Development of a Framework for Enhancing Resilience in the UK Food and Drink Manufacturing Sector

By

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Synopsis

This thesis presents research undertaken to understand and enhance resilience in the UK Food and Drink Manufacturing Sector. It focuses on the development of a conceptual framework which establishes how specific vulnerabilities link to individual mitigation strategies available to the sector and the impact of such strategies on wider sustainability.

The research in this thesis is divided into four main parts. The first part consists of three complementary review chapters exploring resilience as a theoretical concept, resilience in the UK Food and Drink Manufacturing sector and existing methods used to study and/or enhance resilience. The second part of the thesis begins by describing how the pragmatic philosophy and abductive stance underpinning the research, in combination with review findings, helped to determine the research techniques used in this work, which included the systematic review process and the mixed methods case study. Next, the research facilitating a novel conceptual framework describing how real-time vulnerabilities can be identified and mitigated in a way that is complimentary to the wider sustainability of the organisation is discussed.

The third part of the thesis describes the practical set of tools, presented in the form of a workbook, which enable a Food and Drink Manufacturer to utilise the conceptual framework teachings to enhance their own resilience. The final section details key conclusions regarding the conceptual nature and practical enhancement of resilience for Food and Drink Manufacturers and the wider food system, as well as opportunities for future work.

The conceptual integrity and practical usefulness of the conceptual framework and its derivative workbook toolset have been demonstrated through case studies with two UK Food and Drink Manufacturers. Results suggest two major benefits of the framework are the ability to identify an organisation’s vulnerabilities based on actual mapping of their supply network and the ability to evaluate mitigating resilience strategies based on their broader impacts elsewhere within the organisation.

In summary, the research reported in this thesis has concluded that resilience cannot be seen as a one-off solution for returning to how things were before disruption, but instead is a constant process of learning and adaptation in response to a company’s ever-changing operating environments. The framework and workbook presented provide a novel and practical method for UK Food and Drink Manufacturers, of all sizes and production ranges, to identify and respond to their evolving vulnerabilities, as well as providing much needed synthesis and directions for future work at an academic level.

Abbreviations

3PL:	Third Party Logistics
AFSC:	Agri-Food Supply Chain
AFSN:	Agri-Food Supply Networks
AFS:	Agri-Food System
BCM:	Business Continuity Management
CE:	Cost (Economic)
CS:	Cost (Social)
CENV:	Cost (Environmental)
DEFRA:	Department for the Environment, Food and Rural Affairs
EE:	Efficiency (Economic)
ES:	Efficiency (Social)
EENV:	Efficiency (Environmental)
ERM:	Enterprise Risk Management
EU:	European Union
FDM:	Food and Drink Manufacturer
GDP:	Gross Domestic Product
GBP:	Great British Pound
GVA:	Gross Value Added
KPI:	Key Performance Indicator
LGA:	Local Government Authority
OECD:	Organisation for Economic Co-operation and Development
OR:	Organisational Resilience

OSRMP:	Organisation Specific: Raw Material and Production
OSLC:	Organisation Specific: Logistics Control
OSIS:	Organisation Specific: Information System
OSOMS:	Organisation Specific: Organisational Management Structure
QE:	Quality (Economic)
QS:	Quality (Social)
QENV:	Quality (Environmental)
SCM:	Supply Chain Management
SCRAM™	Supply Chain Resilience Assessment Model
SCRES:	Supply Chain Resilience
SEM:	Structural Equation Modelling
SLE:	Service Level (Economic)
SLS:	Service Level (Social)
SLENV:	Service Level (Environmental)
SLR:	Systematic Literature Review
SME:	Small/Medium Enterprise
SNR:	Supply Network Resilience
UK FDM(s):	United Kingdom Food and Drink Manufacturer(s)
UK:	United Kingdom
USD:	United States Dollar
VCRMP:	Value Chain: Raw Material and Production
VCLC:	Value Chain: Logistics Control
VCIS:	Value Chain: Information System
VCOMS:	Value Chain: Organisational Management Structure

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Chapter 1: Introduction

It is increasingly accepted that supply chains in all forms face growing volatility across a range of business parameters from energy cost and raw materials, to currency exchange rates and changing consumer demands [1-2]. Agri-Food Supply Chains (AFSCs) not only share these general risks, but also face their own unique vulnerabilities due to the inherent natural variability in quality and availability of raw materials, the fact that many raw ingredients have a short shelf life, resulting in heavy reliance on chilled transportation, and also the overriding necessity to avoid cross contamination [3]. Food is also unique in other ways. Food is vital for public health and wellbeing, indeed, so fundamental is reliable access to safe and affordable food that it has been implemented in political unrest and even conflict in recent years globally [4]. The food industry is also highly significant from an environmental perspective, accounting for 70 million tonnes of CO^2 equivalent emissions in 2016. It is not unsurprising therefore that food has been labelled "the new oil"[5]

These vulnerabilities are only likely to become more pronounced in the future. For example, the already variable quality and quantity of raw ingredients will likely be adversely affected by projected increases in volatility of extreme weather which could limit yields and hinder logistics through drought, flooding, and increased occurrence of pests, diseases and weeds [6]. Changing climate may also disrupt the extent of fisheries as key species migrate or are adversely affected by changing climate [7]. Moving beyond the projected impacts of climate change, the global population is expected to plateau at around 9 billion by 2050, with much of the growth on current population projected to be in the developing world, in rapidly growing urban areas [8]. As populations grow and develop, evidence also suggests that affluence increases and this is associated with dietary transition away from starch heavy staples towards increasingly meat and dairy based as well as more heavily processed foods [9]. In addition to having significant impacts on health, particularly in terms of obesity and diabetes, these types of foods are also often more resource intensive [10].

Herein lies a major challenge- referred to as a 'perfect storm' by many [11-12]. Not only are we likely to require more food to feed the worlds growing population, but our ability to produce and deliver this food without disruption, thus ensuring food security, is likely to be constrained. It is widely projected that extreme weather volatility, energy price fluctuations and logistics constraints, posed by rapid urbanisation, will mean increased risk of disruption [13].

These challenges are arguably compounded by the way that AFSCs function. In the UK, and increasingly in similar highly international AFSCs seen in Europe and North America, AFSCs are dominated by large retailers, known as 'multiples' [14-15]. This dominance is due to a number of socio-technological developments in recent decades, such as changes in peoples working hours, and increasing prevalence of cars and freezers, which have positioned large, often out of town retailers, to best meet consumer demands for convenience, variety and value. The top retailers now capture so much of total UK food sales that they are effectively the gateways of AFSC to consumers. In order to meet these demands, many retailers have embraced ‘Lean’ supply chain strategies which aim to eliminate any activities in a product lifecycle that are not essential to meet the customer specification and thus do not add value. Due to the purchasing power, economies of scale and proximity of these retailers to end consumers, many manufacturers and even producers have also been forced to adopt ‘Lean’ approaches in order to remain viable. Alternatively, many producers/manufacturers have adapted ‘agile’ strategies which, similar to lean, prioritise increased integration, reduced lead times and decreased inventories. However, unlike lean approaches, agile strategies place a premium on capacity surplus so as to fulfil the core objective of rapid response to consumer demand [16]. Whilst lean and agile manufacturing have undoubtedly resulted in highly cost effective and flexible AFSCs respectively, both approaches prioritise reduced inventory and there is concern that this adds fragility in the face of growing global volatility. It has been argued that this is compounded by the absence of UK Government food reserves (abandoned after the cold war ended) [16-17].

A number of recent disruptions to UK AFSCs, including the 2007-2008 price spikes (in response to low harvests and subsequent export bans on commodities such as rice grown by Asian suppliers) and the January 2017 Spanish Vegetable shortage (caused by unexpected and extreme weather in the South of Spain) both resulted in widely publicised food shortages. This suggests that modern day AFSCs are indeed highly vulnerable to volatility and that the effects can be broader than temporary price fluctuations and shortages. At a societal level, evidence suggests that poorer families spend a larger proportion of their incomes on food. Not only are they more likely to compromise the quality of food they consume in response to any price change, thus effecting broader dietary health, but evidence suggests that as people naturally prioritise food over other purchases, food disruptions can have a dampening effect on other economic sectors [18]. The interlinked nature of these vulnerabilities are summarised in Figure 1.1. This potential risk has not gone unnoticed and one of the frequently proposed alternatives to such systems is to revert to increased national self-sufficiency.

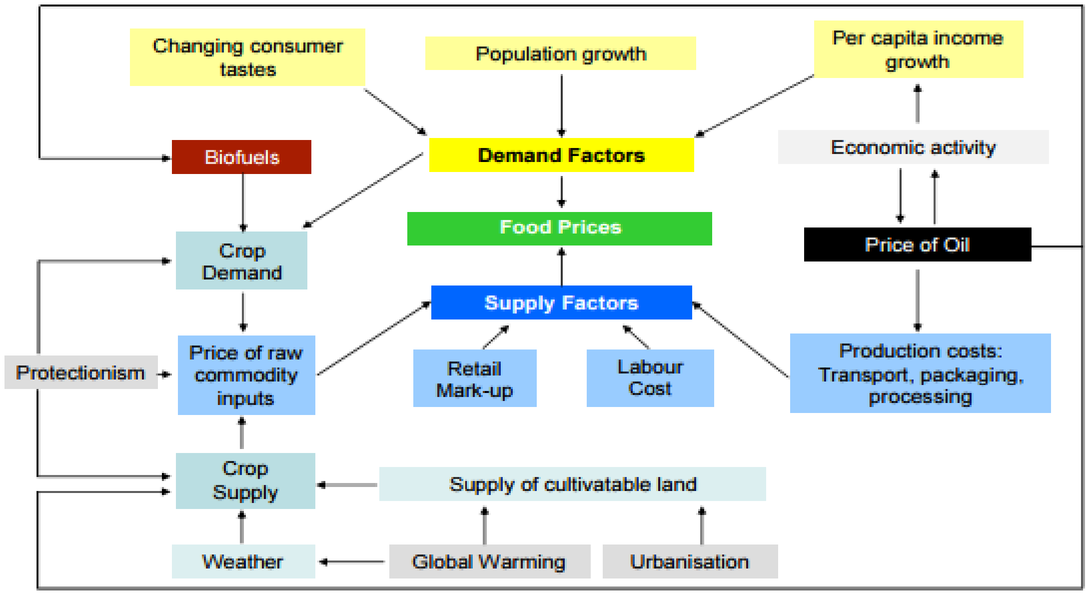


Figure 1.1: Complexity of factors influencing food price. Adapted from the 2009 DEFRA report entitled: "Ensuring the UK's food security in a changing world" [19].

However, such attempts to meet the complex demands of developed world populations entirely through domestic production would be technically challenging, cost inefficient and environmentally damaging [18]. There is, as a result, a need to accept the risk exposure that comes with globalised supply chains and act to make them more resilient to evolving sources of volatility, such as climate change, growing urban populations and competition from abroad.

Within an AFSC, there are a number of stages from primary production through to delivery to final consumers, as summarised in Figure 1.2. Resilience for actors at any given stage will have different determinants to actors in the next stage. Exhaustively modelling these determinants at each stage would have been unfeasible for a single PhD and so focus was placed on just the UK Food and Drink Manufacturing stage. The reason for this is that not only are UK Food and Drink Manufacturers (UK FDMs) highly globalised in terms of where supplies are sourced and produce sold, but they are often in a particularly precarious position because their operations are frequently dependent on a very small number of capital intensive facilities [20]. This exposure is exacerbated by a recent historical trend for 'off-shoring' in search of the cheapest raw material, labour and transport costs, which has resulted in many sites in the UK having closed. As such, UK FDMs are representative of a range of contemporary factors driving resilience in wider supply chains such as globalisation and lean production paradigms.

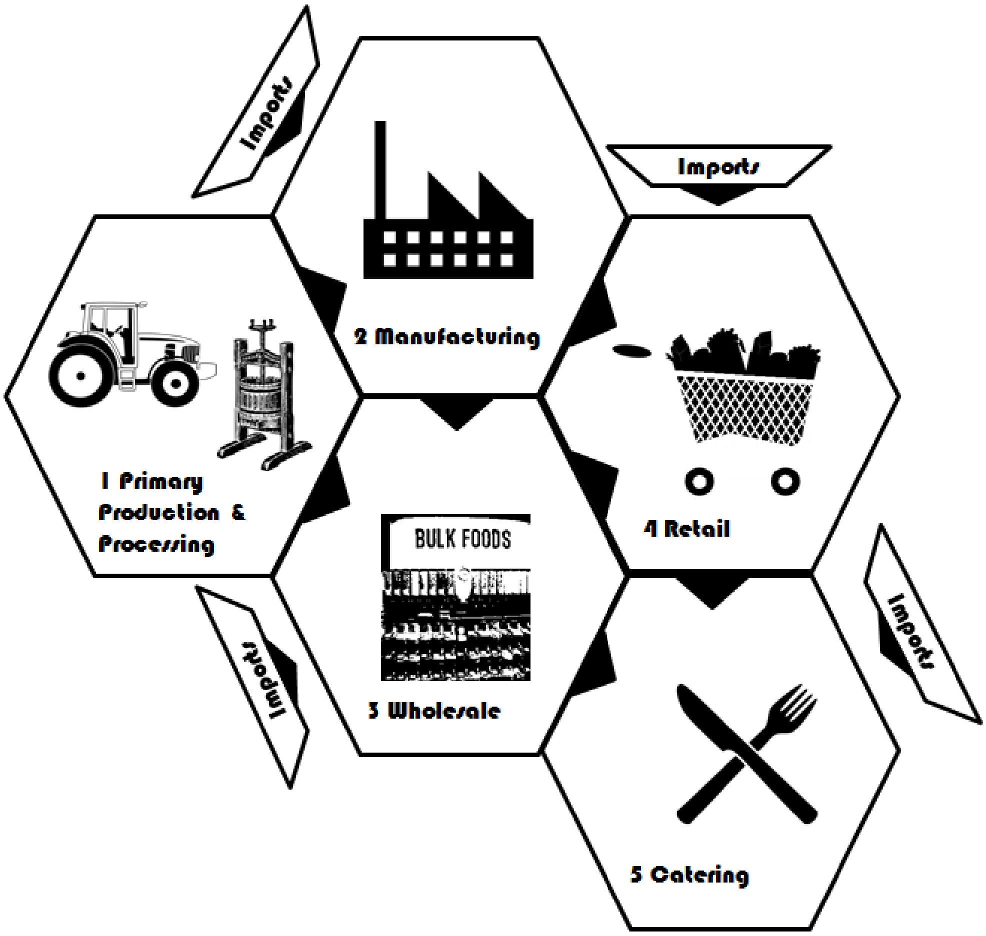


Figure 1.2: Overview of the major stages of the UK agri-food system

Despite the aforementioned drivers for resilience in UK AFSCs, and in the context of UK FDMs more specifically, there are still significant gaps in our understanding of the concept. For example, depending on the research field, the 'definition' of resilience in terms of outcomes sought and vulnerabilities targeted can vary widely. Furthermore, there is often inconsistency in identifying the practical actions, known as 'Resilience Elements', for example, spare inventory or alternate suppliers, which help make an entity resilient [21-22]. Equally, there is also little consensus on the 'strategies' which govern how these resilience elements are employed, for example, how they are linked to the vulnerabilities at hand and how their impact/possible side effects are measured. The aforementioned terms "Definition", "Elements" and "Strategies" have been carefully worded so as to be consistent with terms identified as key principles of resilience in the literature [21–24].

These inconsistencies are compounded by the fact that little work has explored how they may need to be adapted to take into account the unique nature of food concerning aspects such as shelf life and variability in yield quality and quantity. Additionally, works focussing on sectors other than food, typically prioritise how resilience can deliver competitive advantage, whereas in food manufacturing, resilience is inextricably linked to societal factors such as food security and environmental factors such as sustainable agriculture, meaning that resilience cannot be measured by its financial benefits alone.

At a slightly broader level, there is a growing consensus in the academic literature that resilience and sustainability are heavily interconnected, particularly in AFSCs [25–27]. Sustainability concerns the management of an entity's social, economic and environmental assets for long-term continuity and resilience also monitors this same range of assets in order to avoid unexpected disruptions. In this way, the goals of resilience and sustainability are incredibly similar. Yet, whilst many have argued that sustainability without resilience is impossible, it is possible to act in a manner that is resilient and not sustainable [28-29]. For example, harvesting crops early in response to demand fluctuations at the expense of latter yields. As a result, any investigation into resilience must also consider implications for existing sustainability efforts.

To address these myriad issues, this thesis is structured as follows (See Figure 1.3):

Stage 1: Review Section

- Systematic identification and analysis of resilience definitions, elements, strategies and related concepts from a multidisciplinary literature base.
- Exploration of the contemporary scope and activities of UK FDMs and the identification of major failure modes.
- Exploration of how others in the academic literature and in Industry and Government have attempted to model resilience and the tools that exist to help practically enhance it.

Stage 2: Methodology and Theoretical Research

- Development of an appropriate research methodology which enables deductive input from the review findings to be combined with inductive inputs from empirical observations, therefore ensuring that theoretical research is conceptually specific to the UK food and drink manufacturing sector.
- Generation of new knowledge through synthesis of resilience concepts identified in the review chapters into a novel FDM specific conceptual framework of resilience.

Stage 3: Tool Development and Case Study Validation

- Development of the conceptual framework into a practical tool designed to guide FDMs in identifying bespoke vulnerability sources, countering these with appropriate resilience elements and evaluating the wider impact of chosen resilience strategies.

- Use of case studies to validate and enhance the conceptual framework and derived tools.

Stage 4: Research Conclusions

- Presentation of results, important considerations, limitations and opportunities for future work.

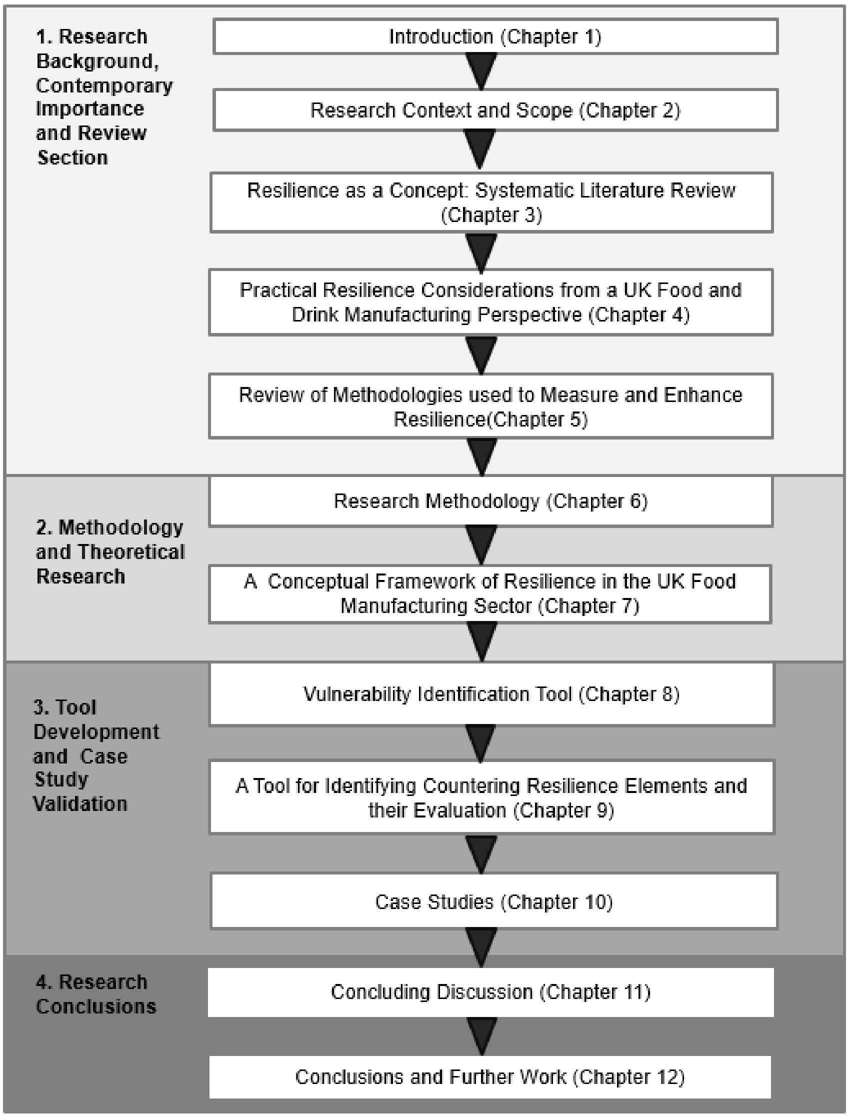


Figure 1.3 **Thesis Outline**

Chapter 2: Research Context and Scope

2.1 Introduction

This chapter begins by discussing the research context, specifically, the decision to focus on UK FDM resilience, as well as positioning the research within the wider academic literature. From this discussion, initial research assertions are described along with the general research hypotheses underpinning the research. Following this, the overall aim and specific supporting objectives in the form of areas of research are outlined. Finally, the research scope section outlines the practical boundaries of each research objective.

2.2 Research Context

As described in the Introduction, this Thesis focuses on resilience in the context of UK FDMs. This is partly as they are fundamental for UK Food Security, but also as they are exposed to a large number of often hidden dependencies that go far beyond the UKs borders, thus making them representative of the volatility faced by AFSCs at a global level. For example, if we consider a UK buyer-seller relationship where a manufacturer produces a chilled ready meal for a retailer, it is likely not only propped up by international supplies of ingredients but also by ecosystems services that enabled that food to be grown (e.g. soil fertility and irrigation), foreign labour sources, infrastructure such as roads and communication channels, economics in terms of exchange rates and political decisions such as trade regulations [30]. This presents significant exposure to a myriad range of vulnerability sources at a time when many have argued that volatility in these areas is increasing [1]. Examples include current occurrences as well as future projections for extreme weather, population growth and associated demand, as well as fuel prices [31]. As a result, whilst the ability to be resilient to disruptions is increasingly important, it is difficult to limit resilience assessment to an individual country's boundaries (regardless of whether that country is developed or developing), as most now have at least some degree of dependence on international supply chains. Indeed, recent events such as the food price shocks of 2007-2008 have shown that the resilience of smallholder growers in the developing world is closely interlinked to food price volatility in the developed world [11].

