi-variable regression including interaction effects. Fourth, we tested the calculated ORI against SR. These results are shown in Table 6.

Taking each variable in turn, resiliency management (RM) is strongly positively associated with stated resilience (SR) ($\beta = 0.69$, p-value < 0.001, $R^2 = 0.47$), indicating support for hypothesis 1. Organisational learning capacity (OLC) is strongly positively associated with SR ($\beta = 0.62$, p-value < 0.001, $R^2 = 0.38$), indicating support for hypothesis 2. Business continuity (BC) is also strongly positively associated with SR ($\beta = 0.66$, p-value < 0.001, $R^2 = 0.44$), indicating

Table 6. Results of regression analysis.

	β	t-value	R^2
Linear regressions			
Resiliency management (RM)	0.69***	10.89	0.47
Organisational learning capacity (OLC)	0.62***	9.06	0.38
Business continuity (BC)	0.66***	10.18	0.44
Operational flexibility(OF)	0.73***	12.24	0.53
Multiple regression			
RM	0.14	1.43	0.63
OLC	0.18*	2.45	0.63
BC	0.18*	2.06	0.63
OF	0.41***	5.26	0.63
Multi-variable regression			
OF + RM + OLC + BC + (OF × (RM + OLC + BC))	0.76***	13.60	0.58
Composite Index			
Organisational Resilience Index (ORI)	0.78***	14.41	0.61

Note: Dependent variable is stated resilience (SR). * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

support for hypothesis 3. Finally, operational flexibility (OF) is significantly and positively associated with SR ($\beta = 0.73$, p-value < 0.001, $R^2 = 0.53$), supporting hypothesis 4. These results support the choice of RM, OLC, BC and OF as relevant antecedents of organisational resilience, and their potential importance to leaders and decision makers as levers to increase organisational resilience. Multiple regression analysis confirms the positive associations between SR and OLC ($\beta = 0.18$, p-value < 0.05), BC ($\beta = 0.18$, p-value < 0.05) and OF ($\beta = 0.41$, p-value < 0.001) respectively, but the null hypothesis cannot be rejected for RM ($\beta = 0.14$, p-value > 0.05).

Results from the multi-variable regression analysis confirms a strong positive association between the interacting blocks of levers OF and RM + BC + OLC ($\beta = 0.76$, p-value < 0.001, $R^2 = 0.58$), indicating support for hypothesis 5. To further investigate this relationship we used the r package mediation (Tingley et al. 2014) to conduct a mediation analysis between the two blocks of levers based on 1,000 bootstrap simulations. We define preparedness (PP) as (RM + OLC + BC) for this purpose and carry out two sets of analysis. Analysis 1 is of the form PP → OF → SR, with the independent variable as PP, the mediator as OF and the dependent variable as SR. Analysis 2 is of the form OF → PP → SR, with the independent variable as OF and the mediator as PP. In Analysis 1, the Average Causal Mediation Effect (ACME) is 0.2507 ($p < 0.01$), Average Direct Effect (ADE) is 0.7212 ($p < 0.001$) and the Total Effect (TE) is 0.9719 ($p < 0.001$). The proportion of the total effect that is mediated by OF is 25.79% ($p < 0.01$). These results indicate a statistically significant mediation effect when OF is the mediator. In Analysis 2, the ACME is 0.5342 ($p < 0.001$), ADE is 0.2615 ($p < 0.01$), TE is 0.7956 ($p < 0.001$) and the proportion of the total effect that is mediated by PP is 67.14% ($p < 0.001$), indicating that there is also a statistically significant mediation effect when PP is the mediator. Comparing the two sets of analyses, Analysis 2 with PP as the mediator shows a stronger ACME, a smaller ADE and a higher proportion of the total effect being mediated than Analysis 1. Although PP has a stronger mediation than OF, the results show that both constructs contribute to SR, and it may prove beneficial to consider them simultaneously and recognise their intertwined nature and complementary roles in influencing organisational resilience.

The composite ORI also indicated a significant and positive association with SR ($\beta = 0.78$, p-value < 0.001, $R^2 = 0.61$). Carrying out regression analyses using the composite index formula for the subgroups job role and area also showed a consistent and positive association with SR across all subgroups, with β ranging from 0.74 to 0.85. Figure 3 shows the associations between OLC, BC, OF and RM with OR in the construct model.