This is reflected by Professor Tim Benton, Champion for the UK Global Food Security Programme:

"Take a relatively simple food produced in the UK like a chocolate Kit Kat – it contains cocoa from Africa, milk products from the UK, whey from New Zealand, palm oil from Asia, sugar from South America, wheat from Europe. So, we simply can't look at the supply chain in terms of the

UK alone. Increasingly, perturbations elsewhere in the world will feed back into the availability and price of food in the UK" [18]

The UK was chosen as the focus of FDM resilience because it was felt to be representative of a number of broader AFSC trends. For example, the large supermarkets who dominate AFSCs in the UK (and increasingly in North America) and who are proposed to have decreased resilience through their promotion of lean manufacturing practices, are shown to be on the rise in Africa and Asia [32]. For example in Thailand, about 85% of people now have access to, and regularly purchase food from, supermarkets compared to 47% ten years ago [33]. Thus, understanding what it means to be resilient in highly global, lean and retailer dominated AFSCs is globally significant. It should be noted however, that the UK possesses a number of unique considerations which will be discussed in this thesis.

The first is that as an island with a maritime climate, the UK is unique in terms of what it can produce domestically and what it must rely upon international AFSCs for. The UK is currently 62% self-sufficient in terms of all food that it consumes, representing a decline from 75 % in 1989 [34]. This highlights a growing dependency on imports and thus exposure to global volatility (see Figure 2.1). Furthermore, many of the UKs key suppliers are extremely concentrated, 29% of the UKs total food and drink imports originate from the EU, of which some of the most important are the Netherlands, France and Ireland. Crucially, these same countries also represent the major port (and rail) routes into the UK for imports from the rest of the EU and further afield [35].

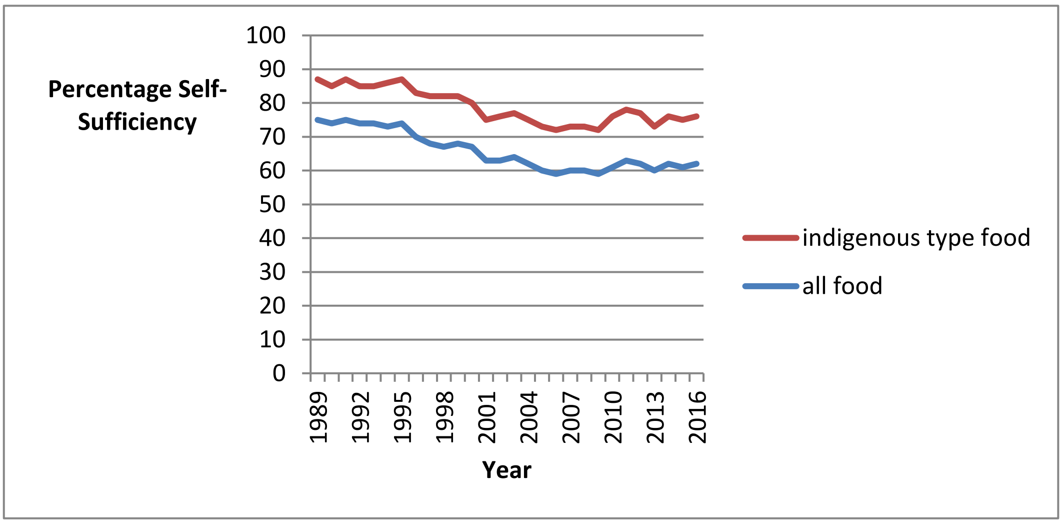


Figure 2.1: UK Food Self-Sufficiency in terms of all foods consumed nationally and in terms indigenous foods that are adapted to growing in the UK.

The UK is also unique amongst developed nations in that it has a population that is projected to increase significantly in coming decades, passing 70 million in 2026 (See Figure 2.2), with over 80% of the resulting population projected to live in urban areas [36]. This poses significant challenges for existing food distribution infrastructure which was planned decades previously and is expensive to expand. The next section explores how the research in this thesis intends to align with existing academic research into the area.

2.2.1 Fit within the Wider Resilience Research Context

Many of the drivers behind the need for resilience in AFSCs, such as globalisation, growing volatility and the stock reduction aspect of lean strategies, are also important for non-food supply chains. A number of recent high-profile disruptions (such as the terrorist attacks in the USA in September 2001 and natural disasters such as the Icelandic eruptions at Eyjafjallajökull in 2010) have driven academic interest in Resilience. In response, a flurry of high quality conceptual research has focussed on developing theoretical resilience constructs, particularly definitions and elements of resilience as well as the strategies by which elements can be used.

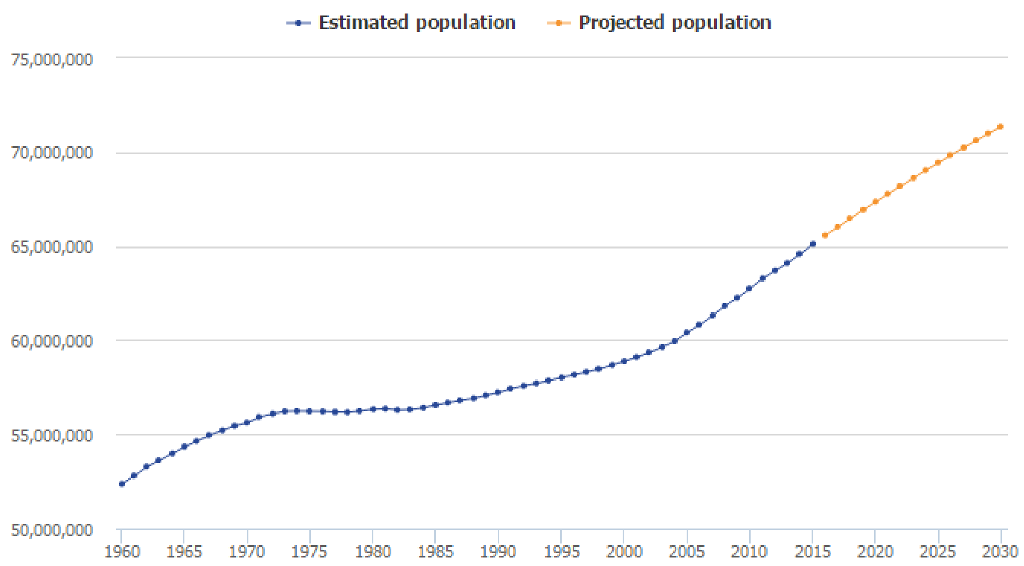


Figure 2.2: Projected UK population growth [36].

However, Ali et al. 2017 [37] in their comprehensive SCRES review note that:

"…the published research on SCRES remains fragmented, with too much disparity in the definitions of the concept"

This is important as an accurate definition is vital in order to determine what is meant by resilience, what it is that is being made resilient, its boundaries, and of course, the threat(s) which it is being made resilient to. In this regard, it is likely that existing definitions of resilience might not be readily applied to UK FDMs who must consider unique food-based vulnerabilities (e.g. shelf life) and practical ramifications of any resilience actions for wider public health and wellbeing. There is also a lack of clarity about which resilience elements are important to enable resilience. Resilience elements can be considered as the management tools available to an organisation to counter specific disruptions. "Flexibility" and "Redundancy" are the most frequently cited resilience elements but certainly not the only ones, with "Collaboration" and "Agility" amongst tens of others also proposed [21]. Tukamuhabwa et al. 2015 [38] note this:

"*The four core strategies discussed above have received the majority of the attention in the SCRES literature. Beyond these four strategies, the literature on means of developing resilience to supply chain threats or disruptions is broad but limited in depth*".

This suggests that there are a great number of resilience elements spanning across different research fields and poses the question of which are most suitable for UK FDMs. For example, works from the business management field of supply chain management typically prioritise organisational competitive advantage [39]. Whilst such an approach is undoubtedly important for UK FDMs, it must also be considered that AFSCs are unique in terms of their overriding importance to societal health and wellbeing and this should be reflected in the strategy by which resilience elements are chosen.

Whilst the majority of resilience studies have attempted to measure the impact of resilience elements on organisational Key Performance Indicators (KPIs) (e.g., [40–44]), there are a growing cohort of authors who propose that resilience elements are not without cost and must be carefully matched to specific vulnerabilities in order to provide 'balanced' resilience [45–48]. However, Elleuch et al. (2016) [47] are among a very small number of researchers so far to have attempted such an approach in an AFSC context and the vulnerabilities/elements they have used appear to be limited compared to the range available in the literature. This suggests that there is a real need for resilience theory development to be supported by real-world, explorative empirical evidence, as suggested by Bhamra et al. (2011) [49]:

"For the theory to be of value in the real world, more real world-based research needs to be done, particularly focused on empirical methods such as case study and survey which can significantly add to and validate theoretical constructs"

Finally, there is growing consensus that due to the interconnected nature of contemporary AFSCs, resilience elements can quickly have broad reaching environmental, societal and ethical impacts that go far beyond an individual company implementing these elements. Therefore resilience and sustainability are effectively interlinked and this must be considered before and attempt is made by individual to enhance their resilience [50-51]. This is summarised by Tendall et al. (2015) [29]:

"Sustainability is the measure of system performance, whereas resilience can be seen as a means to achieve it during times of disturbance".

2.3 Research Questions

Based on the discussion so far, a number of research questions were generated which guided development of the aim and objectives of this research.

1. What sources of vulnerability face UK FDMs, what failure modes might these lead to and what, if any, indicators can be used to assess a FDM's exposure?

2. What are the different resilience 'definitions', 'elements' and 'strategies' and which are most appropriate for UK FDMs to respond to identified vulnerabilities with?

3. What practical tools exist that could support enhancement of resilience in an FDM context?

4. Which resilience elements mitigate which vulnerabilities, thus enabling the generation of balanced resilience?

5. How can the wider sustainability impact of these resilience elements be evaluated?

2.4 Research Aim and Objectives

The overall aim of this research is to generate a synthesised conceptual framework that is specifically tailored to UK FDMs and from this, to develop a set of practical tools which can guide UK FDMs in enhancing their resilience against specifically identified vulnerabilities. To achieve this aim, the aforementioned research questions must be addressed and this is facilitated through the following research objectives:

Research Objective 1: Literature Reviews

A: To conduct a systematic literature review (SLR) of resilience theory, identifying all conceptual definitions, elements, strategies and relations with sustainability that may help to model UK FDM resilience.

B: To review the current scope and activities of the UK Food and Drink Manufacturing sector in order to identify vulnerabilities faced, potential resulting failure modes, and the metrics which can be used to identify exposure.

C: To review how academia and industry/government have attempted to measure, model and enhance resilience.

Research Objective 2: Methodological Design and Framework Development

To use the review findings concerning the nature of supply chain resilience as a unit of study, in addition to observations of relevant methodologies used by others, to develop a suitable empirical research methodology This methodology will then be applied to synthesise the findings from the reviews, in combination with industry interviews, to produce a comprehensive conceptual framework to support UK FDM resilience.

Research Objective 3: Practical Tool Development

To develop practical tools based on the framework, complete with relevant qualitative and quantitative metrics to guide food and drink manufacturers in formulating resilience strategies.

Research Objective 4: Case Study Validation

To undertake case studies for validation and development of the aforementioned framework and associated tools.

2.5 Research Scope and Boundaries

This section outlines the respective scopes and boundaries of activity for each of the four Research Objectives listed above.

2.5.1 Scope and Boundaries for Research Objective 1: To review the resilience literature

The overall scope of Research Objective 1 is to conduct three separate but supplementary literature reviews to address research questions 1-5.

Research Objective 1A is fulfilled in Chapter 3 and consists of a systematic review of the conceptual aspects of resilience, including definitions, elements, strategies and relations with sustainability. As it is realised that many research fields including Social Sciences, Environmental Sciences and Supply Chain Management (SCM) are potentially of relevance to FDM resilience, the boundary for this review includes all relevant research fields exploring system resilience and is not restricted by date.

Research Objective 1B is fulfilled in Chapter 4 and consists of a review of the contemporary scope and activities of the UK FDM sector. The scope was to develop a broad understanding of the types of internal, value chain and wider operating environment vulnerabilities that could be applied to FDMs working in a variety of sectors, irrespective of size. By identifying the broad classes of failure modes that certain vulnerabilities may lead to and then the warning metrics that indicate a predisposition towards certain failure modes, the aim was to identify key components for a vulnerability mapping tool which could be tailored to FDMs of different sizes and operating sectors. Boundaries included that review material was sourced from a wide range of peer reviewed literature, books and grey literature describing FDM supply chain management and that it was published within the last 20 years.

Research Objective 1C is fulfilled in Chapter 5 and comprehensively explores the techniques by which academia, industry and government have modelled resilience and the tools which exist to aid practical enhancement efforts. It analyses the strengths and weaknesses of existing approaches and identifies which are the most appropriate for achieving Research Objective 3, based on the theoretical and industrial findings from Chapters 3 and 4 respectively. With regard to boundaries, all relevant approaches to modelling or enhancing resilience, regardless of research field or publication date were included.

2.5.2 Scope and Boundaries for Research Objective 2: Methodological Design and Framework Development

The development of a suitable research methodology was a fundamental prerequisite for development of the conceptual framework and practical tool. As FDM resilience is a relatively unexplored research area, the methodological approach needed to be able to incorporate new perspectives into existing FDM resilience understandings, i.e. a blend of deductive and inductive research. It also had to enable some way of overcoming literature inconsistency in the formation of a comprehensive framework as well as enabling empirical measurement of supply chains as part of tool development.

Following development of a suitable methodology, there was then a clear conceptual need for a framework, developed from synthesised review findings and industry interviews, which concisely described the concepts underpinning FDM resilience and their relations to each other. The boundaries for this framework were that it would provide an appropriate resilience definition for UK FDMs, establish UK FDM specific taxonomies of vulnerabilities and resilience elements, propose linkages between them, and describe the process by which resilience elements can be evaluated. This research is presented as the FDM-RES Framework in Chapters 7-10.

2.5.3 Scope and Boundaries for Research Objective 3: Practical Tool Development

Research Objective 3 builds on the predominantly conceptual relationship orientated framework by providing the practical charts, metrics and guidance that allow an FDM to identify their bespoke vulnerabilities and select appropriate countering resilience elements. This is presented in the form of a workbook which mirrors the framework and which can be found in Chapters 7-10. One of the requirements for the practical tool was that it provided a dedicated supply chain mapping process to identify a FDM’s exposure to specific failure modes, and from that identification of specific vulnerabilities. It would be important for such a tool to then provide relational matrices describing the linkages between specific vulnerabilities and resilience elements, based on literature evaluation and consultation with industry. This is to be supported by a detailed FDM taxonomy of KPIs to measure the impact of the selected resilience elements on financial as well as environmental and social priorities, thus enabling resilience to be achieved in synergy with existing sustainability goals.

2.5.4 Scope and Boundaries for Research Objective 4: Case Study Validation

The highly explorative nature of this research, particularly regarding the relationships between various concepts such as resilience elements and vulnerabilities, and the need to adapt them to a UK FDM context, means that there is a need for detailed qualitative validation. For this reason, the framework and practical tools developed for Research Objectives 2 and 3 are applied to case studies with two UK FDMs. The boundaries for case study selection were that companies must be UK based and in similar areas of food and drink manufacturing so as to allow comparability between findings. However, slight variations in size, range of products, and numbers of sites were acceptable and even sought out, so as to test the models in different real-world situations. The findings, analysis, and identification of limitations to the tool and framework are presented in Chapter 10 and further discussed in Chapter 11.

2.6 Chapter Summary

This chapter began by describing the context of the research in terms of the need to consider resilience from a global supply perspective, the suitability of UK FDMs for transferability of findings and the fit of the proposed research within the wider resilience research field. From this, a number of research questions were outlined. Finally, the overall aim and specific supporting objectives were presented. This concludes the context, aims and scope section of this thesis. The following three chapters address research objectives 1A, 1B and 1C respectively. They explore, in order, resilience as a concept, real world FDM resilience considerations and finally, the methodologies used in academia and industry/government to model and practically enhance resilience.

Chapter 3: Resilience as a Concept: Systematic Literature Review

3.1 Introduction

The purpose of this chapter is to systematically review the multidisciplinary literature concerning resilience as a theoretical concept and in doing so, address research objective 1A. The chapter begins with a brief introduction, justification for the SLR methodology employed and description of the SLR methodology. The remainder of the paper concerns the analysis of findings through the core review question of: ***Given the volatility increasingly faced by UK Food and Drink Manufacturers, what definition(s), resilience elements and resilience strategies are important for accurately modelling and enhancing resilience?*** This is facilitated via three supporting sub-questions which explored resilience definitions, elements and strategies respectively. The chapter ends with a summary of the key findings for each sub-question (many of which form the basis for synthesis in research chapters 7-9).

3.2 Chapter Purpose

The first objective of this chapter is to systematically explore how resilience for UK FDMs can be defined, whilst the second objective is to identify resilience elements that are relevant to UK FDMs, address literature inconsistencies in terminology and finally categorise these resilience elements according to when in a disruption they should be employed. The final objective of this chapter is to identify what factors influence the formation of strategies guiding when and how resilience elements are employed and their effects measured. This requires an understanding of the types of negative events that resilience elements are designed to counter, variously referred to as 'vulnerability', 'risk' and 'uncertainty' [52–54] and the failure modes they may lead to. It also requires an exploration of the relation between resilience and sustainability in a AFSC context. These objectives are summarised in Figure 3.1. It was identified in Chapter 2 that whilst research into the resilience as a concept was well established, there was still significant inconsistency in terms of how various authors, particularly from different disciplines, defined resilience, and selected appropriate resilience elements. For example, sometimes resilience elements are investigated based on their popularity in the literature (e.g.[55–58]) and their effect on performance measures, whereas others suggest that a broader range of resilience elements should be used and that these should be closely matched to specific vulnerabilities so as to ensure effectiveness and avoid needless cost [21, 46].

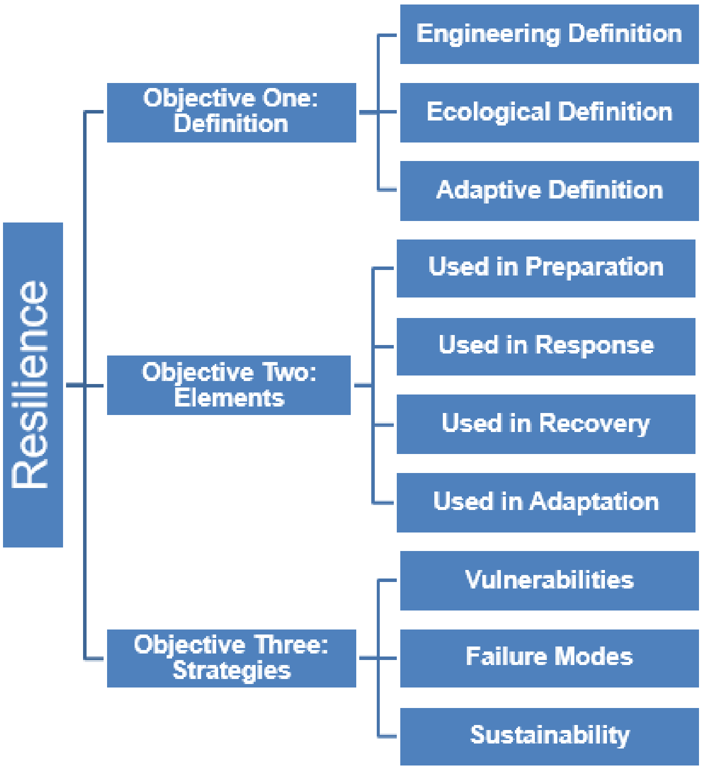


Figure 3.1: Review Objectives.

As FDMs must consider not just their own economic resilience, but also that of the natural environments upon which they depend and that of the societies who depend upon their products, it is important that resilience considerations from many disciplines are considered, despite the inconsistency. For this reason, this review uses the SLR process which enables the thorough and repeatable categorisation of available knowledge and which facilitates cross-comparison based on principles, rather than nomenclature, thus overcoming inconsistency. The next section describes in detail the SLR methodology used.

3.3 Systematic Literature Review Methodology

This review followed the well-established methodology of Denyer and Tranfield (2009) [59] and consisted of five distinct steps which are outlined in Figure 3.2 and which are now described in detail.

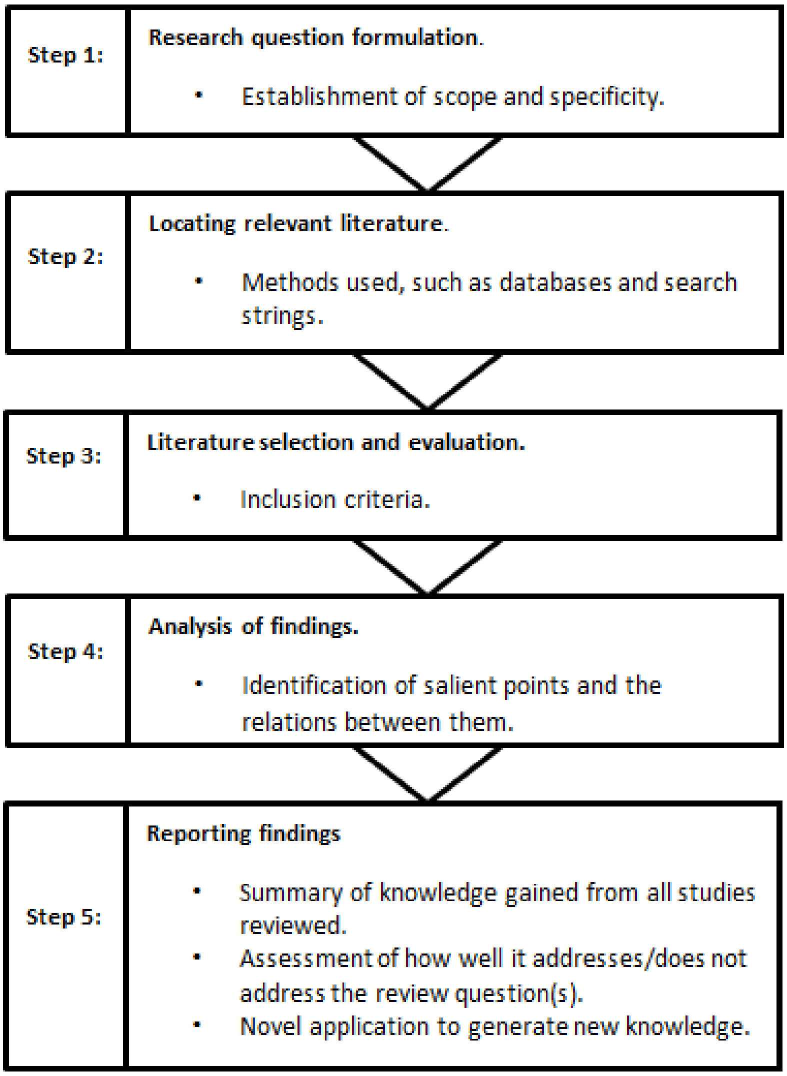


Figure 3.2: Systematic Review Methodology Adapted from Denyer and Tranfield (2009)[59].

3.3.1 Step 1: Review question formulation

The first step in an SLR is the formulation of a specific, purposeful, review question in order to determine the scope and focus of the review. The well-established PICO framework for review question formulation was utilised to ensure that the review question adequately reflected the **P**roblem, the **I**ntervention, the **C**omparison (if there is one) and the **O**utcome described in Section 3.2 [60]. In this review, the **Problem** is volatility facing UK FDMs as part of global supply networks, the **Interventions** are the definition(s), elements and strategies described in section 3.2, and the **Outcome** is a better understanding of resilience and the ways in which it may be enhanced.

There is no comparison, although this is not a mandatory component of the PICO framework. This provided the following review question:

Given the volatility increasingly faced by UK Food and Drink Manufacturers, what definition(s), resilience elements and resilience strategies are important for accurately modelling and enhancing resilience?

This core question is addressed via three sub-questions:

Sub-question 1: What definitions of resilience are appropriate for UK Food and Drink Manufacturers?

Sub-question 2: What resilience elements are described in the literature and are there any special considerations when applying them to UK Food and Drink Manufacturers?

Sub-question 3: What factors must be considered by a food and drink manufacturer when designing strategies for the application of resilience elements?

3.3.2 Step 2 Locating Relevant Literature

The purpose of this phase is to design search criteria in such a way as to ensure the identified literature is comprehensive enough to capture all salient points relevant to the review question from all relevant disciplines [59]. Therefore, the following multiple database, cross-disciplinary online citation services were used; Google Scholar, Web of Science, ProQuest, Science Direct Wiley Online, Emerald and Scopus. Consistent with a number of other SLR's in the area of resilience, this paper used a number of defined key words as search criteria as summarised in Table 3.1. The search was performed initially in December 2016 and was repeated in November December 2017. The search for key words was restricted to title and abstract. Keywords were initially selected based on the authors' collective knowledge of the field which were subsequently critiqued and validated through consultation with other research colleagues allowing development of the shortlist presented in Table 3.1. Search strings were composed of primary keywords and secondary key words. The primary search phrase used in all databases was either 'Community', 'Socio-Ecological System' or 'Supply Chain'. Each primary search phrase was accompanied by AND 'resilience/resiliency'. In addition, each search involved a secondary key word which was one of either: 'Risk/Risk Management', 'OR Vulnerability', 'OR Volatility', 'OR Security', 'OR Mitigation', or 'OR Business Continuity'. These variations were run exhaustively. For example, 'Community' AND 'Resilience' AND 'Security'.

Table 3.1: Literature sourcing key words

Primary Phrases	Secondary Phrases	Database Search Strings
UK Food and Drink Manufacturing AND Resilience/Resiliency Agri-Food Supply Chain AND Resilience/Resiliency Community AND Resilience/Resiliency Socio-Ecological AND Resilience/Resiliency	Risk/Risk Management OR Vulnerability OR Volatility OR Security OR Mitigation OR Business Continuity OR Disruption	Primary and secondary keywords were applied in databases as follows. Searching within abstract and title: Key word: ONE of either Supply Chain/ Community/ Socio-Ecological System AND: Resilience/Resiliency AND: Risk/Risk Management OR Vulnerability OR Volatility OR Security OR Mitigation OR Business Continuity OR Disruption

3.3.3 Step 3: Literature selection and evaluation

From the initial search criteria, this review sourced a total of 1270 articles. To maintain transparency and to ensure fit of identified material to the review question stringent selection criteria were applied to this initial search pool. Whilst material was not limited by publication date, materials were restricted to those published in the English language. Additionally, in line with other SLR’s in the area of resilience [21-22], material was limited to peer reviewed publications as an indicator of the academic rigour of identified literature [61]. Once duplicates, non-peer reviewed results and non-English publications were excluded, the remaining pool numbered 239 articles. Scanning of Introductions and Conclusions provided a better understanding of the fit of the material to the review question and its associated sub-questions. At this stage, 104 articles were excluded due to either being inaccessible (6 articles), or being beyond the scope of AFSC relevant resilience definitions, elements and strategies. Work cited in all accepted articles was also scanned for titles that matched the key word criteria. In total, this provided a final review size of 137 articles, as outlined in Figure 3.3.

3.3.4 Step 4: Analysis of findings

The objective of this stage was to analyse the final literature pool of 137 articles to identify salient points of resilience in relation to the research question and sub questions established in step one. Therefore following an initial descriptive analysis, each of the sub question topics, were analysed in more detail.

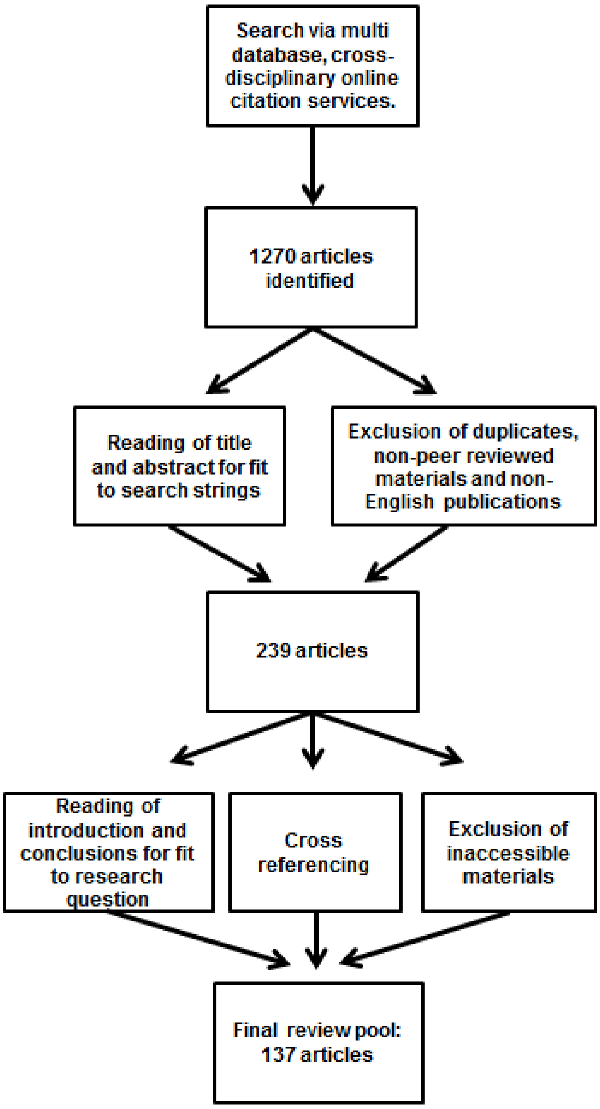


Figure 3.3: Review process for literature selection and evaluation.

Analysis was conducted using a Microsoft Excel spreadsheet to record summaries of the positions of each of the 137 articles regarding the aforementioned areas. As this step is by far the most substantial stage of the SLR process and is beyond the remit of a methodology section, it is presented in detail in Section 3.4.

3.3.5 Step 5: Reporting the findings

In this stage of the SLR, the findings from the analysis of the entire review pool, the relationships between salient concepts and the extent to which this information has addressed the review questions is reported [59]. Again, as this stage of the SLR process is beyond the scope of a methodology section, it is presented in detail in Section Four. As Figure 3.2 highlights, it is also common at this stage to apply this information in a novel context, thus generating new knowledge in the field and driving theory development. However, in this thesis, this novel application will occur in Chapter 7 when findings from all three review Chapters (3-5) are synthesised.

3.4 Analysis of Findings

This section fulfils Step 4 of the SLR process described above and presents the analysis of the final literature pool of 137 articles based on their respective contributions to resilience definitions, elements and strategies. Firstly, in order to understand how resilience by publication as a concept has developed over time and across multiple disciplines, a descriptive analysis of articles by publication date, publication journal, subject area and methodology has been performed. Following the descriptive analysis, the literature is investigated from the perspective of each of the three review sub-questions respectively.

3.4.1 Descriptive Analysis

Figure 3.4 highlights that 75% of all articles considered in this review have a Supply Chain Management or Operations Management origin. Relatively few of these focussed on AFSC Resilience (only 28) (See Figure 3.4). However, less common but still important contributions to the resilience literature were found in journals from a range of other disciplines which included Ecological Systems, Social Systems and Engineering/Physical Systems. For example, Social Systems research disproportionately focussed on AFSCs with a focus on the adaptive capacity of complex systems [28-29]. This suggests that the supply chain management and operation management literature is predominantly focussed on individual business continuity and competitive advantage, which is at odds with the need for resilience in an FDM setting to also consider the wider food security implications of resilience. Another notable observation is that all of the articles reviewed were published post 2000 with 65% being published post 2010, suggesting that interest in the application of resilience as a concept is a recent and growing phenomena.

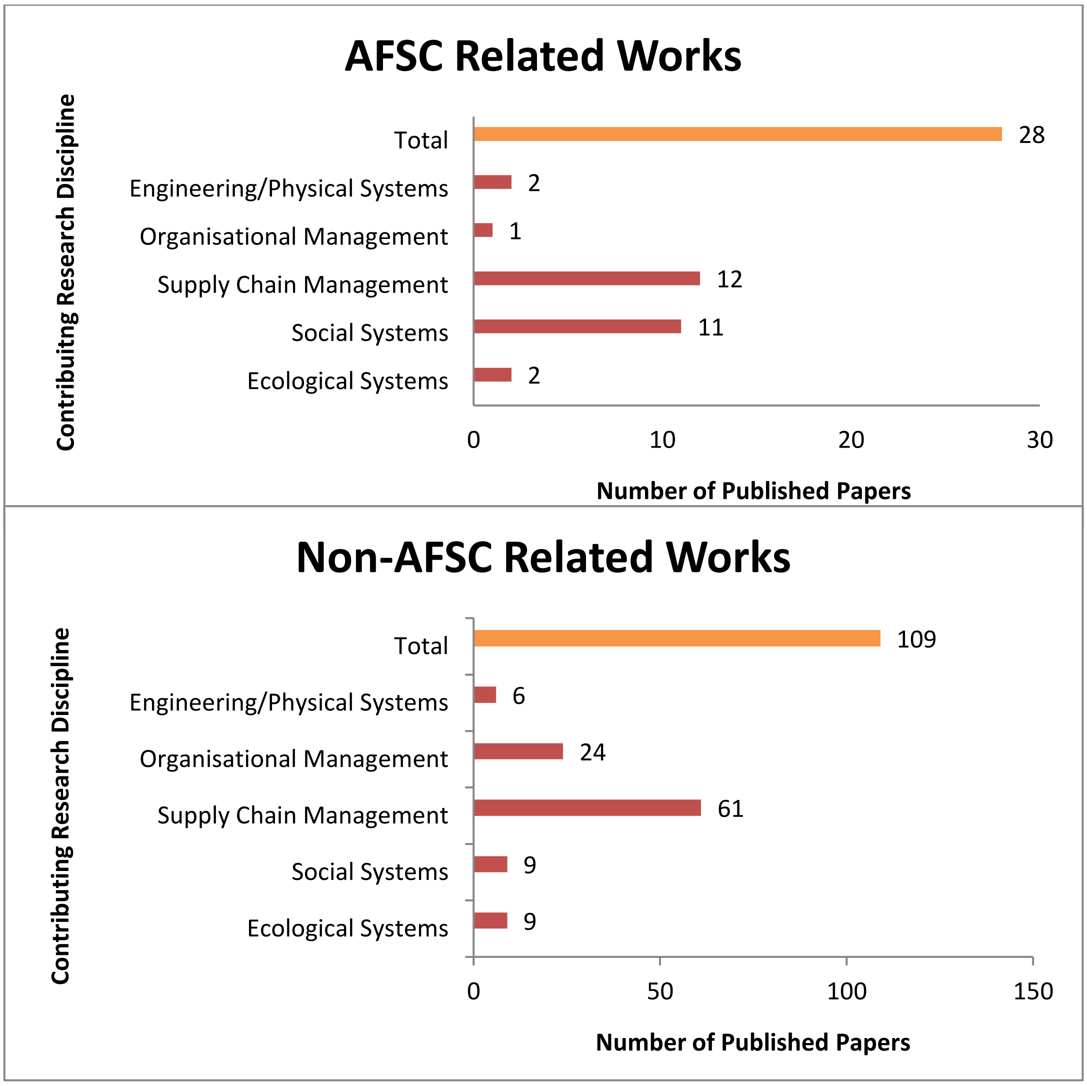


Figure 3.4: Analysis of literature by research context and specificity to agri-food supply chains.

Evidence suggests that this is in response to a number of wide ranging and unexpected disruptions including Hurricane Katrina, the Icelandic eruptions at Eyjafjallajökull in 2010, the Fukushima nuclear disaster, as well as major terrorist incidents such as the 9/11 attacks in America and the 7/7 attacks in the UK [62–65].

3.4.2 Addressing SLR Sub-Question 1

This section addresses review sub-question 1: ***What definitions of resilience are appropriate for UK Food and Drink Manufacturers?***

Whilst a relatively new addition in the context of AFSCs and FDMs, resilience is by no means a new concept. The term has Latin origins, stemming from the word 'resi-lire', meaning to spring back and was first used by physicists to describe the stability of materials and their ability to resist external shocks [66]. It entered popular use in the field of Ecology in the 1960's and from there began to be translated to a range of new subject fields aided by a seminal article by Crawford Stanley Holling in 1973 [67]. This article divided resilience into two distinct definitions that are commonly used today: Engineering Resilience and Ecological Resilience.

In the Engineering definition, resistance to disturbance and the speed by which the system returns to a state of equilibrium are the mark of resilience. The phrase 'a state of equilibrium' refers to the notion of optimal day to day operations [68]. Heavy emphasis is placed on return time, efficiency, constancy and predictability, which it is claimed, are the marks of a sound engineering design and hence the name [69]. In the ecological definition, resilience is also measured by resistance to disturbance and speed of return to a state of equilibrium but this definition also accepts that there are multiple possible equilibriums that the system could flip into depending on the magnitude of the disturbance [70].

It has been pointed out that a major shortcoming of both the engineering and ecological definitions of resilience is that they presume closed systems within which different actors can establish states of equilibrium. This is clearly not the case in something as complex as a food system where intertwined social, environmental, economic and political factors drive constant change across key operating parameters. In response to this, several authors have proposed a third definition of resilience which has been termed 'Evolutionary' or 'Adaptive' Resilience [71–74]. This is referred to as Adaptive Resilience from now onwards.

Adaptive Resilience describes complex social–ecological systems where the interactions between different scales (for example, from individual species, to forests, to entire ecosystems), time periods (referred to as temporal scales) and geographic distances (referred to as spatial scales) are all considered vital for overall system resilience. In AFSCs these different scales are analogous to interactions between actors at different stages of a supply chain (e.g. producers, retailers and even suppliers of suppliers or providers of infrastructure), acting at different time points (for example, the growing season is often far out of synchronisation with manufacturing cycles) and at different global locations, creating significant complexity and uncertainty [75]. As such, there cannot be a 'state of equilibrium' because external interference is continuous. Instead, resilience is something that is cyclical and cumulatively developed by a continual process of adaptation and learning from ongoing disturbances.

It has been proposed that this continuous adaptive cycle has four distinct stages: exploitation, conservation, release, and reorganisation as shown in Figure 3.5 [71-76]. Using the example of a business, the first phase is exploitation, marked by use of readily available resources to form structure and core business priorities. An example might be that of a new start-up company with a novel product and market dominance. However, as an organisation grows, it will eventually reach a point where its size binds ever larger quantities of resources and its connectivity increases cross-scale interactions, known as the conservation phase. The existence of the phase is supported by evidence collected by Peck et al. (2005) [77] in multi-sectorial supply chain interviews. An example view expressed by a consultant in Electronics Manufacturing is: *'It's when the supply chain is supposed to be in the established steady state that it is most vulnerable, because that's the point when it's most susceptible to external effects. That's when most people are trying to optimise and reduce control limits to reduce the variability of the process, but external risks may have changed the original scenario.*'[77].

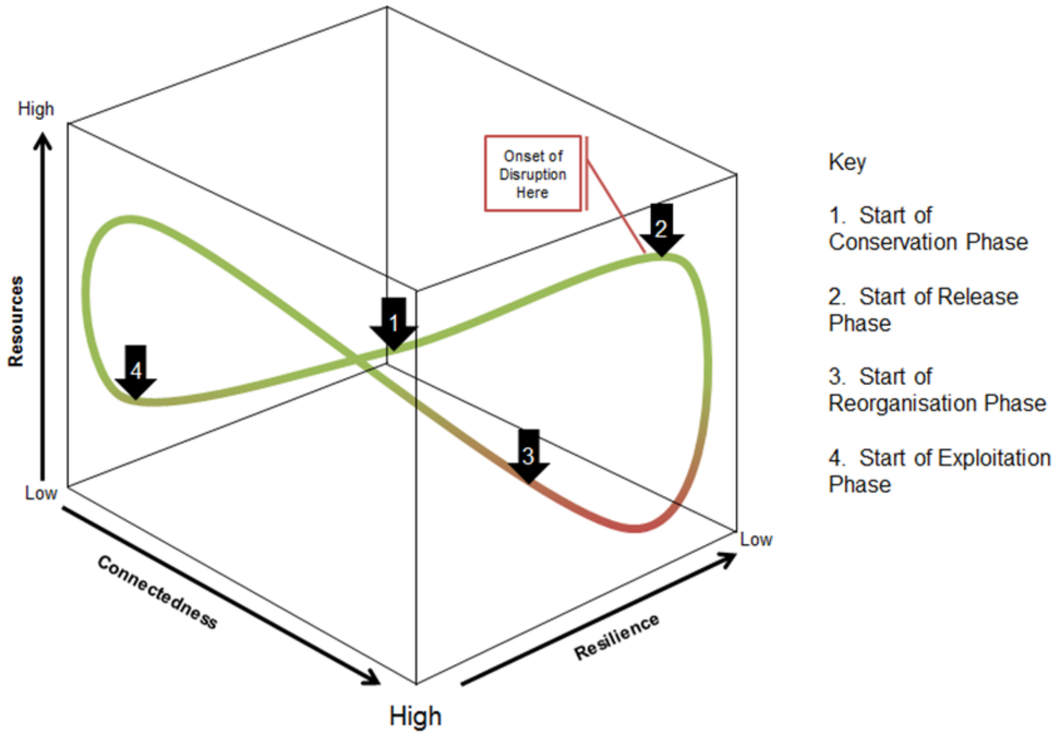


Figure 3.5: The Adaptive Cycle of System Dynamics (Adapted from information provided by Walker et al. (2006) and Gunderson et al. (2001).

In AFSCs in specific, this phase has been likened to contemporary drives towards intensification of agriculture and centralisation of factories and distribution centres, representing accumulation of capital and growing interconnectivity. Other assets bound up in AFSCs include significant amounts of land, water, carbon and other nutrients embodied in food [78]. This phase is where susceptibility to disturbance is at its highest because so many assets are tied up in the current way of doing things and connectivity means exposure is at its highest. There is the potential for significant loss of resources if a big enough disturbance occurs and this is known as the 'Release' phase. This does not necessarily comprise pure financial loss but might also concern loss of resources bound up in no longer tenable business structures.

The business does not necessarily collapse at this point, but there will need to be some sort of adaptation (the Reorganisation Phase) at which point the cycle begins again [79]. The Adaptive Cycle also differs from the Engineering and Ecological definitions of resilience by its underlying consideration of 'Panarchy' [76]. This represents complexity in a system where disruptions do not necessarily have to originate within the same time period or geographic proximity as the focal organisation. This means that the relationships between cause and effect of a disturbance do not necessarily have to be linear. As such, small influences such as the input of single staff members in the face of disruption can have just as much or more impact than large scale interventions. Such unpredictability challenges the adequacy of conventional tools for risk management, such as extrapolation of past trends as a way of forecasting future events [80].

In Table 3.2, the review pool is analysed according to which of the Engineering, Ecological, and Evolutionary definitions authors adopt. 48 of the 137 articles being reviewed offered a definition for resilience. As sub-question one concerns identifying suitable definitions of resilience for AFSCs, literature definitions were compared on whether they were from articles considering AFSCs in specific, or from different perspectives on resilience. 12 of the articles offering definitions considered AFSCs in specific (although this did not always come across in the definitions chosen) and 35 were more general in focus. The broader research contexts of the review articles were also compared in order to identify if certain research fields prioritise a specific type of definition.