4.2. Analysis of CR and the ORI

The relationship between CR and SR based on the survey responses is shown in Figure 4. The range of responses is closer at the extremes of 1 and 5 and the largest variation between CR and SR is at the midpoint of 3, although the majority of responses display clustering between 2.5 and 3.5. Figure 4 also shows outlier responses that merit further investigation. For example, one response scores all questions on the highest level possible, resulting in a CR of 5, but then scores overall resilience at 3. This indicates that either the respondent has provided individual responses that are overly optimistic or do not represent their real views but hesitated to suggest that overall resilience was at the same level. It is also possible that the CR does not take into account the specific elements of resilience that the respondent had in mind.

The mean of the CR, which is the basis of the calculation of an organisational resilience index (ORI) as per Equation (2), is close to the mean of the combined

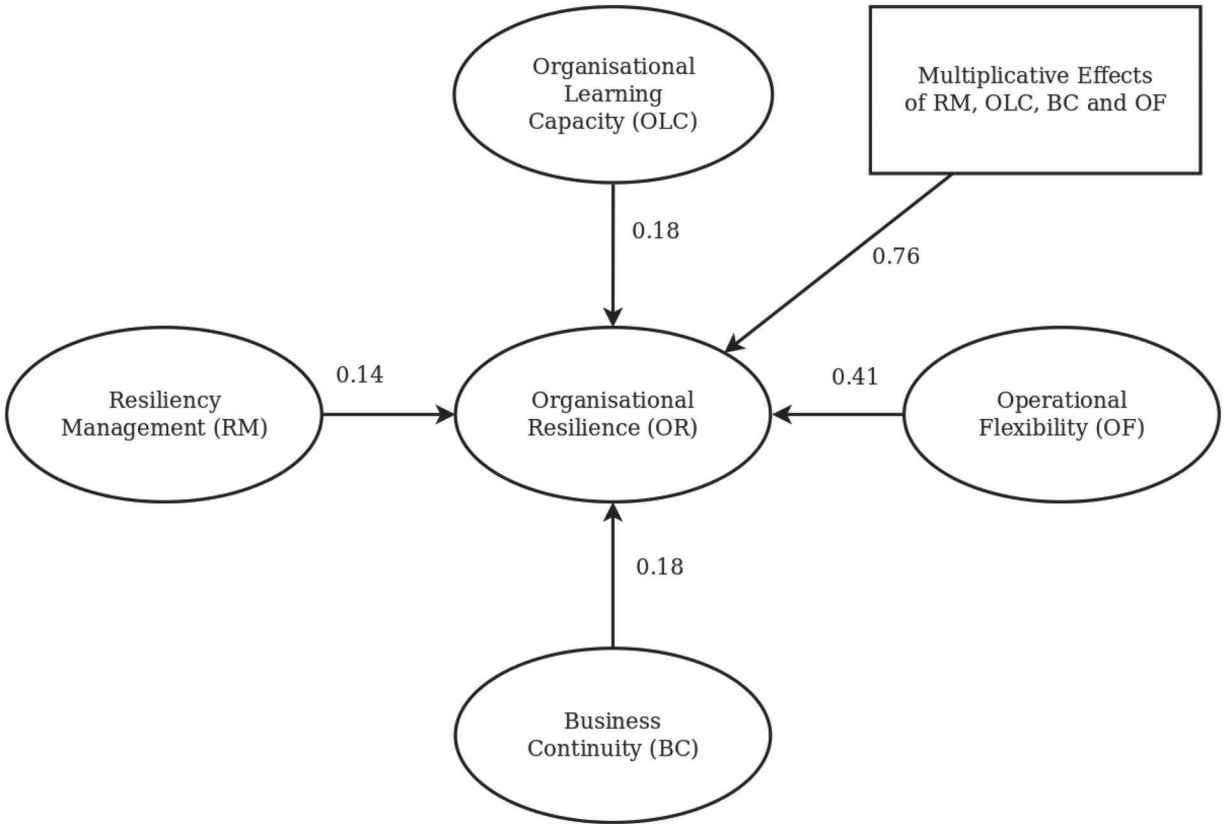

Figure 3. Contribution (β values of multiple regression) of resiliency management (RM), business continuity (BC), organisational learning capacity (OLC) and operational flexibility (OF) factors to organisational resilience (OR).