Table 3.2: Categorisation of reviewed literature by the type resilience definition used. ('AFSC specific' in bold italics indicates a definition from a work that focussed on AFSC in specific)

Research Field	Author	Definition	Type of Definition
Social Systems	Milestad (2003) [28]	"The magnitude of disturbance that can be experienced before a system moves into a different state with different sets of controls" ***(AFSC Specific).***	Ecological
	Smith et al. (2015) [81]	"The existence, development, and engagement of community resources by community members to thrive in an environment characterised by change, uncertainty, unpredictability, and surprise and to develop new trajectories for the community's future" ***(AFSC Specific).***	Adaptive
	Tendall et al. (2015) [29]	"Capacity over time of a food system and its units at multiple levels, to provide sufficient, appropriate and accessible food to all, in the face of various and even unforeseen disturbance" ***(AFSC Specific).***	Adaptive
	Sinclair et al. (2013) [82]	''The capacity of a system to absorb disturbance and reorganize so as to retain essentially the same function, structure, identity and feedbacks'' ***(AFSC Specific)***.	Adaptive
	Macfadyen et al. (2015) [83]	"Here we talk about resilience in terms of production variability and the ability of agro-ecosystems to maintain stability in production levels even in the face of disturbances" ***(AFSC Specific)***.	Engineering
	King (2008) [72]	"A system's ability to adapt and respond to external impacts on a system" ***(AFSC Specific).***	Adaptive
Supply Chain Management	Carvalho et al.(2012) [84]	"Supply Chain resilience is concerned with the system's ability to return to its original state or to a new, more desirable, one, after experiencing a disturbance, and avoiding the occurrence of failure modes" ***(AFSC Specific).***	Ecological
	Ivanov et al. (2012) [85]	"Resilience refers to the capacity of organizations or systems to return to full functionality in the face of disruption" ***(AFSC Specific)***.	Engineering
	Yang and Xu (2015) [86]	"The ability of a system to return to its original state or move to a new and more desirable state after being disturbed, or to adapt existing resources and skills to new situations and operating conditions" ***(AFSC Specific).***	Adaptive
	Fałkowski (2015) [87]	"The term "resilience" refers to the ability of a system to maintain output close to potential in the aftermath of shocks or, alternatively, the ability of a system to return to its original state after being disturbed" ***(AFSC Specific).***	Engineering
	Leat and Revoredo-Giha (2013) [75]	"Resilience aims at developing the adaptive capability of the chain to prepare for unexpected events and to respond to disruptions and recover from them" ***(AFSC Specific).***	Adaptive
	Manning and Soon (2016) [88]	"Strategic resilience is not about responding to a single crisis or rebounding from a setback, it encompasses anticipating and reacting to secular trends that can permanently impair the earning power of the core business" ***(AFSC Specific).***	Adaptive
	Ponomarov et al. (2009) [89]	"The adaptive capability of the supply chain to prepare for unexpected events, respond to disruptions and recover from them by maintaining continuity of operations at the desired level of connectedness and control over structure and function".	Adaptive
Social Systems	Milman and Short (2008) [90]	"Resilience includes more than maintaining given system characteristics; it includes the adaptive capacity of the system—its ability to adapt to stresses and changes and to transform into more desirable states".	Adaptive
	Manyena et al. (2006) [66]	"Resilience could be viewed as the intrinsic capacity of a system, community or society predisposed to a shock or stress to adapt and survive by changing its non-essential attributes and rebuilding itself".	Adaptive

	Davoudi et al. (2012) [79]	"Resilience is not conceived of as a return to normality, but rather as the ability of complex socio-ecological systems to change, adapt, and, crucially, transform in response to stresses and strains".	Adaptive
	Rose (2011) [68]	"The ability of a system to maintain function when shocked and to hasten the speed of recovery from a shock".	Engineering
	McDaniels et al. (2008) [91]	"A complex system's capacity to absorb shocks while maintaining function. Enhanced by both risk mitigation activities undertaken before the disaster and response activities following the event".	Engineering
Ecological Systems	Derissen et al. (2011) [92]	"The magnitude of disturbance that can be absorbed before the system changes its structure by changing the variables and processes that control behaviour".	Ecological
	Fiksel (2003) [27]	"Resilience can be defined as the capacity of a system to tolerate disturbances whilst retaining its structure and function".	Ecological
	Tukamuhabwa et al. (2015) [38]	"The adaptive capability of a supply chain to prepare for and/or respond to disruptions, to make a timely and cost-effective recovery, and therefore progress to a post-disruption state of operations – ideally, a better state than prior to the disruption".	Adaptive
	Lebel et al. (2006) [93]	"Resilience is a measure of the amount of change a system can undergo and still retain the same controls on structure and function or remain in the same domain of attraction".	Ecological
	Redman (2014) [25]	"Resilience is the capacity of a system to experience shocks while retaining function, structure, feedback capabilities, and therefore identity".	Ecological
	Folke (2006) [73]	"The capacity of the system 'to absorb disturbance and re-organize while undergoing change so as to still retain essentially the same function, structure, identity, and feedbacks''.	Adaptive
Supply Chain Management	Colicchia et al. (2010) [94]	"The ability of a system to quickly react to the undesired events when they happen".	Engineering
	Carvalho et al. (2012) [43]	"Resilience refers to the ability of the supply chain to cope with unexpected disturbances. It is concerned with the system ability to return to its original state or to a new one, more desirable, after experiencing a disturbance, and avoiding the occurrence of failure modes".	Ecological
	Todo et al. (2015) [95]	"Defined as speedy recovery through the repair and reconstruction of capital stock".	Engineering
	Kamalahmadi and Parast (2016) [22]	"The dynamic capability of an enterprise, which is highly dependent on its individuals, groups, and sub- systems, to face immediate and unexpected changes in the environment with proactive attitude and thought and adapt and respond to these changes by developing flexible and innovative solutions".	Adaptive
	Pereira et al. (2014) [24]	"Supply chain resilience is defined here as the capability of supply chains to respond quickly to unexpected events so as to restore operations to the previous performance level or even to a new and better one".	Engineering
	Pettit et al. (2008) [96]	"The capacity for an enterprise to survive, adapt and grow in the face of turbulent change".	Adaptive
	Elleuch et al. (2016) [97]	"In this context, resilience is defined as the ability of a system to return to its original state or a more favourable condition, after being disturbed".	Engineering
	Brandon-Jones et al. (2014) [98]	"We define supply chain resilience as the ability of a supply chain to return to normal operating performance, within an acceptable period of time, after being disturbed".	Engineering
	Peck et al. (2005) [77]	"The ability of a system to return to its original [or desired] state after being disturbed".	Ecological
	Ambulkar et al. (2015) [74]	"Firm's resilience to supply chain disruptions is defined as the capability of the firm to be alert to, adapt to, and quickly respond to changes brought by a supply chain disruption".	Adaptive
	Jüttner et al. (2011) [55]	"Supply chain resilience addresses the supply chain's ability to cope with the consequences of unavoidable risk events in order to return to its original operations or move to a new, more desirable state after being disturbed".	Ecological

	Christopher et al. (2004) [23]	"The ability of a system to return to its original state or move to a new, more desirable state after being disturbed".	Ecological
	Li et al. 2017	"Supply chain resilience refers to a supply chain's capability to cope with changes, which is formed through being prepared to endure future changes, being alert to changes and being agile in response to changes"	Engineering
Organisational	Asbjornslett et al. (1999) [99]	"Resilience may be defined as a system's ability to return to a new stable situation after an accidental event".	Ecological
	Fahimnia and Jabbarzadeh (2016) [26]	"The capacity of a SC to absorb disturbances and retain its basic function and structure in the face of disruptions".	Engineering
	Kim et al. (2015) [100]	"We define supply network resilience as a network-level attribute to withstand disruptions that may be triggered at the node or arc level".	Engineering
	Annarelli and Nonino (2016) [101]	"Organizational resilience is the organization's capability to face disruptions and unexpected events in advance thanks to the strategic awareness and a linked operational management to internal and external shocks. The resilience is static, when founded on preparedness and preventive measures to minimize threats probability and to reduce any impact that may occur, and dynamic, when founded on the ability of managing disruptions and unexpected events to shorten unfavourable aftermaths and maximize the organization's speed of recovery to the original or to a new more desirable state".	Ecological
	Aigbogun et al. (2014) [102]	"Resilience confers on the supply chain the ability to return to original or perhaps better supply chain performance under emergency risk environment".	Ecological
Engineering/Physical System	Levalle and Nof. 2017[103]	"a resilient supply network can be defined as a system which is capable of continuously transitioning in an adaptive manner among multiple robust designs and operation strategies in order to anticipate, prepare for, and overcome disruptions".	Adaptive
	Caschili et al. (2015) [104]	"We can use the concept of resilience in order to describe the capacity of a hierarchical economic system (composed of several sub systems), to recover after being subject to a variety of challenges (shocks, disruptions, attacks, etc.) which move the system from its equilibrium".	Ecological
	Cimellaro et al. (2010) [41]	''Intrinsic capacity of a system, community or society predisposed to a shock or stress to adapt and survive by changing its non-essential attributes and rebuilding itself ''	Adaptive
	Spiegler et al. (2012) [42]	''The ability of a system to return to its original state or move to a new, more desirable state after being disturbed''	Ecological
	Soni et al. (2014) [105]	"Supply chains must be multidimensional and multidisciplinary, designed to incorporate event readiness, provide an efficient and effective response and be capable of recovering to their original state or improved state after a disruption; this is the meaning of supply chain resilience".	Ecological
	Berle et al. (2011) [106]	"In this paper, resilience is defined as the ability of the supply chain to handle a disruption without significant impact on the ability to serve the supply chain mission".	Engineering

3.4.2.1 Suitable definitions for AFSCs

It was identified that overall; there was a slight preference for the adaptive definition of resilience (18 of the 48 definitions identified, compared to 16 for ecological and 14 for engineering). This is particularly true in works that were AFSC specific in focus, many of which originated in fields other than SCM [73-76-92-107–109]. Here, AFSCs are considered within the sphere of the wider natural world, where change is constant and control over that change by any given actor is small. For example, as complex social-ecological systems, AFSCs are dependent on a number of ecosystem services to produce food, and significant social-economic factors to manufacture and transport food.

A breakdown in any one of these areas can lead to harvests failing, transport links breaking and consumer demands and tastes changing [86-90]. Therefore logically, to be resilient in such a world is to prioritise constant adaptation and reorganisation. Key features of such adaptive food definitions included the ability to maintain ‘function’ as well as the ability of systems to adapt rather than to return to existing states of equilibrium. Tendall et al. (2015) [29] advance the field by linking ‘function’ with the United Nations Food and Agricultural Organisation definition of food security which concerns the four pillars of availability, access, utilisation and stability of food to end consumers.

Moving forward, a number of definitions in Table 3.2 refer to one or more of the following abilities: to ‘Resist’, to ‘Recover’ and/or ‘Adapt’. Ponomarov et al. (2009) [89], categorised these into the distinct phases of Readiness, Response and Recovery. Readiness refers to an organisation’s ability to anticipate disruption and either prepare for it or avoid it. Response refers to either innate or pre-planned capabilities that mitigate the impact of a disruption as it happens. Recovery refers to the ability of an organisation to repair losses caused by a disruption and return to meeting core priorities. Hohenstein et al. (2015) [21] add the fourth phase of ‘Growth’ which concerns learning from and adapting core priorities post disruption so that competitiveness actually improves compared to pre-disruption levels. However, it has been noted that many articles overwhelmingly see disruption in light of the reactive and recovery phases only, thereby perpetuating the idea that resilience is a one off fix rather than a cumulative process of resilience improvement in response to multiple disruptions [e.g. 21,81].

This concludes the review of resilience definitions and this chapter now moves on to sub-question two in order to identify AFSC relevant resilience ‘elements’ and ‘strategies’.

3.4.3 Addressing SLR Sub-Question 2

This section addresses SLR sub-question 2: ***What resilience elements are described in the literature and are there any special considerations when applying them to UK Food and Drink Manufacturers?***

A number of works have proposed that resilience can be controlled by a portfolio of variously named ‘antecedents’, ‘attributes’, ‘capabilities’, ‘elements’, and ‘enhancers’ which are management tools to counteract specific vulnerabilities [21-22, 39, 82]. For consistency with the predominant literature terminology [21-22, 46], the phrase 'elements' is used from now onwards. 61 articles proposed one or more key elements for resilience. Many of these sources were inconsistent with their use of names for these resilience elements, but by picking out the functional aspects of each resilience element proposed by each author, 34 unique resilience elements were identified overall. This breadth of resilience elements has, to the author's knowledge, not been attempted previously in the literature. These elements varied significantly in terms of 'scope'. This refers to whether resilience elements were applicable in response to disruptions within an individual organisation (for example, machinery faults) or within a supply chain (for example, loss of a specific supplier), in which case, elements addressed ways in which the supply chain could collectively adapt. The list of identified elements, their respective scope and publication sources are given in Table 3.3. It should be noted that some elements appear in both the Intra-Organisational and Intra-Supply Chain columns albeit with different contexts. For example, Redundancy at an organisational level refers to spare capacity and inventory but at a Supply Chain level describes alternative transport routes between stages or backup infrastructure. When ranked according to the number of papers mentioning a specific element, Agility, Flexibility, Risk Aware Culture, Redundancy and Early Warning Detection Systems were the most commonly cited elements at an organisational level. At a supply chain level, Collaboration, Flexibility, Visibility and Adaptability were respectively the most commonly cited elements.

Despite there being a number of highly cited resilience elements, the overwhelming majority of elements identified appeared in less than 10% of papers reviewed. This suggests that there is poor consensus on what elements are the most important for resilience. For example, Fiksel (2003) [27] proposes four elements: diversity, efficiency, adaptability and cohesion. Pettit (2010) [46] on the other hand identifies 14 different elements. Without empirical validation, it is difficult to be sure that just because a resilience element is cited more frequently, that it is more significant for resilience than a less commonly cited capability. In particular, many of the less commonly cited elements are from less active research fields, such as ecological and social systems. Such elements concern interactions and relations between organisations, communities and the natural environment as well as their ability to adapt, which are of major significance to 'adaptive resilience' in AFSCs. Therefore, there is a need to capture the relationship between such elements and the more commonly cited elements. This concludes the analysis of resilience elements as part of sub-question two and this review now moves on to explore resilience strategies as part of sub-question three.

Table 3.3. Survey of resilience elements from the literature.

Scope	Capability	Details	No.	%	Sources
Organisational Resilience (OR)	OR1. Agility	• The ability to respond quickly to unpredictable changes in supply and demand by changing configuration at tactical level. • Logistics capabilities • Manufacturing flexibility	17	27.8	[21-22, 31, 46, 58, 82–93]
	OR 2. Flexibility	• Ability of an organisation to adapt with minimum time and effort. • Concerns supply base, transport, labour and fulfilment.	9	14.75	[22, 31, 52, 82, 90, 94–97]
	OR 3. Risk Aware Culture	• Describes the infrastructure a firm has in place to manage risk	9	14.75	[22, 46, 58, 67, 82, 93, 98-100]
	OR 4. Redundancy	• Spare capacity and inventory	8	13.11	[22, 31, 39, 82, 90, 94, 96-97]
	OR 5. Early Warning Detection Systems	• Foresight to extend preparation time • Intelligence generation through big data and the internet of things	5	8.1	[39, 46, 94, 98, 101]
	OR 6. Security	• Both information and physical	4	6.5	[39, 93, 94, 102]
	OR 7. Efficiency	• Resource utilisation • Efficiency standards such as six sigma	4	6.5	[39, 102–104]
	OR 8. Inventory Management	• Increased visibility of supplier operations and transport mediums to reduce the amount of redundancy required in a disruption • Closely related to the supply chain orientated element of 'IS3 Visibility'	3	4.9	[51, 94, 105]
	OR 9. Financial Strength	• Availability of easily accessible financial assets. Linked to 'IO2 Flexibility'.	3	4.9	[39, 82, 106]
	OR 10. Leadership Commitment	• Cognitive style • Ability to prioritise • Inspiration • Important in establishing effective risk management culture	3	4.9	[22, 99, 106]
	OR 11. Relationships	• Communication • Flow of information	3	4.9	[46, 99, 107]
	OR 12. Risk Management	• Implementation of independently accredited risk management procedure which identifies, evaluates and mitigates risk regularly for all significant company operations • (Not limited to mission critical assets as in BCM)	2	3.2	[49, 99]
	IO 13. Business Continuity	• Contingency planning for the protection of 'mission critical assets'.	2	3.2	[70, 98]

		• Key component of 'IS10 Robustness'.			
	OR 14. Human Resource Management	• Skillsets (particularly ability to fulfil multiple roles) • Risk Identification	2	3.2	[94, 99]
	OR 15. Innovation	• Presence of shared beliefs, openness to learning and joint decision making.	2	3.2	[22, 108]
	OR 16. Knowledge Management	• Workers skills and knowledge retention	2	3.2	[58, 82]
	OR 17. Market Position	• Factors such as market share, product differentiation and customer communications which can be manipulated to aid recovery in the event of a disruption.	1	1.6	[46]
	OR 18. Adaptive Management	• Active monitoring of decisions and outcomes for incremental learning	1	1.6	[28]
Supply Network Resilience (SNR)	SNR 1. Collaboration	• Shared forecasting, postponement and risk sharing. • Cooperation and partnership • Aim of reducing uncertainties and complexity • Integration of systems	19	31.1	[21, 22, 31, 39, 46, 49, 58, 90-93, 101-102,106-107, 109-114]
	SNR 2. Flexibility	• Degree by which a supply chain can respond to changing environment and customer requests • Supply chain wide alternative options achieved through partnerships • Ability to move staff and equipment rapidly	18	29.5	[37-38, 45, 49, 85-86, 91, 95, 98, 104-, 109, 113, 115–120]
	SNR 3. Visibility	• The ability to see structures, processes and products from one end of the supply chain to the other. • Sharing of risk information • IT infrastructure	15	24.5	[22, 39, 46, 49, 82, 90, 94, 99, 101, 107, 109-110, 113, 121-122]
	SNR 4. Adaptability	• The ability to adapt effectively to change at a strategic level	9	14.75	[37, 39, 45, 87, 103, 117-118, 123-124]
	SNR 5. Velocity	• Speed at which products reach end consumer. • Includes efficiency • Reduction of lead times • Synchronisation of schedules	6	9.8	[22, 46, 49, 82, 108, 112]
	SNR 6. Redundancy	• System wide design of emergency back up and storage facilities • Surplus pathways between nodes • Extent to which elements are replaceable.	6	9.8	[45, 81, 108, 114, 124-125]

SNR 7. Node Criticality	• Increases as relative number of suppliers and customers increases • Single geographic regions of extensive primary food production which increase vulnerability	6	9.8	[22, 71, 89, 93, 98, 125]
SNR 8. Established Communication Lines	• Efficient and robust flow of information	6	9.8	[22, 37, 46, 82, 92, 106]
SNR 9. Robustness	• The ability to withstand a given amount of stress without loss of function	6	9.8	[45, 83, 117, 126–128]
SNR 10. Trust	• Problems can be discussed openly • Key determinant of 'IS1 collaboration'	3	4.9	[22, 82, 92]
SNR 11. Cohesion	• The existence of unifying relationships between supply chain organisations, such as shared goals (on ethics for example) which might allow closer partnerships and standardisation of materials and processes	3	4.9	[102, 106, 122]
SNR 12. Contingency Plans	• Speed of response via crisis management teams and recall procedures.	3	4.9	[49, 95, 105]
SNR 13. Diversity	• Refers to inputs, suppliers, staff and customers. Related to the existence of redundancy	2	3.2	[102, 122]
SNR 14. Network Complexity	• Number of nodes and length	2	3.2	[39, 98]
SNR 15. Bargaining Power	• Use of supply chain position and power to influence others	1	1.6	[125]
SNR 16. Community resources	• The range of ecological, economic, social, physical, institutional and cultural resources a community can draw upon when faced with disruption. • Similarities with both supply chain wide flexibility and redundancy	1	1.6	[81]

3.4.4 Addressing SLR Sub-Question 3

This section addresses SLR sub-question 3: ***Which factors can help to form resilience strategies to guide the application of resilience elements?***

In formulating strategies by which to employ resilience elements, it is important to consider that many resilience elements have side effects such as inefficiencies elsewhere. For example, the commonly cited element of redundancy will have significant costs in terms of capacity and inventory management when there may be much more suitable yet lesser known resilience elements available [42]. Therefore, simply employing resilience elements in a blanket approach may well erode organisational and ultimately supply chain performance, paradoxically reducing resilience. By linking specific resilience elements to specific negative events, it is possible to 'balance' resilience (See Figure 3.6)[46].

'Balanced' resilience occurs when the correct mix of resilience element is employed to optimally mitigate the negative event(s) at hand, but not to cause excessive cost (either in terms of direct implementation or side effects elsewhere. The relationship between resilience elements and negative events will not necessarily be one to one, for example, in certain situations, more than one element might be appropriate for a given negative event and in others, a single 'element' may be effective in countering multiple negative events. To proceed with addressing SLR Sub-Question 3, it is important to define the nature of the negative event which resilience elements are being used to counter, something which is variously labelled as 'risk', 'vulnerability' or 'uncertainty' in the literature.

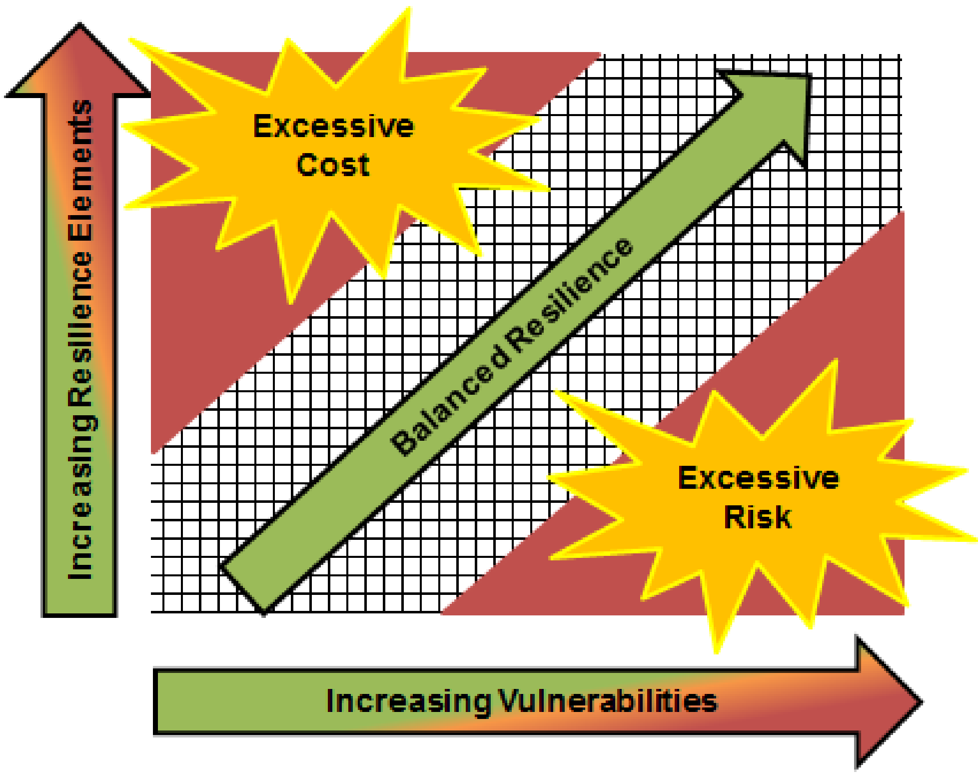


Figure 3.6: Zone of balanced resilience. Based on work by Pettit et al. 2010[46].

3.4.4.1 Supply Chain Vulnerability

Research interest in the concept of vulnerability has grown alongside the intertwined fields of risk management and resilience and like resilience, it is a relatively new research field [38]. At its simplest, dictionary definition, vulnerability refers to the risk of something being 'lost' or damaged'[52]. In a supply chain context however, a number of variations on this basic definition can be found. Some early definitions such as that by Asbjornslett (1999) [99] focus on the properties in manufacturing systems such as equipment or human resources which influence its susceptibility to disruptive events [99]. others focus on 'exposure' to disturbances which cause deviations from normal operating parameters [38, 120, 146-147], the 'consequences' of disruptions (for example, in terms of fluctuations in the values of key performance indicators) [2-148] and the ability of a supply chain to collectively react to disturbances [8, 98]. Palovita et al. (2016) [150] combine these three aspects ('exposure, sensitivity and adaptive capacity') and focus on food systems in specific, describing the concept of 'double exposure' whereby vulnerability can stem from multiple stressors including environmental and social sources [150-151]. They also note that as a theoretical construct, vulnerability is difficult to measure. The various definitions highlight that the concept of vulnerability is closely interrelated with the concepts of risk and disturbance/disruption which are now explored in more detail.

3.4.4.2 Supply Chain Risk and Risk Management

Risk refers to the probability of an occurrence(s) which interrupts an event, activity or process. Whilst there are many definitions of risk, it has been proposed by Ritchie and Brindly (2007) [54] that the majority have in common:

(1) The likelihood of occurrence of a particular event or outcome;

(2) The consequences of the particular event or outcome occurring; and

(3) The causal pathway leading to the event.

The likelihood of an event occurring is somewhat measurable, often based on past occurrence, with varying degrees of accuracy [117, 152-153]. The consequences of a particular occurrence can vary depending on the goals of the individual doing the assessment, for example, the consequences could be considered in terms of profit loss, health and safety, or when considering AFSCs, in terms of policy and societal impacts and so risk is a highly multidimensional concept [122, 154]. The causal pathway leading to an event is suggested to be particularly important as it concerns the nature of the event, the sources and the causes that generate it (sometimes known as risk drivers) [54]. Risk management is therefore the tool by which all three of these aspects are managed to drive performance and minimise the loss, probability, speed and exposure to consequences of a negative occurrence [148, 155-156].

3.4.4.3 Is Agri- Food Supply Chain Risk Increasing?

It is commonly claimed that in supply chains, and AFSCs in specific, risk is increasing [2,123, 136, 156–158]. Christopher and Holweg (2011) argue that a range of contemporary crisis's including spiralling shipping costs in 2003, rising oil prices in 2008 and the global financial crisis in 2008 signify that 'volatility' (defined as unpredictable shifts in key variables that determine business environments) is increasing. They support this with a 'Supply Chain Volatility Index' which compares 8 indices (Euro/GBP exchange rate, USD/GBP exchange rate, UK clearing banks base rate, Crude Oil-Brent prices, Gold Bullion rates, LME-Copper rates, VIC-Chicago board options and the Baltic Dry Index) over 40 years according to co-efficient of variance (See Figure 3.7).

The authors highlight that whilst similar shocks had occurred in the past, rarely had so many business parameters been affected simultaneously, and that therefore the way supply chains were structured in the past for relatively stable operating environments, may no longer be appropriate for the modern age. The rationale is that the observed increased volatility results in increased uncertainty. This obscures information on likelihoods, consequences and causal pathways which are the linchpins of successful risk management, thus lending some credence to the notion that supply chains risk is indeed increasing. Reduced ability to manage risk, as was identified previously, is linked to decreased resilience [20, 54, 159]. Cited AFSC specific examples include livestock disease (Foot and Mouth Disease and BSE), food contamination scares (Sudan 1), Fuel Protests (2000), Oil Depot Fires (Buncefield 2005), Flooding (2007 and 2016, the later seriously disrupting McVities Biscuit production) and extreme weather (European winter 2016-2017 vegetable crisis) [70,149]. Interestingly, the disturbances/disruptions cited are not only one off isolated events, but can be 'creeping' (where a small event escalates across multiple supply chains) as well as one-of events [77].

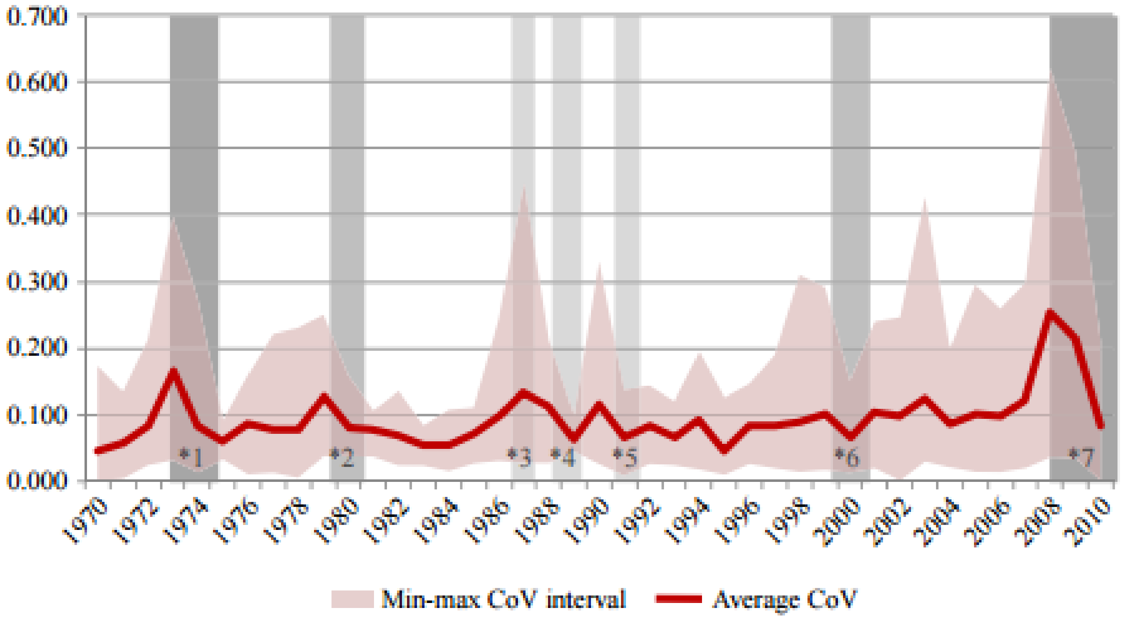


Figure 3.7: The Supply Chain Volatility Index 1970-2010 [1].

3.4.4.4 Disturbances/Disruptions and their Relation to Risk/Vulnerability

The negative 'occurrences' which risk management seeks to allay are commonly referred to either as a disruption [51,67,130,150-151] or a disturbance [126,152-153]. The literature suggests that many researchers tend to focus on highly unpredictable, low-frequency, high-impact events, such as the September 11th 2001 terrorist attacks in the USA, the 2003 SARs epidemic and the 2000 fuel strikes in the UK [57,150,154]. Such events have the potential to impact the viability of organisation or even entire supply chains and are commonly labelled as 'disruptions'[168]. Disruptions can begin with a tiny event that is almost unrecognisable at a supply chain level but which quickly propagates, as in the Robert Bosch GmbH case, in which a single component defect resulted in the recall of several thousand vehicles [38]. These disruptions are often referred to as 'creeping' disruptions [169-170].

Disturbances on the other hand involve more common, day to day events, such as staff taking time of sick, which despite their individual low impacts cumulatively at up to be highly costly [171-172]. For consistency with the wider literature, these are the definitions used in this thesis from now onwards. In summary, disruptions/disturbances can be viewed as risk sources that have been realised [136]. Unsurprisingly, risk management is frequently associated with a reduced incidence of disruption/disturbance and therefore increased resilience, yet the limitation to risk management is uncertainty [1,36,51,141].

3.4.4.5 Uncertainty

Uncertainty is defined as existing when insufficient knowledge or understanding is available to enable any one or more of the three risk constructs to be determined [54, 173-174]. In supply chains, uncertainty can span multiple parameters including consumer's requirements, resource capacity, transportation time, production time, costs, quality, priorities, and lack of information, among others. As uncertainty grows in any or all of the aforementioned sources, risk grows proportionately, thus indicating a very close relationship between the two concepts [175–177]. Indeed, it has been noted that the two concepts are often used interchangeably [38, 54]. However, there are differences between the two concepts in the sense that risk is generally accepted to involve the potential for loss or damage received whilst uncertainty leads to an unknown outcome- it may be positive or negative [142]. Furthermore, whilst risk can be measured because it is a function of the probability of an event occurring multiplied by its outcome, uncertainty by nature clouds both of these variables meaning that it cannot be measured. Building on these definitions, the next section analyses vulnerability, risk, uncertainty and disruptions/disturbances based on their suitability for informing resilience strategies

3.4.4.6 Vulnerabilities, Risk, Disruptions/Disturbances and Uncertainty: Which Should Resilience Elements be targeted against?

Based on the review of the related concepts of risk, disruption, disturbance, uncertainty and volatility, this thesis makes the following assumptions:

1. Uncertainty can be thought of as the lack of knowledge that determines risk.
2. Risk itself concerns the likelihood, consequences and pathways to impact of a disturbance/disruption.
3. Specifically, the term disruption typically refers to high impact, low frequency events, which can fundamentally alter a supply chain, whereas the term disturbance refers to lower impact events, which whilst still potentially high impact, do not affect supply chain structure.
4. Whilst both risk and vulnerability can be seen to focus on consequences of a disruption/disturbance, risk is particularly concerned with the likelihood of occurrence and mechanism of impact, whereas vulnerability can be considered more in terms of the exposure to a particular disturbance/disruption and flexibility to adapt.

Based on these assumptions, a key limitation to using risk to design resilience strategies is that the more complex the supply chain situation, the more it is exposed to volatility and thus uncertainty. Vulnerability on the other hand is determined by the level of exposure to negative events and the relative ability of a supply chain and actors within to adapt to that disturbance/disruption and thus offers more flexibility to unexpected events when designing supply chain resilience strategies [2, 37, 77, 105]. The caveat, as mentioned previously, is that vulnerabilities are much more challenging to characterise than risk [150-151]. In response, Section 3.4.4.7 investigates how vulnerability has been categorised by different authors in the literature.

3.4.4.7 Identifying Sources of Vulnerability

This review identified 34 works which offered examples of supply chain vulnerabilities, 16 of which provided vulnerabilities which were specific to AFSCs. Across all of these works, the starting point for vulnerability source classification was to identify whether exposure was being considered from the perspective of an organisation within a wider supply chain, or the entire supply chain itself. Such approaches are known as “atomistic” or “holistic” respectively [149, 177–180]. 28 of the 34 works provided examples of vulnerabilities faced from the perspective of a company within a wider supply chain (“atomistic”). These vulnerability sources could be broken down into supply side vulnerabilities, production processes, logistics control, information system, and organisational management structure and demand side vulnerabilities (See Figure 3.8).

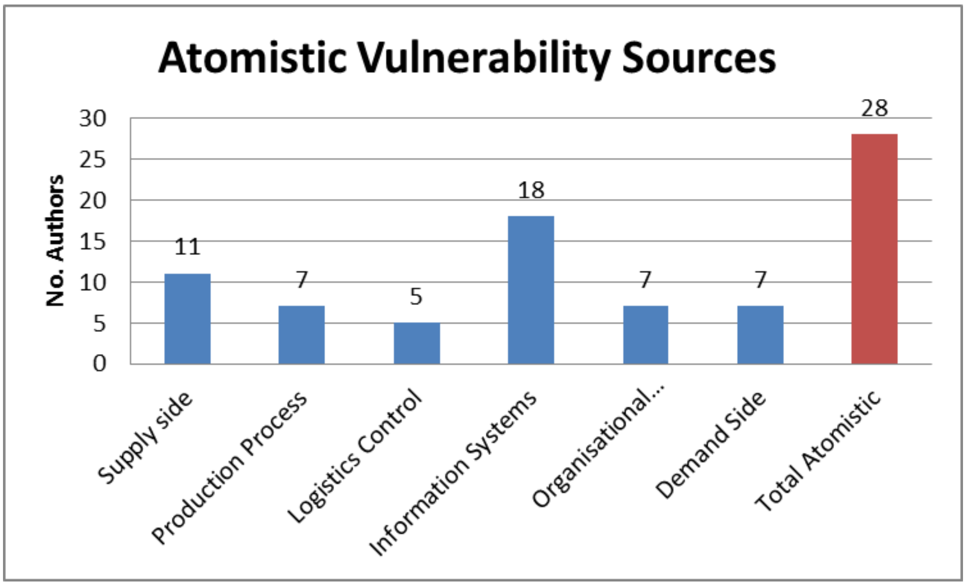


Figure 3.8: Atomistic Sources of Vulnerability observed in the literature.

Holistic vulnerability sources on the other hand, are those which determine the exposure of entire supply chains to disruptive events rather than the exposure of a specific company within that supply chain. This review identified 25 different works listing vulnerability sources form a holistic perspective (see Figure 3.9). Holistic vulnerability sources could broadly be categorised as Financial, Market, Government, Infrastructural, Societal, and Environmental.

Whilst useful theoretical classifications of where FDM vulnerabilities might arise, the ‘atomistic’ and ‘holistic’ categorisations above do have downsides. First and foremost is the notion that an entity would only be interested in internal in value chain or extra-value chain vulnerabilities- findings so far suggest that systems as complex as AFSCs would inherently need to consider both. Secondly, the ‘atomistic’ and ‘holistic’ categorisations are too broad to be practical guides that a company could use to identify their own personal exposure. They are effectively lists of causal pathways which could lead to a disruption/disturbance being realised.

In order to more accurately identify vulnerabilities it has been suggested that focus should be directed at the ultimate consequence of a vulnerability being realised, known as a failure mode (see Table 3.6)[84]. As each failure mode will have a limited number of possible causal vulnerabilities, and each FDM will have specific priority failure modes, this technique could in theory provide a much more accurate list of vulnerabilities than would be achieved by simply brainstorming the ‘atomistic’/’holistic’ taxonomies based on past experience. From there, Failure Mode Effect Analysis can be used to identify the specific causative vulnerabilities and counter them with linked resilience elements [106, 152, 166, 182].

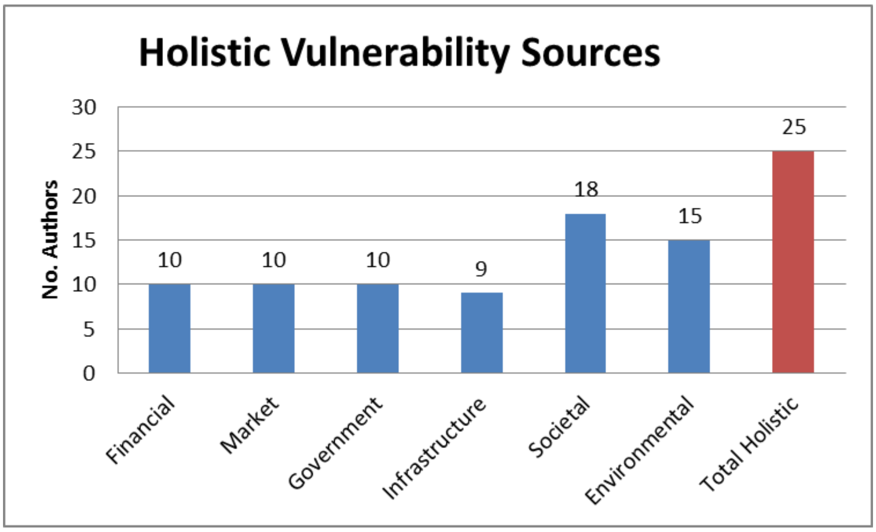


Figure 3.9: Holistic Sources of Vulnerability observed in the literature.

These are exemplified in Figure 3.10. Despite seemingly offering a number of advantages in the identification and selection of bespoke and relevant vulnerability sources, the authors of this thesis note that to date, Carvalho et al. (2012) [84] are the only ones to apply failure modes in a resilience context and that the failure modes presented are not FDM specific. Therefore, there would appear to be significant scope for expanding the supply chain exposure metrics and associated failure modes and adapting them to an FDM context.

3.4.4.8 Using Vulnerabilities to Select Resilience Elements

Independent of how vulnerability sources are actually characterised, a small number of authors have proposed directly linking resilience elements to specific vulnerabilities which they mitigate, enabling the 'balanced' resilience described in Figure 3.6. Pettit et al. (2010) [46] triangulate theoretical linkages, survey results and focus groups to identify 311 specific linkages between taxonomies of 7 vulnerability factors (40 sub-factors) and 14 capability factors (71 sub-factors). They identified the strongest links between the vulnerability of turbulence and the resilience element of collaboration, between the vulnerability of resource limits and the resilience elements of flexibility, capacity and financial strength and between supplier/customer disruptions and flexibility. Elleuch et al. (2016) [47] are also noteworthy in taking a similar approach, this time focussing on the agri-food processor ALCO to identify linkages between 16 vulnerability factors (weighted using analytic hierarchy protocol) and 19 resilience capacities (ranked using quality function deployment in relation to the aforementioned vulnerabilities).

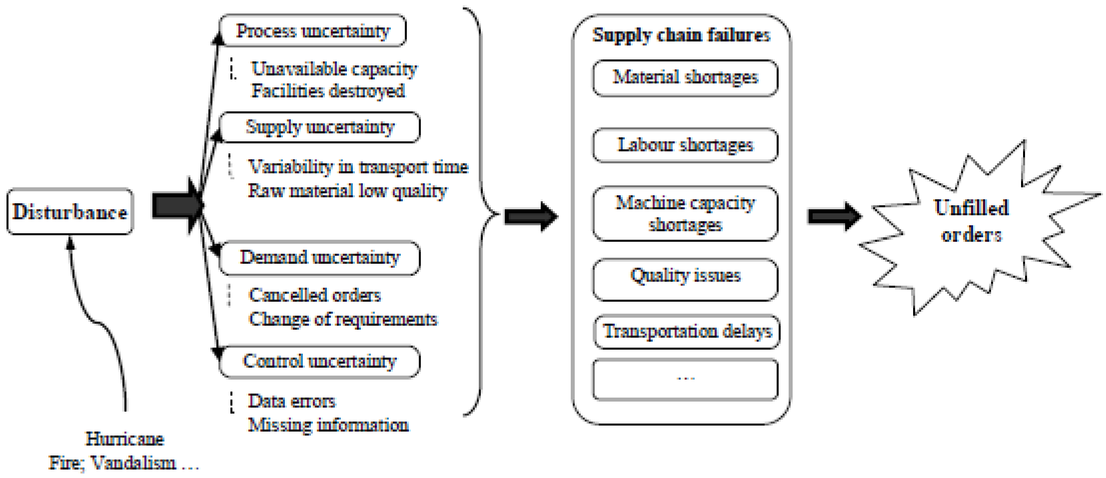


Figure 3.10: The range of uncertainty (and thus risk and vulnerability) captured by a single failure mode[166]. Adapted from Carvalho et al. (2012) [84]

They identified that the most significant vulnerabilities were import dependency and single supplier dependence at the value chain level and union strength & labour unrest at the organisational level.

Philip Leat and Cesar Revoredo-Giha (2013) [75] also explore linkages between resilience elements and vulnerabilities in an AFSC, this time in the form of case studies in collaboration with producers, processors and retailers of the ASDA PorkLink supply chains in Scotland. They identified major external vulnerability sources stemming from consumer animal welfare concerns, sudden policy change, market access, animal disease, feed prices and pig price (end product) uncertainty. Major Value chain vulnerability sources include the risk of non-payment. At an organisational level, the main vulnerability was production risk and inefficiency.

Taken together, the results (summarised in Table 3.7) show that the commonly cited resilience elements of redundancy, flexibility and collaboration do appear to be rated highly by industry, including AFSC actors. However, this cannot be taken as a universal rule and individual organisations will often have very unique priority resilience elements, such as the trained engineers in the case of Elleuch et al. (2016).

3.4.4.9 Can Resilience Strategies be aligned with Broader Organisational Sustainability?

Using the definition of sustainability outlined in the Brundtland Report; ‘meeting the needs of the present without compromising the ability of future generations to meet their own needs’, sustainability can be described as a measurement for how environmental, economic and social assets are managed for long term viability [183]. As we have seen, resilience on the other hand, is commonly perceived as a means of withstanding and/or adapting to disturbance so as to continue fulfilling core functions [45, 64]. There is the potential for conflict between these two approaches because the means by which resilience is achieved (i.e. the resilience ‘elements’ used) may not align with sustainability best practice. However, Milestad and Darnhofer (2003) [28] highlight that sustainability must involve the ability to resist disruption to a degree, but also to realise when the parameters of what is sustainable in economic, social and environmental senses have changed and to adapt. This closely aligns with resilience, so much so, that Folke et al. (1998) [108] suggest that the goal is to “build resilience for sustainability”. This view is also shared by Lebel et al. (2006) [93] who point out that “strengthening the capacity of societies to manage resilience is critical to effectively pursuing sustainable development”.

Table 3.7: Summary of literature linkages between vulnerabilities and resilience elements.