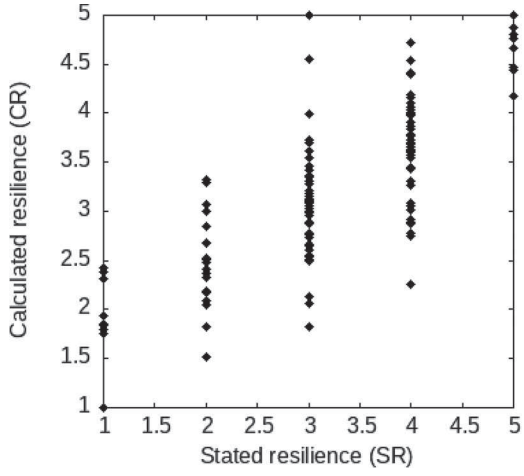

Figure 4. Calculated resilience (CR) vs stated resilience (SR).

stated resiliences (3.17 compared to 3.15) showing that the ORI is predicting resilience at an overall level, whilst reducing the standard deviation from 1.02 to 0.84 and the variance from 1.05 to 0.70. These results are shown in Table 7. We also assessed the composite index calculations with respect to two subgroups: area and job role, and found that the calculations continued to provide similar means to the stated resilience for the subgroups, with

Table 7. Descriptive statistics.

	Mean	Std Dev	Variance	Minimum	Maximum	Sum
RM	3.26	0.91	0.83	1.00	5.00	436.57
OLC	3.51	0.93	0.87	1.00	5.00	470.00
BC	3.19	1.04	1.08	1.00	5.00	428.00
OF	2.91	0.94	0.88	1.00	5.00	389.67
ORI	3.17	0.84	0.70	1.00	5.00	424.52
SR	3.15	1.02	1.05	1.00	5.00	422.00

a lower variance. We find that the ORI arrives at a similar mean to a simple measure of stated resilience based on a single question to respondents, while decreasing the measured standard deviation, enabling managers to analyse how individuals in key roles assess the implementation theoretical levers of resilience in their organisations.

The operational form of the ORI is then used to generate organisational insights from the entire data set. For example, Table 8 calculates resiliency indexes for different business areas and shows that, in the current sample set, respondents working in research, development and testing perceive the least level of organisational resilience with a score of 2.86 ($n = 170$). The key contributors to this score are the lack of operational flexibility (2.59) and business continuity (2.82) compared to organisation level scores of 2.95 and 3.24 respectively. Discussing

Table 8. Analysis of results using the ORI for different business types.

Business type	*N*	RM	OLC	BC	OF	ORI
Manufacturing	43	3.50	3.64	3.61	2.86	3.35
Office Based	78	3.32	3.59	3.19	3.15	3.26
Research, Development & Testing	24	2.98	3.26	2.82	2.59	2.86
Services	25	3.15	3.88	3.17	2.82	3.18
Organisation level	170	3.29	3.60	3.24	2.95	3.22

these results with the expert group led to the suggestion that research, development and testing activities require specialised physical infrastructure and laboratory space which cannot easily be carried out or shifted to alternative locations in the event of a disruption. Manufacturing, on the other hand, shows a high level of ORI and appears to indicate that despite challenges with operational flexibility (2.86), facilities are more prepared (higher RM, OLC and BC) to respond to disruption.

A dashboard tool has been created in Excel that allows for similar analysis to be carried out on other parameters.

5. Discussion

5.1. Theoretical implications

Debates around connection between resource efficiency view and resilience are scarce. Organisational resilience results from the effective interaction of individuals, groups and partners in networks but a holistic view of antecedents and their impact on organisational resilience is still missing (Su and Junge 2023). There is a lack of inquiry into how organisational resilience is affected by differences in the matching of internal and external resources relating to the internal competences of organisations and external network structures (Li et al. 2022). Research into quantifying resilience in the manufacturing value chain is scarce (Alexopoulos et al. 2022). Although factual observations from activities such as audits can demonstrate compliance with standards, studies containing empirical findings often deal only with general terms such as resources, organisations, or business models and innovations (Vakilzadeh and Haase 2021). These issues are also recognised across the supply chain literature, with empirical research evidence lacking on factors such as supply chain resilience, robustness and disaster readiness (Ruel and El Baz 2023). There is also a lack of inquiry into resiliency risks arising from unexpected sources such as greater product innovation (Ambulkar et al. 2022) and the way in which interconnected parts of supply chains with interdependencies contribute to the overall process of developing resilience (Agrawal et al. 2022; Mageto et al. 2022; Sá et al. 2020). Many organisations only implement strategies to increase resilience once a shock has happened rather than proactively designing resilient systems due to perceived barriers relating to product complexity, partnership complexity and process complexity, that make it difficult for managers to deploy the levers discussed in the literature or design acceptable measures of resilience (Cohen et al. 2022). Existing measures of resilience examine the impact of key variables such as supply chain disruption orientation, resource reconfiguration and risk management infrastructure in low and high impact disruption situations (Ambulkar, Blackhurst, and Grawe 2015) or have found that proposed variables are insufficiently supported by the data (Lee, Vargo, and Seville 2013). We found that expert groups were divided over their understandings of the definitions of these variables and this paper contributes to the debate on articulating relevant constructs. For example, activities for both supply chain disruption orientation and risk management could be grouped under the governance and scanning functions of a department for risk management, which itself has a much wider remit of operations than building resilience capability.

This study addresses these limitations by conceptualising organisational resilience as a capability resulting from four levers: resiliency management; business continuity; organisational learning capacity; and operational flexibility, and proposes a method to capture, measure and analyse managerial perspectives on the extent of resilience within their organisations that is implementable within their organisations and enables leaders and decision makers to take action to improve resilience. It draws on the IREV framework, which provides a theoretical scaffolding for the development of an empirical approach to measuring resilience that constructs a composite index from relevant antecedent variables. The resulting organisational resilience index (ORI) shows a good correlation with responses to a check question that asked respondents to rate the resilience of their facilities, validating its suitability for ongoing use as an analytical tool for managers in organisations.

The findings advance the IREV theoretical base to organisational resilience in two ways: first, the ability of an organisation to respond in a resilient manner to a disruption is circumscribed by its operational

characteristics, which enhance or limit flexibility. Our findings show that OF may explain up to 53% of the variance in stated resilience as expressed by respondents. Operational flexibility also aligned with the notion of 'gravity', a term used by the participants to express a sense of the difficulties associated with escaping the fundamental operating characteristics of a business. Second, RM, BC and OLC are a collection of supporting constructs that the expert group recognise as expressing an organisational notion of 'preparedness' and of being ready to face disruptions to the organisation. These specific findings extend IREV by integrating these degree of flexibility and preparedness within the systems (i.e. a form of integrated resources) in the measurement of organisational resilience (ORI), demonstrating the interdependency between resource efficiency and organisational resilience. This work contributes to the literature by answering calls to operationalise measures of resilience (Cohen et al. 2022; Münch and Hartmann 2023) and sets out a novel approach and methodology that can be extended to include additional indicators and/or begin to prioritise indicators for inclusion based on the additional contribution each indicator makes to the results of a composite index.

5.2. Practical implications

The ORI provides leaders and decision makers with critical insights into managerial perspectives on organisational resilience within their organisations and allows for the analysis of relevant contributing factors and structured multi-level comparisons between differing job roles, responsibility levels, businesses, countries, facilities and areas by using anonymised demographic data.

The measurement of organisational resilience articulated in this study argues that organisational resilience capability results from (a) its operational ability to respond flexibly and (b) the preparedness of the organisation for disruption. Operational flexibility is linked to the organisation's ability and resource limitations on being able to respond flexibly, and is conceptualised by the participants interviewed as 'gravity'. Preparedness is demonstrated through the implementation of resiliency management, business continuity and the development of organisational learning capacity. The combination of increased preparedness and operational flexibility is argued as leading to organisational resilience and operationalised through a calculation of resilience and the computation of an index based on the set of calculated resilience for each response.