Vulnerability Factor (as it appears in the literature)	**Linked Resilience Element (as it appears in the literature)**
Turbulence [45]	Flexibility in Sourcing, Flexibility in Order Fulfilment, Capacity, Visibility, Adaptability, Anticipation, Recovery, Dispersion, Collaboration, Security
Deliberate Threats[45]	Adaptability, Anticipation, Recovery, Dispersion, Security
External Pressures[45]	Flexibility in Sourcing, Flexibility in Order Fulfilment, Visibility, Adaptability, Anticipation, Market Position
Resource Limits[45]	Flexibility in Sourcing, Flexibility in Order Fulfilment, Capacity, Efficiency, Adaptability, Anticipation, Dispersion, Market Position, Financial Strength
Sensitivity[45]	Efficiency, Adaptability, Dispersion, Security
Connectivity[45]	Flexibility in Sourcing, Flexibility in Order Fulfilment, Efficiency, Visibility, Adaptability, Anticipation, Collaboration, Organization, Market Position, Security, Financial Strength
Supplier/Customer Disruption[45]	Flexibility in Sourcing, Flexibility in Order Fulfilment, Capacity, Visibility, Recovery, Dispersion, Collaboration, Market Position, Financial Strength
Consumer Concern [75]	Animal Welfare Guarantees
Customer Non-Payment [75]	Insurance
Production Risk [75]	Benchmarking and Monitoring
Policy Change [75]	Representation
Market Access [75]	Contracted Access
Animal Disease [75]	Diseases Monitoring and Control
Feed Price Rises [75]	Input Price Support
Pig Price Uncertainty [75]	Price Transparency
Defect Detection [75]	Process Control (Six Sigma) and Raw Material Quality Audit
Import Dependency [47]	Broaden Supply Base, Broaden Inventory Capacity, Visibility,
Food Perishability [47]	Visibility and Collaboration
Non-Computerised Production Scheduling [47]	Process Control (Six Sigma), Procurement of Process Management Software and alignment with existing enterprise resource planning system.
Traceability of Workflow [47]	Process Control (Six Sigma), Procurement of Process Management Software and alignment with existing enterprise resource planning system.
Remoteness of Weighbridge and Congestion [47]	Procedure such as ticketed entry system.
Limited Traceability and Quality Control [47]	Process Control (Six Sigma) and Systematic batch expiry date system.
Lack of Quality Health, Safety and Environment System [47]	Raw Material Quality Audit, Systematic batch expiry date system, Restricted access areas, Temperature monitoring, Sterile conditions, Recruitment of maintenance technician.
Lack of Control on Press Pellet [47]	Recruitment of maintenance technician, Temperature monitoring and Sterile conditions
Lack of Emergency Power Generators [47]	Spare parts and Recruitment of maintenance technician
Insufficient Maintenance [47]	Spare parts and Recruitment of maintenance technician
Dependency on single supplier for parts/repairs [47]	Spare part and Recruitment of maintenance technician
Low Raw Material and End Product Storage Capacity [47]	Flexibility and Extra Storage Capacity
Union Strength and Labour Unrest [47]	Staff Productivity Reward Scheme
Lack of permanent Maintenance Technician [47]	Spare parts and Recruitment of maintenance technician

As such, resilience can be seen as a key attribute for complex systems with long-term sustainability goals and ever-changing drivers, such as AFSCs. Therefore, to ensure that resilience strategies in AFSCs are synergistic with long term sustainability, there is a need for measurable indicators that describe the impact of the former on the later. Milman and Short (2008) [90] suggest that such indicators would need to not only describe the current state of a system but also to provide early warning of potential disruptions by reflecting the ability of the system to absorb stress and cope with change. To represent this connection, they use the Organisation for Economic Co-operation and Development (OECD) developed state-pressure-response model to link resilience to sustainability indicators in the urban water sector. In this model, 'State variables' refer to functions which are crucial to the sustainable performance of the water system, such as the level of access provided, the quality of access and the cost of the system. 'Pressures' refer to potential sources of disruption facing the system, for example, population growth, climate change and changing regulation. 'Capacity to respond' considers aspects such as system redundancy and flexibility. By considering all three indicator categories, a measure of relative resilience is gained. Furthermore, the model incorporates a feedback loop by which 'Capacity to respond' actions are linked to outcomes in state variables (which are proxy measures for sustainability) and this enables the consequences of resilience actions at one given scale (for example, a company) to be assessed in terms of impact on sustainability and resilience at a different scale (e.g. a food system).

This review was unable to identify a case where this model had been applied to FDMs in specific. However, it was noted that the resilience elements identified in Section 3.4 closely match the purpose of the 'Capacity to respond' indicators in the OECD model in the sense that both are tools available to mitigate disruption. Similarly, the 'Pressures' indicators in the OECD model often focus on a type of disruption and the risk, vulnerability and uncertainty governing its likelihood of occurrence and its severity presenting clear overlaps with the vulnerabilities identified in Section 3.4.4.7. However, it was more challenging to find resilience analogues for the OECD model 'State Variables' as this would need to be some sort of an indicator of the impact of FDM resilience efforts on sustainability.

Whilst the sustainability metrics literature is well developed, the majority of efforts have focussed on economic and environmental measures, particularly the minimisation of GHG emissions, (for example, IMPACT 2002+[184], Eco-indicator 99 [185], and CML2001 [186]). For social performance measurements there is less consensus but good examples include SA8000 [187], GRI [188] and GSLCAP [189]. However, these examples are all incredibly broad in scope, being ideal for measuring entire systems but not key performance measures from a FDM perspective. There is therefore a real need to identify FDM specific measures of sustainability performance that can be used to gauge the impact of assigned resilience elements.

3.5 Reporting Findings (SLR Process Step Five)

This section now describes the major findings from each of the three review sub-questions.

3.5.1 SLR Sub-Question 1 Findings and Research Gaps

The first review sub-question was: *What definitions of resilience are appropriate for describing agri-food supply chains?* 48 papers offered definitions, all of which were based on one of either the Engineering Definition (single optimum state of equilibrium), the Ecological Definition (multiple possible states of equilibrium), or the Adaptive Definition (no states of equilibrium, but rather a constant process of evolutionary learning in response to constant changes stemming from external systems). Analysis of publication dates suggest that the adaptive definition is increasing accepted as the most appropriate way of describing complex systems such as supply chains, particularly AFSCs. Regardless of definition 'type' it was identified across multiple definitions that there were certain phases in which an entity can act on a disruption which were in 'readiness', 'response', 'recovery' and 'growth'. It was identified that in an AFSC setting, the priority must not only be to resist disruption, but also to maintain the core function of supplying food to end consumers. Therefore, resilience has to be based on the ability to adapt to ever changing operating environments, something which the phases of 'readiness' and 'growth' can facilitate.

Research Gaps Identified:

- There is a need for synthesis of a resilience definition that is not only consistent with the identified core components of a resilience definitions (as described in section 3.4.2.1) but which is also adapted to be FDM specific. ***This gap is addressed in Chapter 7.***

3.5.2 SLR Sub-Question 2 Findings and Research Gaps

The second review sub-question was*: What resilience elements are described in the literature and are there any special considerations when applying them to agri-food supply chains?* In answering the first part of the question, 34 unique resilience elements from 61 separate works in the literature. Agility, Flexibility, Risk Aware Culture, Redundancy and Early Warning Detection Systems were the most commonly cited elements at an organisational level. At a supply chain level, Collaboration, Flexibility, Visibility and Adaptability were respectively the most commonly cited elements. However, the majority of these resilience elements stem from the field of supply chain management, yet there was also a significant range of less common elements. Such elements, tended to focus for example, on the broader relationships, knowledge management, and capacities for learning and adapting which arguably are not only vital in achieving more mainstream elements such as flexibility and redundancy, but also in building the 'adaptive' resilience identified in Section 3.4.2 as being paramount for AFSCs. [104].

Research Gaps Identified:

- There is a need of synthesis of the 34 identified resilience elements to remove inconsistency and adaptation to suit an FDM context, with the identification of measurable actions for each element being crucial. ***This gap is addressed in Chapter 9***

3.5.3 SLR Sub-Question 3 Findings and Research Gaps

The final sub-question was: *What factors must be considered by a food and drink manufacturer when designing strategies for the application of resilience elements*? It was identified that resilience elements have historically been viewed as a counter to the risk (i.e. likelihood, impact and causal pathway) of a negative event occurring and that risk management techniques generally have a positive impact on resilience. However, as uncertainty in complex systems is high and there is evidence that volatility is growing, thus compounding this situation, there are questions surrounding the accuracy of risk management. As such, vulnerability (i.e. the exposure to and ability to adapt to a specific disruption) may be a more accurate gauge upon which to base selection of resilience elements.

Furthermore, when designing resilience strategies, care must be taken to ensure that resilience strategies align with wider sustainability. The review identified the OECD Pressure-State-Response model as being an ideal way to measure the vulnerabilities facing a system (i.e. 'Pressures' in the OECD model), the resilience elements available to it (i.e. 'Responses' in the OECD model) and their overall impact on sustainability performance (i.e. 'State Variables' in the OECD model). However, no research was identified that had employed this model in an FDM context and analogous 'State Variables' were particularly challenging to identify, with those that do exist often not being food specific and when they are AFSC focussed, they are often too broad to be practically used by a UK FDM. These relationships are summarised in Figure 3.11.

Research Gaps Identified:

- There is a need for a FDM specific taxonomy of vulnerability sources that considers both atomistic and holistic sources. ***This gap is addressed in Chapter 8.***
- This taxonomy needs to be associated with FDM specific failure modes. ***This gap is addressed in Chapter Four and subsequently in Chapter 8.***
- There is a need to understand the linkages between specific vulnerabilities and resilience elements in a FDM context. ***This gap is addressed in Chapter 8.***
- There is also a need for the development and validation of metrics that can measure the impact of resilience elements on wider system sustainability performance. ***This gap is addressed in Chapter 7.***

3.6 Chapter Summary

This Chapter systematically reviewed the academic literature regarding resilience in order to address the following core research question: "Given the volatility increasingly faced by UK Food and Drink Manufacturers, what definition(s), resilience elements and resilience strategies are important for accurately modelling and enhancing resilience?" It considered a number of key components of resilience including 'definitions', 'resilience elements' and 'resilience strategies' presenting the findings from analysis of each, as well as identified research gaps. These findings, in combination with those form Chapters 4 and 5 will be used for synthesis of and FDM specific framework of resilience in Chapter 7. This Chapter has fulfilled Thesis Research Objective 1A and is followed by Chapter 4: Practical Resilience Considerations from a UK Food and Drink Manufacturing Perspective which addresses Thesis Research Objective 1B.

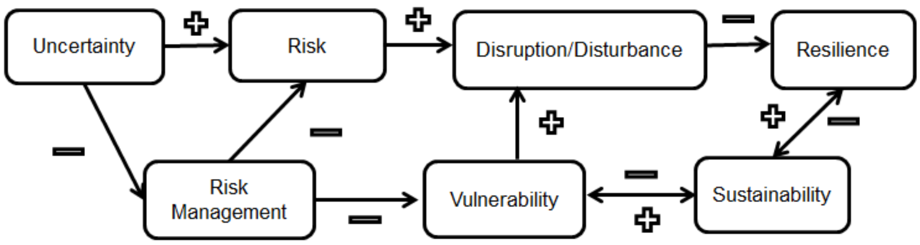


Figure 3.11: Important concepts guiding resilience strategies and their relationships with each other.

Chapter 4: Practical Resilience Considerations from a UK Food and Drink Manufacturing Perspective

4.1 Introduction

The aim of this Chapter is to identify the scope of contemporary FDM activities in the UK and the practical metrics by which FDM specific vulnerability can be measured. It therefore addresses Thesis Research Objective 1B. The chapter begins by exploring how long term socio-economic and technological trends concerning how food is produced, sourced, prepared, sold and consumed have impacted the scope and activities of FDMs in the UK. The findings are analysed to identify a number of UK FDM specific failure modes and the metrics which can be used to identify these. The chapter concludes with an example application of these metrics and failure modes in a novel FDM vulnerability mapping process.

4.2 The Historical Evolution of AFSCs in the UK and Associated Implications for FDM Resilience

UK FDMs can be said to consist of primary and secondary processing activities of food and sit within a broader UK food system that comprises of upstream primary production and downstream wholesaling, retailing, catering, the last two of which ultimately form the gateways through which consumers access the food network (see Figure 4.1). Whilst these broad stages of UK AFSCs have remained relatively constant over the past century, their respective value chain activities, scope and power have changed significantly with significant implications for what it actually means to be resilient in contemporary AFSCs.

Much has changed since the beginning of the 20th century with regard to how the UK feeds itself. Prior to 1900, food was a relatively local affair with primary producers frequently dictating what was consumed in their local area. In some ways, this was much less resilient as localised crop failures, manpower limiting factors such as disease and factors which influenced the ability to get food out of the field and into town could result in famine and what we would consider to be severely restricted diet.

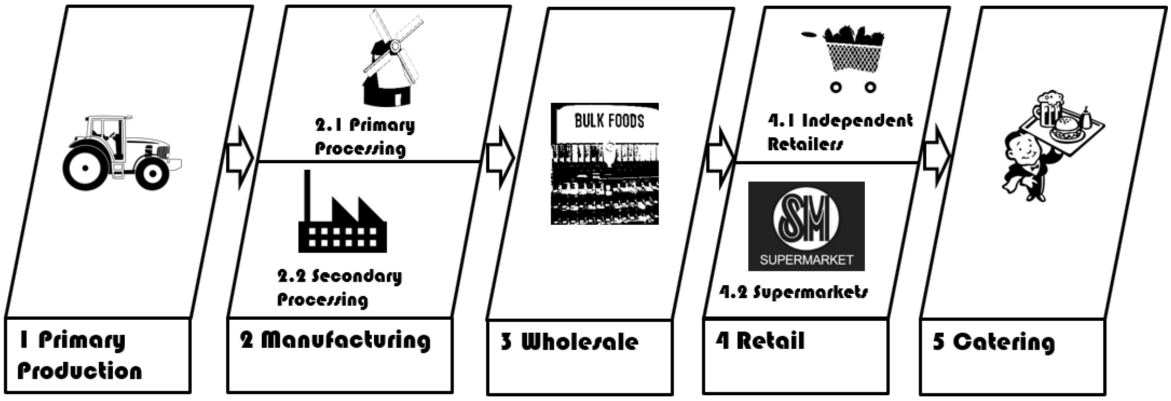


Figure 4.1: Key stages in the UK Agri-Food System.

On the other hand, physical production of food was closely tied to local natural capital (for example, soil fertility, water availability and pollinators) which had to be well managed and allowed to recover if next year's harvest was to be successful. In other words, there was a very close feedback loop between environmental resilience and food security. Arguably, this is very different today where production of food in the UK and in much of the world has undergone a "Green Revolution". Now, fertilisers, mechanisation, better irrigation and novel crop varieties have pushed yields to all-time highs [190-191]. Yet whilst domestic efficiency has improved significantly, simultaneous developments such as cheaper transport, pursuit of low labour costs and better packaging and technology have made it more economically competitive for a wealth of products to be shipped into the UK from all around the world [14]. This has had significant implications for what is grown in the UK.

Primary production in the UK can broadly be classified as crop production (both arable and horticultural), livestock production and fisheries (both from wild stocks and from aquaculture). Crop production in the UK accounts for just over a third (approximately 6 million hectares) of the 17.1 million hectares used for agriculture overall and is dominated by cereals and to a lesser degree, oilseeds (see Figure 4.2). A major development over recent decades has been for fewer yet larger and more specialised growers to produce on contract, as opposed to supplying the spot market. For FDM's it has been suggested that this brings advantages in the sense that raw materials are more uniform and that it encourages long-term collaborative partnerships, but also disadvantages in that it may reduce potential alternative suppliers [15]. Indeed, the UK has a significant fruit and vegetable trade deficit, particularly in winter months, making EU supply key consideration for UK FDMs [34].

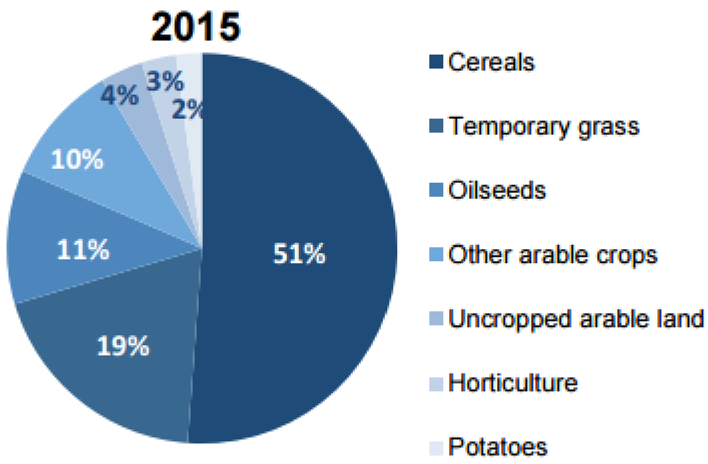


Figure 4.2: Breakdown of the 6 million hectares used for crop production in the UK.

Livestock production and processing can be broadly broken down into Dairy, White Meat (Pork and Poultry) and Red Meat (Beef/Veal and Lamb/Mutton). Livestock accounts for 11 million hectares (of the total 17 million hectares used for agriculture in the UK) and concerns production of meat and/or animal products including fur, eggs and fat [192].

The UK has seen a decline in demand for traditional and minimally processed products such as milk, eggs and traditional cuts of meat since the 1950's and an increase in demand for foods such as cheeses, processed meats and poultry (virtually unheard of in 1950's Britain yet with the average person now consuming 33 Kg per year [193]). Whilst poultry production in the UK has increased to meet these changing consumer demands, historically, livestock production is geared towards red meats and so supply of white meats is used by FDMs must often be supplemented on the international market, particularly via South East Asia with associated transport considerations for UK FDMs [194].

Capture Fisheries and Aquaculture play a much smaller role, contributing just 0.07% of national and landing 708,000 tonnes of fish worth £775 Million in 2015 [195]. Capture fishing is in long term decline, partly due to falling fish stocks, but also tight regulation in the form of quotas and heavy competition from abroad. However, there are signs that aquaculture is growing quickly, driven by strong exports- indeed, whereas livestock and crop production predominantly supplies

UK markets, fisheries and aquaculture exported 443,000 tonnes in 2015- well over 50% of production.

It is important to note that despite this significant production base, contemporary societal changes mean that much of the value of food is no longer generated in primary production alone and instead is actually generated by processing and transport to where the demand is. The 1920's to late 1940's saw a steady rise in the incomes of UK families and a change in working styles which meant that that not only did families increasingly have money to pay for someone else to process foods for them, but they also had less time to process food themselves. This led for growing demand for large scale food manufacturing at a national (rather than domestic) scale, and which inherently also brought benefits in terms of preservation of food, allowing much longer food supply chains [15]. To put this into perspective, in the early 1970's approximately 50% of the final value of a food item went to the farmer, in the early 2000's that figure was nearer to 20% [14].

Indeed, such has been the growth of FDM that in 2016 it accounted for 16% of all UK manufacturing, making it the largest manufacturing industry in the country, employing 400,000 people and contributing 6.8% to National Gross Value Added (GVA). In the context of this thesis, food manufacturing is taken to refer to any post farm gate processing activities which add value to food but traditionally do not directly supply consumers. In some cases, this involves turning inedible raw materials such as flour and unpasteurised milk in to safe and edible staples such as milk, pasta and bread. In other cases it can benefit consumers in terms of preservation, convenience and nutrition control [15, 195].

The major food and beverage manufacturing sectors in the UK by GVA are displayed below in Figure 4.3 in addition to the number of SME's engaged in each sector (SME's represent 96% of food and beverage manufacturers by number)[34]. By far the most productive by value are the secondary processing activities, particularly the beverages sector (which includes soft drinks and water in addition to alcohol) but also including Meat Products and Bakery, the latter of which occurs for a third of all SMEs engaged in UK FDM. Indeed, secondary food processors dominated supply chains prior to the 1960s, to the extent that the role of retailers (which at the time were commonly smaller independent stores) was to market manufacturer produce [197].

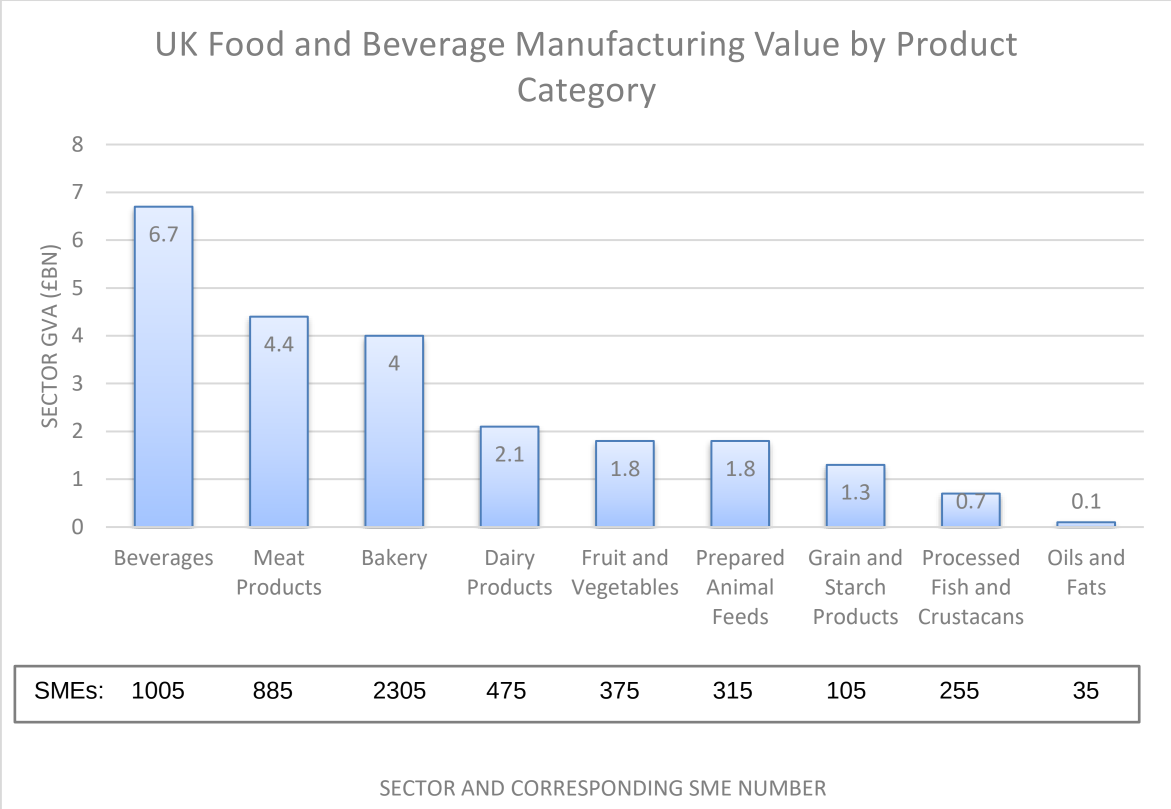


Figure 4.3: UK Food and Beverage Manufacturing Value by Product Category in 2016 [34].

However, in the UK, Western Europe and North America, manufacturer 'push' has given way to retailer 'pull' and secondary processors have increasingly come under pressure from large retail chains with high purchasing power due to the number of customers they represent and closer proximity to consumer demand, as well as stagnating home markets, and growing global competition. This has resulted in widespread concentration with the majority of food production in the UK (66% in 1990 compared to an EU average of 40%) being attributed to large, international manufacturers who dominate the market in their product category. For example, Walkers accounts for over 50% bagged snack sales, Mars, Cadbury and Nestle dominate chocolate and confectionary sales and McCain's is the predominant supplier of frozen potato products.

Even so, the general trend across food manufacturing is one of falling product margins for manufacturer branded goods, due to a combination of low population growth, fierce international competition and retailer 'everyday low prices' business models. As retailers also face fierce competition for consumers amongst themselves, a major outcome has been the growth in strategic collaboration between FDMs and individual retailers to make their value chains more competitive

Category SME Number

than others. Indeed, a number of UK manufacturers no longer focus on brand labels and instead produce just for retailer private labels (See Table 4.1). For example, Hazelwood Foods, has an annual turnover of £1.7 billion and employs some 7000 people at 20 plants in the UK and Europe.