The participants in the study communicated the results and benefits of the study to key members of leadership teams and asserted that the study helped to demonstrate their organisations' commitment to improve resilience, provided clarity on the elements of resilience, provided a single metric to measure performance on resilience, created a method to benchmark resilience, and communicated the importance of managerial perspectives on the constructs underpinning resilience. The methodology captured 'opinion', which was an important factor that had not previously been studied in measuring resilience in the participating organisations. Combining these results with 'factual observations' (e.g. from audits) provided a unique understanding of how well a management team understood what was required of it to deliver a resilient business, and how opinion and motivation played a part in the group assessment of resilience. This enabled leaders and decision makers to implement strategies that could attempt to close the gap between 'opinion' and 'reality' on the ground. Specifically, the ORI helps managers to target attention and resources on improving preparedness, and take action to mitigate constraints on operational flexibility before a disruption event occurs. The ORI has now been adopted by the participants in the study as a regular and ongoing measurement tool in their scheduled cycle of activities.

6. Conclusions

This paper contributes to the resilience literature by extending the measurement of resilience to incorporate managerial perspectives on the extent to which relevant levers of organisational resilience are implemented within their organisations. We propose an approach to calculate resilience from survey results and construct an organisational resilience index (ORI), building on the framework and methodology articulated in the integrated resource efficiency view (IREV) to derive a composite index of relevant variables. This approach contributes to theory by advancing the literature on operationalising organisational resilience and its measurement with a method that draws on the IREV and IRE-index that is implementable in organisations (i.e. ORI), whilst extending the interdependency between resource efficiency and organisational resilience.

We develop and validate a measurement scale based on four levers, namely resiliency management, organisational learning capacity, business continuity and operational flexibility, validated through statistical testing and review from stakeholders within the participating organisations, that (a) considers the extent of preparedness for disruption across an organisation combined with the operational characteristics of the organisation that limit

its ability to respond flexibly in the event of a disruption, and (b) allows for analysis at multiple levels. Findings show that the proposed measurement scale results in a value of calculated resilience that has a high level of correlation to stated resilience, while reducing the magnitude of standard deviation and variance. Based on the standardised co-efficient values organisational resilience is strongly positively associated with each of the four relevant levers studied in this paper: resiliency management, organisational learning capacity, business continuity and operational flexibility. Non-linear multiplicative effects amongst the levers have been identified, along with significant mediating roles of preparedness and operational flexibility. The results show that a composite index based on these levers is strongly associated with increased organisational resilience while reducing the standard deviation associated with a simple measure of resilience.

The development of a composite index is a novel addition to existing work. Future work could look at reconciling definitions for constructs in the literature and testing approaches to incorporating measures for resilience antecedents from different sources using the composite index approach set out in this paper. A parsimonious approach to index formation may allow researchers to prioritise and evaluate antecedents and develop a set of key measures from a larger set of relevant measures.

Leaders and decision makers can operationalise the composite organisational resilience measurement to understand and measure these relevant variables and compute ORI, which provides significant and useful managerial implications to take bespoke action to enhance organisational resilience through improving preparedness and mitigating the constraints on 'gravity' or operational flexibility.

Future work can also extend the ORI to examine resilience of supply chain partners to determine whether specific nodes make more of a contribution or pose more of a risk to supply chain resilience (Martins de Sá et al. 2020) and pursue a multi-tier approach to ensure that resilience is pursued at a wider level than the organisation itself (Hartmann and Moeller 2014). The study demonstrates an association among variables therefore, there is also scope for further research to combine the ORI with organisational datasets to extend its measurement capability to encompass the determination of causal relationships, and also to operationalise it between organisations that make up a supply chain, providing greater insight into organisational resilience across a group of interacting, intertwined and interdependent networks.

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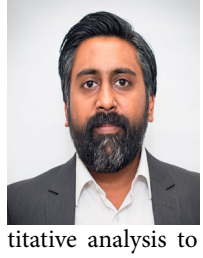

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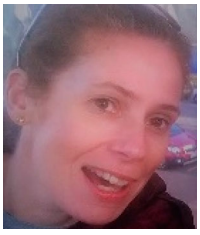

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Data availability statement

Data available on request from the authors.

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Appendices

Appendix 1. Question set.

Resiliency Management

Resiliency management refers to the structure of resources that are in place to identify and monitor resiliency risks to the organisation

RM1. Senior management requires the facility to report resiliency risks to the operations that have been identified

RM2. This facility documents which employees own specific resiliency risks and ensures they receive appropriate training.

RM3. This facility sets out its resiliency risk appetite (recovery time objective (RTO)) and agrees it with the correctly identified risk owner.