Obviously, for manufacturers that have historically relied on the profit margin provided by their brand names, this is a major source of competition. Yet this rapid growth in own label products is also a response to changing consumer demand, not just for value but also for 'flexi-eating' products (such as home meal replacements, convenience foods, prepared fresh foods and snacks)[198]. Many such meals are chilled, therefore making shelf life and as such, production lead time vital. This in turn has driven "lean" and "agile" production paradigms in FDM operations [15].

However, such strategies are often at odds with the traditional role of FDMs as holders of spare inventory in modern AFSCs and increasingly, that function has passed to the wholesalers. The UK wholesale sector supplies a range of business customers including food processors, caterers and retailers but not domestic end consumers (who typically require smaller quantities). Indeed, there is strong evidence that retailers, with limited stock reserves in their own depots, would look to their wholesalers in response to major upstream disruption[20]. It is clear therefore that from farm to manufacturing and even wholesaling, respective activities are universally shaped by retailers. Retailers in the UK are a mixed collection of large firms, independent stores and cooperatives which together, accounted for £179.1bn of sales in 2016, an increase of 0.6% on 2015 [199]. However, as Figure 4.4 highlights, the vast majority of sales come from the large multiple retailers who are effectively the "gateways" to UK food consumers.

Table 4.1: Increasing market penetration of large grocery multiples [200].

Country	**Market Penetration of Large Grocery Multiples (1997)**	**Market Penetration of Large Grocery Multiples (2015)**
UK	29.7	51.8
BELGIUM	25.8	39.9
SPAIN	16.2	41.5
FRANCE	16.8	34.1
GERMANY	11.3	38.4
USA	14.1	16.4

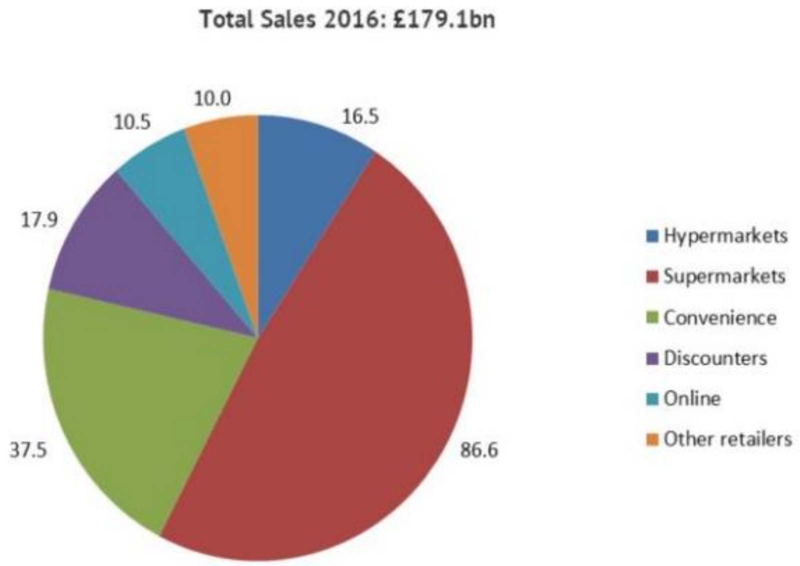


Figure 4.4: Total UK Food and Drink Sales by Outlet Type. Source: Institute of Grocery Distribution [200].

The emergence of the large multiple retailers as dominant players in food supply chains can be linked to a number of societal changes that have shaped end consumer demand. The recession in the UK in the 1980's saw an unprecedented number of women join the workforce meaning not only were families less able to prepare their own food, but they also had less time to visit high street shops on a daily basis.

Combined with easier access to modern facilities such as personal transport and refrigerators, visiting a large out of town supermarket weekly or even monthly became more feasible. Through purchasing power and incredibly lean logistics networks, the large multiple retailers are able to better meet consumer demand for convenience in terms of heavily processed, long shelf life and out of season foods than their competitors. In this way the four largest supermarkets in the UK (Tesco, Sainsbury's, Asda and Morrison's) account for over 70% of market share (see Figure 4.5) [201]. However, these demands are passed back up the supply chain to the original growers, accounting for the hugely reduced influence of growers in supply chains compared to 50 years ago. As a result, the power balance in modern AFSCs can be said to have progressed from a market control model, depicted to the left of Figure 4.6, to in many cases, a Captive or even Hierarchy based model.

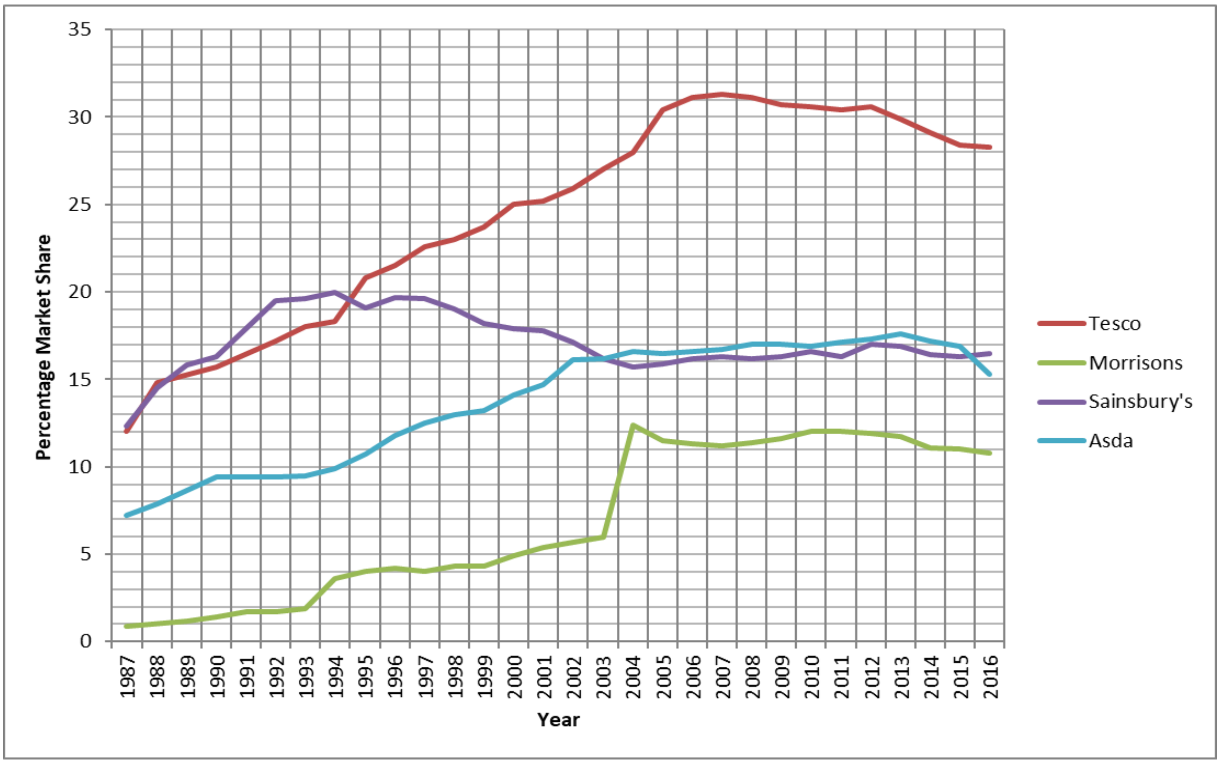


Figure 4.5: Historical Growth of UK Supermarket Market Percentage Share [200]

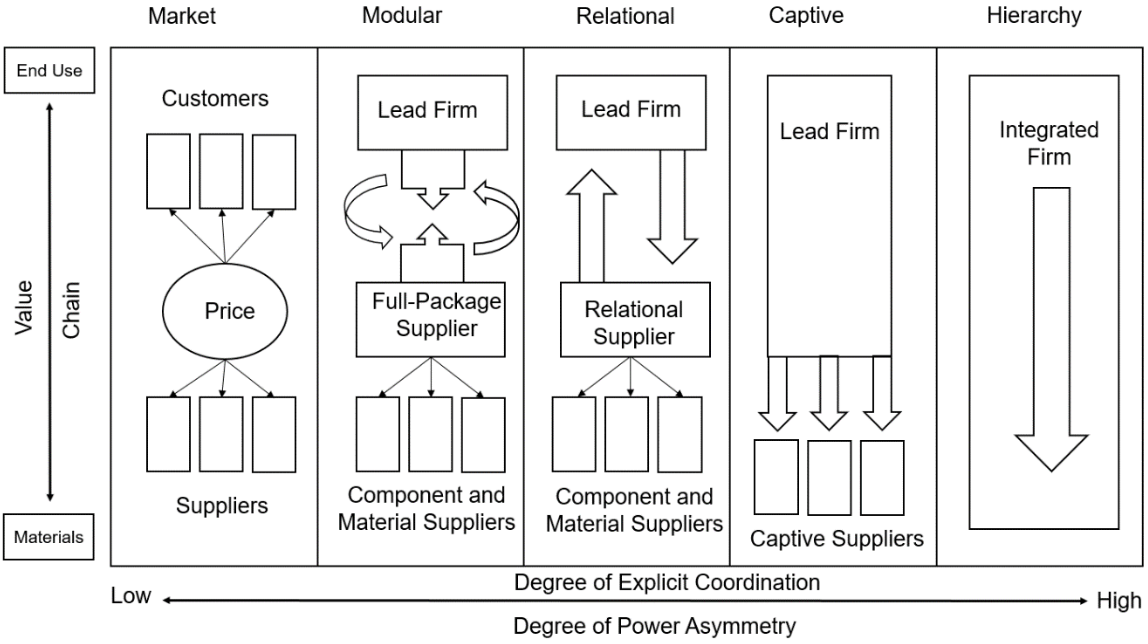


Figure 4.6: Comparison of possible dominant forces in value chains Adapted from Gereffi et al. (2005) [202].

The final stage of UK AFSCs to be considered in this Chapter is catering, which represents 48% of the post-farm gate supply chain. This supply chain stage is actively growing and is responsible for over 1.6 million jobs and £29 billion value added (comparable to £30.4 billion in retail) [34]. The significant growth witnessed in the UK catering sector is representative of similar drivers to those pushing convenience foods in manufacturing, that of ‘time poverty’[14]. It is therefore a major market consideration for UK FDMs and the catering sector therefore represents a major market for many UK based FDMs particularly in the chilled convenience food sector.

4.3 Identification of FDM Specific Failure Modes and Practical Identification Metrics

From the discussion in section 4.2, it is possible to infer a number of points where failure modes might occur in a FDM value chain. These are indicated on the simplified FDM Supply Chain in Figure 4.7.

The first of these concerns raw material physical availability (FM1 in Figure 4.7). In 2016 just 52% of UK Food and Drink requirements were produced domestically. Clearly what we do produce as a nation is dependent on a) what can be sustainably and efficiently grown and b) what is in consumer demand. For example, the UK produces 80% of its meat, dairy and egg requirements, 62% of its cereal requirements, yet only 23% of its fresh fruit and vegetables [192]. This leaves the UK heavily dependent on food imports (worth £42.5bn in 2016) from a staggering 168 countries. Compounding this, is the fact that for fruit and vegetables, just two countries supplied over 69% of imports [34]. This means that for many raw materials, supply has to be international in nature, is frequently dependent on just a few key suppliers and is also often dependent on infrastructure bottlenecks such as the channel ports and motorways [28]. This is amplified by the fact that over the last 5 years, 72% of manufacturers and 65% of retailers have made reductions in inventory [34].

Not only does this put pressure on food manufacturers to meet more frequent orders and to reduce lead time, but it also means that retailers themselves can have as little as 24 hours stock of fresh fruit and vegetables (although supplies of ambient products can reach between 1-4 weeks) [35-162]. However, it is not just physical availability of raw materials that is in question, it is also quality (FM2 in Figure 4.7). For example, crops can become infested with aphids and fish stocks can move out of trawler range in line with the seasons and this means that the source (and by default physical quality) of ingredients changes throughout the year.

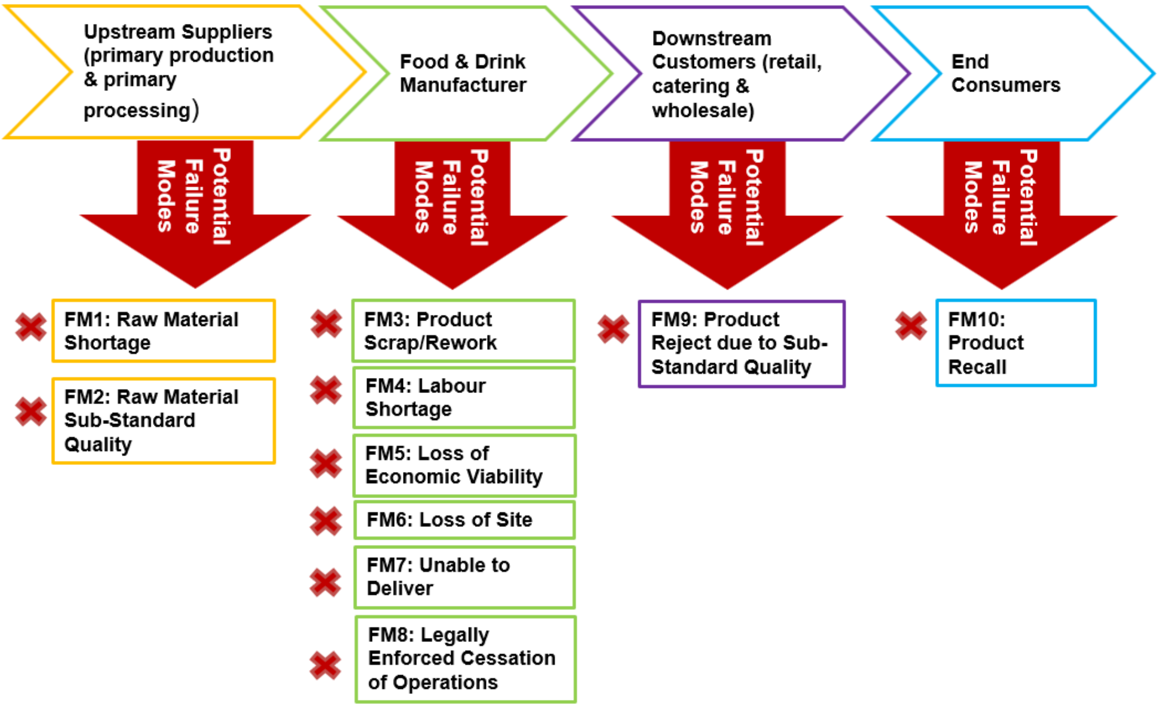


Figure 4.7: UK FDM Failure Modes

As weather is not always predictable with perfect accuracy, it may be that alternative suppliers are not available when expected and that slightly sub-standard raw materials must be accepted, for example, smaller prawns or aphid infested lettuces. Whether this is an immediate failure mode depends on whether the ingredients can be utilised, for example, they may be taken on at a concession rate if the product is going to be heavily processed and will not affect taste and texture. However, immense care must be taken to ensure that such factors do not breach retailer sourcing standards nor health and nutrition requirements and product labelling.

Moving on to FDM internal processes, many UK manufacturers are incredibly dependent on manual labour (FM4 in Figure 4.7), particularly in the chilled ready-meal sector and so any significant restriction on staff availability would seriously impact production[20]. Another key failure mode would be any range of disruptions which led to a product needing to be scrapped or re-worked (FM3 in Figure 4.7), for example, one of the side effects of efforts to lean food manufacturing is that there is very little opportunity to store food. Therefore, if a forecast is inaccurate and an alternative buyer or use is not possible, then that food must be wasted. Given the incredibly tight margins FDMs work to, particularly on private label products, it is very common for even slight disruptions to result in a loss of economic viability (FM5 in Figure 4.7). One key reason for this is that growers now increasingly supply to contract rather than the spot market and so if there is a sudden increase in demand for a product, i.e. a new consumer trend, which increases market demand substantially, the price can often rise so much as to make the product prohibitively expensive. Equally, growing competition from populations elsewhere in the world (for example, the growing demand for pork in China) and piracy (for example, certain spices which are geographically limited in production to East Africa) can be enough to make a product economically unsound.

For many FDMs their key assets are their manufacturing plants themselves as this is where a significant amount of their capital is invested (in direct contrast to retailers for whom the loss of a store would be comparatively minor). Whilst many of the larger FDMs do have more than one production site, there are often limitations to what sister sites can practically achieve and so loss of a site (for example the McVities biscuit factory flood in Carlisle, Dec 2015) can still have a catastrophic impact (FM6 in Figure 4.7).

Another unique characteristic of FDM manufacturing in the UK is that it is incredibly dependent on road infrastructure for delivery. Therefore, whilst there are often plenty of 3PL logistics providers available, broader disruptions such as, snowy roads or fuel protests would be a significant failure mode (FM7 in Figure 4.7) [17-162].

Of course, FDMs have obligations that go far beyond their immediate customers and effect the broader natural environment, the wellbeing of their employees and the health of end consumers. Any realised disruption that resulted in either harm to an employee, emissions breaches to the environment, or a case of allergen contamination/excess microbial content runs a very high risk of a legally enforced ban on production until clear procedures had been implemented to remedy the situation (FM8 in Figure 4.7). For example, the numbers of food ingredients which can cause an allergic reaction and must be controlled by manufacturers have increased tenfold in the past decade [203].

Failure modes can also arise beyond the threshold of the FDM in question even if a finished goods product is successfully delivered to the retailer depot. FDMs are commonly required to run thorough quality and safety check on all products before they leave the factory gate and so it is unlikely that they will knowingly pass on sub-standard or harmful products under normal conditions (FM9 in Figure 4.7). However, there are a number of situations, where, perhaps in relation to transport delays (particularly on short shelf life products) or where the manufacturer is struggling to find enough raw materials of the right quality (for example, during the 2016 winter vegetable crisis) that a retailer may reject deliveries. Equally there are situations where the food may even pass the retailers quality checks and it is only when consumer complaints are received, or news of a breakdown in supply chain traceability emerges that a recall is issued (FM10 in Figure 4.7). This might for example, occur when a microbiological test run by the FDM which takes 5-6 days, will return with a positive result after a sandwich with a shelf life of 3-4 days has reached supermarket shelves.

In order to be able to objectively measure a FDMs exposure to the aforementioned failure modes there is a need for indicators which can be used to measure a supply chains current functionality at a given point in time. Five broad categories of exposure metrics are proposed to achieve this as summarised in Figure 4.8.

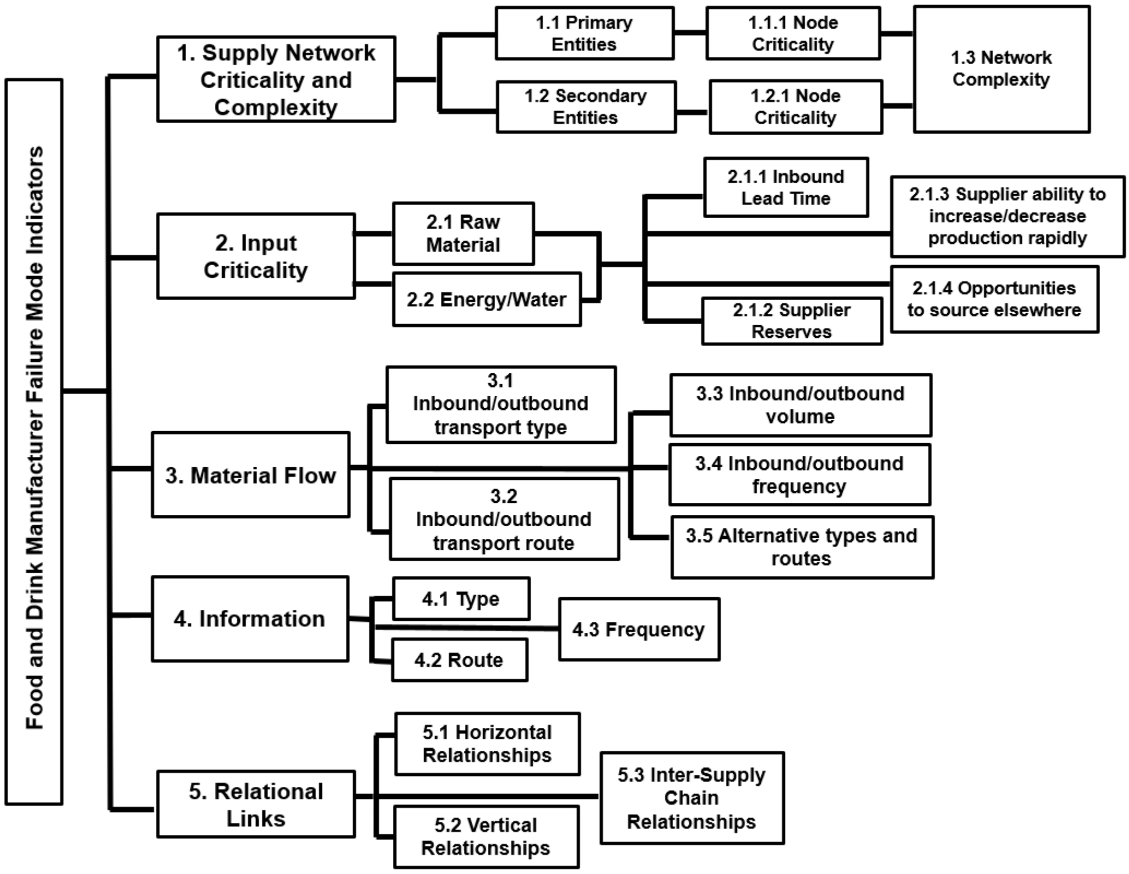


Figure 4.8: Summary of identified Agri-food supply network exposure metrics.

4.3.1 Exposure Metric 1: Supply Network Complexity and Criticality

It is important to consider that whilst the previously described failure modes represent ways in which FDM activities can go awry, the underlying causes actually extend far beyond the FDMs immediate value chain. For example, even a relatively simple product such as a prepared curry, can consist of chicken from the UK, rice from India, tomatoes from Spain, ginger form China and Sugar from Brazil. This may require several processing stages before a FDM can assemble the final curry which is then delivered to potentially multiple retailers thus fulfilling the value chain.

However, each of these suppliers will have their own suppliers and dependencies for packaging, power, water and infrastructure and will be susceptible to respective domestic governmental policies, societal pressures and market forces. As such, many are advocating for the term ‘chain’ to be replaced with network [50,198-199] and the complexity of this network must be captured in measurable metrics to facilitate identification of associated failure modes. Lambert et al. (2000) [205] propose that it is possible to measure supply chain network complexity by mapping out primary entities (direct contribution to a value chain) and secondary entities (resources, utilities, knowledge or assets that indirectly enable a value chain). In line with this, this thesis will now use the term Agri-Food Supply Network (AFSN) as opposed to Agri-Food Supply Chain (AFSC). In certain contexts, there is a need to make reference to just the immediate primary entities surrounding an FDM and this is referred to as the “value chain”.