RM4. Management of this facility hold regular meetings (face to face or online) to share information on resilience.

RM5. The set of resiliency risks and controls have been subject to appropriate independent assurance.

RM6. This facility, or someone on behalf of this facility, sets out controls to manage resiliency risk and ensures that those controls are effective.

RM7. Facility Management receives regular briefing reports on resilience.

Operational Flexibility

Operational flexibility is the ability of an organisation to resupply, reconfigure, realign and reorganise resources in response to changes in the organisation's external environment

OF1. The organisation maintains multi-sourcing or can find new suppliers of critical materials (direct purchasing) for this facility if one fails within its Recovery Time Objective (RTO).

OF2. This facility can shift operations from one location to another within its Recovery Time Objective (RTO).

OF3. This facility can repurpose or reconfigure equipment, personnel, machinery, areas and processes to maintain operations as usual within its Recovery Time Objective (RTO).

OF4. This facility's suppliers can replace indirect purchase resources (e.g. consumables, utilities) within its Recovery Time Objective (RTO).

OF5. The expertise, ability and capacity to support resource reconfiguration at this facility within its Recovery Time Objective (RTO) also exists outside this facility and can be called on when needed.

OF6. This facility has excess capacity to respond to operational disruption within its Recovery Time Objective (RTO).

Organisational Learning Capacity

Organisational learning capacity is characterised by how effectively an organisation analyses and learns from prior disruptions and how effective it is at documenting and sharing such lessons learned throughout the organisation

OLC1. Senior management encourages transparency in reporting operational failures.

OLC2. The organisation has a process for identifying, documenting and sharing lessons identified and learned that impacts our ability to operate (including major and minor incidents).

OLC3. Hand overs of work between business areas happen in an effective manner.

Business Continuity

Business continuity infrastructure refers to the structure of resources that are utilised in response to a disruption event

BC1. This facility exercises business continuity documentation (Business Impact Assessment, Business Continuity Plan, Business Recovery Plan) in a simulated environment annually.

BC2. This facility receives guidance, training and second-line assurance activities from GSART on business continuity procedures.

BC3. Business continuity documentation (Business Impact Assessment, Business Continuity Plan, Business Recovery Plan) for this facility are clearly documented and accessible.

Organisational Resilience

OR1. The facility being considered is resilient.

Appendix 2. Computation options

Id	Formula	Mean	Std Dev
SR	n/a	3.15	1.02
CR_1a	$\sqrt{BC \times OF}$	3.02	0.91
CR_1b	$(BC + OF) \div 2$	3.05	0.90
CR_2a	$\sqrt{OLC \times OF}$	3.16	0.85
CR_2b	$(OLC + OF) \div 2$	3.21	0.83
CR_3a	$\sqrt{OLC \times BC}$	3.31	0.89
CR_3b	$(OLC + BC) \div 2$	3.35	0.87
CR_4a	$\sqrt[3]{OLC \times BC \times OF}$	3.15	0.85
CR_4b	$(BC + OF) \div 2$	3.20	0.83
CR_5a	$\sqrt{RM \times OF}$	3.05	0.85
CR_5b	$(RM + OF) \div 2$	3.08	0.85
CR_6a	$\sqrt{RM \times BC}$	3.21	0.93
CR_6b	$(RM + BC) \div 2$	3.23	0.92
CR_7a	$\sqrt[3]{RM \times BC \times OF}$	3.08	0.87
CR_7b	$(RM + BC + OF) \div 3$	3.12	0.86
CR_8a	$\sqrt{(RM \times OLC)}$	3.36	0.85
CR_8b	$(RM + OLC) \div 2$	3.38	0.84
CR_9a	$\sqrt[3]{RM \times OLC \times BC}$	3.28	0.87
CR_9b	$(RM + OLC + BC) \div 3$	3.32	0.85
CR_10a	$\sqrt[4]{RM \times OLC \times BC \times OF}$	3.17	0.84
CR_10b	$(RM + OLC + BC + OF) \div 4$	3.22	0.82
CR_11	$\sqrt{\frac{(RM+OLC+BC)}{3} \times OF}$	3.09	0.84
CR_12a	$\sqrt[3]{RM \times OLC \times OF}$	3.18	0.82
CR_12b	$(RM + OLC + OF) \div 3$	3.22	0.81