Based on this, the following criteria are proposed for mapping out the entities in an FDM’s Supply Network:

1. Primary Entities
    a. Supplier sites (e.g. primary production and processing)
    b. Internal asset locations (e.g. factory, storage and staff)
    c. Customer sites (e.g. depots, stores, wholesalers, caterers)
2. Secondary Entities
    a. Government (e.g. departments such as DEFRA)
    b. NGOs (e.g. collaborative and compliance-based stakeholders)
    c. Water and energy suppliers
    d. Waste removal
    e. 3rd party logistics (type, route, frequency and cost)
    f. Key infrastructure (roads, communications, grid)

The available alternatives for each primary and secondary entity provides that entities' Node Criticality and cumulatively, the numbers and locations of each primary and secondary entity determine a given AFSN's Network Complexity.

4.3.2 Exposure Metric 2: Input Criticality

Input criticality concerns the relative importance of each of the inputs that underpin an FDM's operations. An obvious example is raw ingredients, for which growing, processing and delivery times, alongside factors such as the presence of alternative suppliers and supplier flexibility to alter production, all determine criticality. However, it is important to consider that it is not just food imports that underpin UK FDM operations but also energy, particularly in the form of gas and oil imports. It has been argued that shortages of energy or power would have a greater impact on food security than price rises, due to the fact that energy is used at every stage of the supply chain from the initial production of fertiliser to consumers driving to supermarkets [17]. Indeed, DEFRA analysis suggests that the surge in energy prices in 2008 was the most important driver of the now infamous food price spike of that year [17]. Furthermore, research for the Sustainable Development Commission found that a doubling of oil prices from $50 to $100/b would increase UK consumer food prices by an estimated 5-10% [206].

In particular, food manufacturing accounts for a larger share of energy use in the UK food system than any other stage, 15% (60-65TWh) in 2011, of which the majority was provided by natural gas (61%) and electricity (31%), predominantly for boilers linked to process and space heating [196]. It is not inconceivable that the UKs geographically limited supplies of natural gas (predominantly Norway, Belgium and Russia) and capacity to supply electricity on demand may not always be able to meet the requirements of food manufacturers which in turn could limit their ability to fulfil orders, particularly when lead times are tight [17]. The metrics proposed to reflect input criticality are:

1. Raw Material
    a. Inbound lead time (hours)
    b. Supplier reserves (hours)
    c. Supplier ability to increase/decrease capacity (% no. units)
    d. Presence of alternate suppliers (no. and considerations such as changes to lead time, quality and cost)

2. Energy/Water
    a. Inbound lead time (hours)
    b. Supplier reserves (hours)
    c. Supplier ability to increase/decrease capacity (% no. units)
    d. Presence of alternate suppliers (no. and considerations such as changes to lead time, quality and cost)

4.3.3 Exposure Metric 3: Material Flow

Material flow moves on from measuring the criticality of an input, to consider how it is moved from one point in the supply network to another. This requires capturing the variety of infrastructure, particularly roads and ports, but also water and energy distribution grids, airports, railways and communications lines that ensure deliveries arrive at the right location and at the correct time. Due to the prioritisation of 'lean' paradigms, in combination with the proliferation of short shelf life foods, frequent movement is important. As rail and air freight are prohibitively expensive, most food in the UK is transported by road freight. Indeed, in the UK food, drink and tobacco accounts for almost 30% of goods moved by Heavy Goods Vehicles [17].

For food that is imported, The major ports of Dover, Felixstowe, Southampton, Thames, Medway and the Humber, are key, together accounting for 50% of UK food imports [35]. Not only do these ports accept much of EU road freight imports as well as some international imports, but they are also highly specific in terms of the types of incoming ships which they can accept. For example, Roll On Roll Off and Load On Load Off ships would require diversion to a respectively configured port in the event of a disruption thus making these ports key potential bottlenecks which are highly susceptible to storm surges in the channel or disruption in Europe (where 29% of food imports originate).

The diverse material flow challenges are captured by the following metrics:

1. Inbound/outbound transport type/requirements (i.e. road, rail, ship vs. ambient or chilled)
2. Inbound/outbound volume (unit no./kgs.)
3. Inbound outbound frequency (hours)
4. Inbound/outbound transport route (what road/rail/sea routes are used, what are the alternatives and trade-offs?)

5. Presence of alternative types/routes (no. and for each, the relative ability to satisfy the volume, condition and frequency requirements?)

4.3.4 Exposure Metric 4: Information Flow

Having considered the flow of materials across a supply network the next underpinning metric is the information flow that supports the flow of materials. In FDM a number of factors have made regular, predominantly electronic flows of information vital. One is the fact that the phenomenal asymmetric power balance in favour of the large multiple retailers, who in turn are highly sensitive to consumer demands for quality, mean that for FDMs, the ability to ensure consistency and traceability is paramount. This requires a comprehensive upstream flow of information to the effect that food can be traced, within hours, to the point of production. Breakdowns in information type, route, frequency and content can mean that foodstuffs are out of sync with existing product labels, for example ‘free range’ or ‘allergen free’ and this will now open the FDM up to potential product liability lawsuits and seriously jeopardise future retailer relations. Equally, pressure from retailers and other manufactures over recent decades has led to many FDMs becoming increasingly concentrated and specialised to meet specific contracts. This means that turnover is often high and the ability to rapidly generate production schedules in response to tight order lead times all the while ensuring raw material supply is replenished in a timely manner are crucial. As was discussed in section 4.3.1, there are rarely significant reserves of raw materials or finished inventory to tide FDMs over in the event of a mistake.

These challenges are captured by the following metrics:

1. Inbound and outbound information type (i.e. paper or digital)
2. Inbound and outbound information route (infrastructure required and repositories)
3. Inbound and outbound information frequency (hours)

4.3.5 Exposure Metric Five: Relational Links

The final set of metrics concerns the measurement of the relationships between the primary and secondary AFSN entities themselves. As a general rule, food value chains can be said to be becoming more collaborative and transparent, so that it is increasingly value chains competing with value chins rather than actors within a given chain competing and this trend is expected to continue

[15]. One of the main drivers for this has been fierce competition between the large retailers, which has driven the requirement for their products to be consistent, safe and increasingly, sustainable [207]. This means that such retailers are increasingly encouraging FDMs who may be competitors in some areas and suppliers/customers of each other in different areas, to work together to the effect that the end products are more consistent. For example, a producer of hummus in chilled pots may be encouraged to become the supplier of a salad producer who uses hummus as a dressing. This possesses advantages in the sense that the value chain becomes more integrated. However, there are potential risks that this could put certain suppliers in a position of price monopoly as well as also reducing diversity of supply in the network. Given the increased concentration of FDMs in the UK, it is also likely that companies may find themselves working with, or in some cases against, vertically integrated companies (i.e. companies at different stages of a value chain owned by the same parent company). Equally, given the importance of food and drink to human health and also the increasing drive for sustainability, FDMs increasingly find themselves working with a number of partners, some regulatory such as the Environment Agency and others advisory, such as the forestry association for example.

Therefore, it is important to capture the relational links present between entities within a supply network and it is proposed that this can be achieved via the following metrics:

1. Horizontal relationships. Is the relationship:
    a. A Buying–Selling Relationship? In which case is it:
        i. Adversarial?
        ii. Collaboration?
    b. Long-term partnership?
2. Vertically Integrated Relationships. Is the relationship:
    a. Competition?
        i. What is the level of integration?
    b. Collaboration?
        i. What is the level of integration?
3. Relationships with Actors Outside of Direct Value Chain. Is the relationship:
    a. Adversarial?
    b. Collaborative?
    c. Advisory?
    d. Enforcement?

4.4 Example Application of Failure Mode Exposure Identification Metrics

The Five broad categories of failure mode identification metrics identified in section 4.3 are applied to a very simple FDM supply network in Figure 4.9. The network is broken down into primary entities and secondary entities which are in this case, exemplified by a grower, water supplier and retailer in the primary tier and a port, end consumers and the fertiliser supplier of the primary grower in the secondary tier. For each, the metrics of input criticality, material flow, relational links and information flow are described. The advantage of this approach is that it is a rigorous and replicable approach to identifying potential weak spots that will likely be a) more thorough and b) real-time in comparison to more general risk assessment techniques which review hazards based on historical occurrence. Furthermore, because it is highly visual, it can enable the linkage between key variables that may have previously not been associated. For example, using the scenario in Figure 4.9, whilst it is well known that due to the time it takes to grow food as a biological resource, there is a three-month lead time at least, the consideration of single annual delivery of fertilisers might not have been associated as being a potential weak point, nor the fact that a single fertiliser supplier supplies multiple growers.

This is a key advantage of physically mapping out supply networks in a way that considers not just primary but also secondary supply network actors that might not normally be considered. There is no reason why in a more detailed example, this categorisation system could not be applied to entities as important but diverse as government bodies, consumer interest groups and even the natural environment as a provider of ecosystems services. This is facilitated because the failure mode exposure indicators describe not only to the design characteristics of physical systems (facilities numbers and transport modes) but also the management and control characteristics (information frequency and stock level).

4.5 Chapter Summary

This chapter explored the contemporary structure and activities within the wider UK AFSN within which food and drink manufacturers operate. In doing so, it enabled the identification of a number of areas that underpin resilience, and which will need to be considered within the later framework required as part of Thesis Research Objective 2. By identifying exposure metrics for these areas, it allows the current state of resilience and vulnerability within a supply network to be inferred in a way that could not be achieved by company specific KPIs.

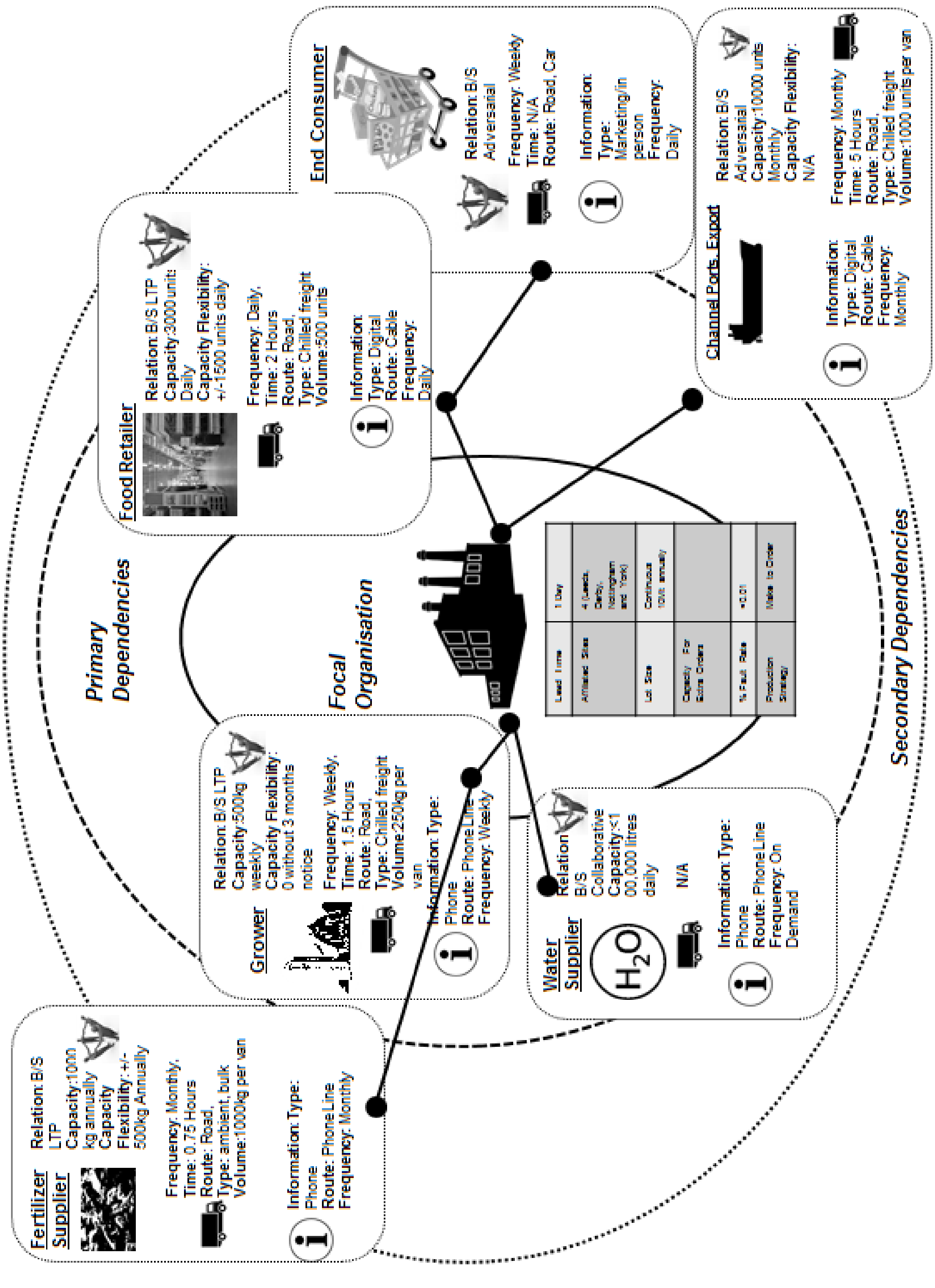


Figure 4.9: Example application of the failure mode indicators to an example supply network.

Chapter 5: Review of Methodologies used to Measure and Enhance Resilience

5.1 Introduction

This chapter addresses Thesis Research Objective 1C by reviewing the methods used by academia, industry and government to model resilience conceptually and to practically enhance resilience. The chapter begins by introducing a categorisation system for each of the aforementioned approaches before evaluating the strengths and weaknesses of each approach. The final section compares the strengths and limitations of the research methodologies identified in this chapter, alongside the conceptual and real-world research needs identified in Chapters 3 and 4 respectively, in order to set out a vision for the research methodology, conceptual framework and practical tool required to fulfil Research Objectives 2 and 3 of this thesis.

5.2 Literature Categorisation

It is important to acknowledge that there is a clear distinction between approaches that have attempted to model resilience as a concept and then attempt to validate this model through empirical measurement and approaches which have sought to physically enhance resilience at a company or national level. By nature, the former is typically (but not universally) confined to academia and the later to Government and Industry. Both approaches are potentially of relevance to the aim of this thesis and thus, the scope of this review included Academia, Government and Industry sources. As a concept, approaches to model resilience can broadly be broken down into those which are exploratory, seeking to stimulate theoretical debate and identify novel ways of viewing a concept, those which are more structured, providing testable models of existing theory, and those which are empirical, often seeking to validate theories and models through real world observations. Practical tools on the other hand tend to be predominantly Government and Industry derived and may or may not follow the latest in conceptual understandings of resilience, often taking the form of modifications of existing Business Continuity Management (BCM) and Enterprise Risk Management (ERM) activities. These different approaches are summarised in the categorisation system shown in Figure 5.1 which also provides section headings to guide the reader through the review section of this chapter.

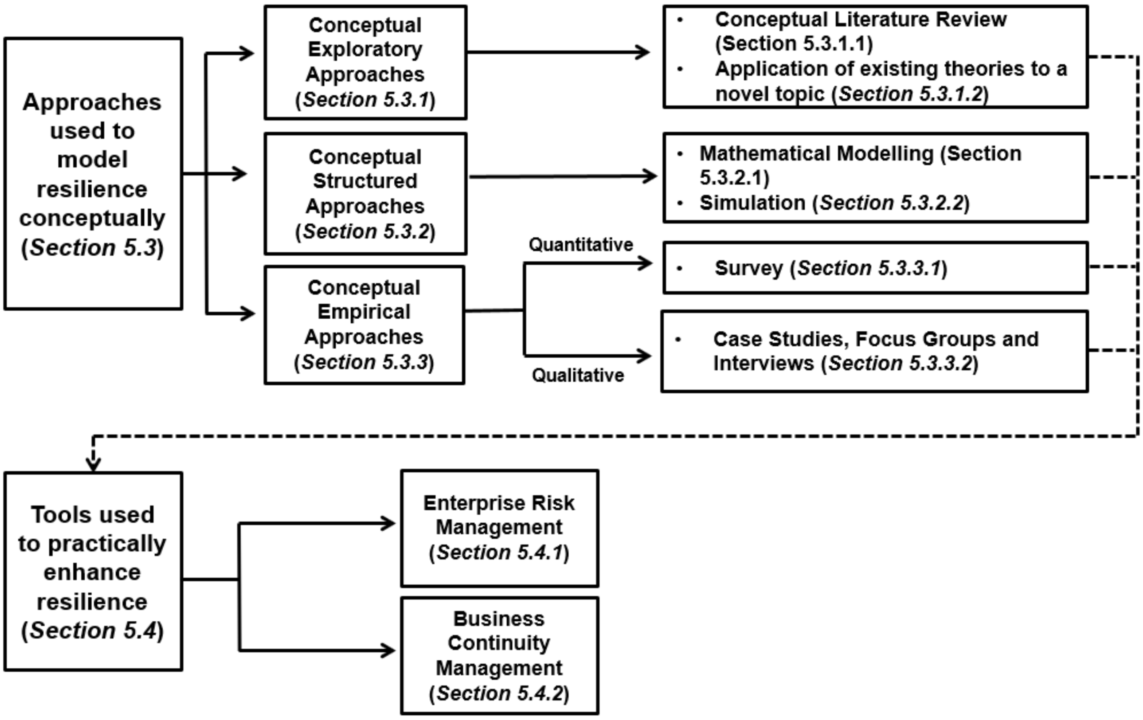


Figure 5.1: Categorisation of approaches used to measure and model resilience and of tools used to enhance resilience.

5.3 Approaches used to Model and Measure Resilience as a Concept

As a concept, resilience has been modelled and measured in three broad ways which can be described as exploratory, structured and empirical. Given that resilience with regard to supply chains is a relatively new topic, a number of works have used more ‘exploratory’ approaches. These consist of techniques such as literature reviews and the application of existing theories to generate novel ways of approaching and understanding resilience as a complex phenomenon [208]. As the field has begun to mature in recent years, a number of works have begun modelling resilience in what are known as conceptual structured works. Common structured approaches include mathematical modelling and simulation approaches. Such approaches typically do not generate empirical data themselves, and either use existing empirical data, or, more commonly given the challenges of obtaining reliable data that is representative of entire supply chains, generate artificial data.

However, this review also identified a number of methods which sought to validate existing exploratory and structured understandings of resilience through Empirical means, i.e. the measurement of real world observations to establish causal relationships. As Supply Chain Resilience is not a tangible construct, it's empirical measurement frequently relies on asking relevant industry experts questions and typical approaches include surveys to generate quantitative data and Case Studies, Focus Groups and Interviews to generate qualitative data. Of course, exploratory, structured and empirical approaches cannot be considered in isolation and frequently overlap, for example, exploratory works being used as the basis for structured models, which in turn form the foundation for empirical investigations. It is for this reason that all three approaches are considered in this review.

5.3.1 Conceptual Exploratory Analysis

Conceptual Exploratory methods typically describe the methods by which testable theories are built when there is insufficient knowledge to directly apply structured or empirical approaches. A common analytical approach used in exploratory conceptual works is the conceptual (also sometimes referred to as systematic) literature review process which offers the ability not only to map knowledge using thorough statistical techniques, but also to synthesise it, and in doing so generate new conceptual understandings. The use of existing theories as a novel lens for understanding a new topic also falls within this area and both are now explored in detail.

5.3.1.1 Conceptual Literature Review based approaches

This review identified that the field of SCRES is relatively rich in conceptual literature review based approaches [e.g. 45, 90, 101, 105, 128, 219-220]. Such approaches rigorously evaluate multidisciplinary literature around a set of carefully defined review questions to identify the current state of the art knowledge and research gaps [132]. However, this approach has the potential to go further and identify novel linkages between findings and thus effectively develop new knowledge [211]. Vlajic et al. (2012) [30] use a conceptual review supported by previous empirical observations from industry workshops to develop a research framework for designing robust AFSCs (See Figure 5.5).

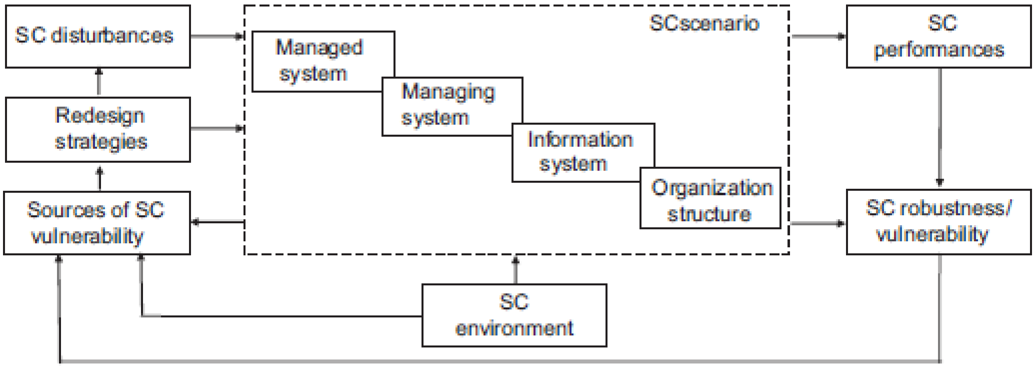


Figure 5.5: Framework for designing robust Agri-Food Supply Chains[30].

In doing so, the authors pull together a number of key components that previously were separate works in their own right, for example, KPI's, disturbances, underlying vulnerabilities, performance under different disruption scenarios and redesign strategies for different value chain stages respectively. By considering these areas in parallel, new knowledge is generated, for example, the relationships between supply network redesign principles and disrupting prevention and impact reduction. However, whilst such approaches are extremely good at synthesising knowledge around a topic, a potential drawback is that the resulting frameworks, whilst highly descriptive, can be difficult to practically operationalise.

5.3.1.2 Application of existing theories

This approach takes an existing theory and applies it to a novel topic. For example, Sinclair (2014) [82] takes the adaptive resilience theory developed by Holling (1973) [67] for describing resilience of complex ecological systems and applies this to evaluate the resilience of the Australian dairy sector. This approach allowed the author to identify economic, biophysical and social thresholds of the industry to disruption and to apply these specifically form a dairy farmers perspective. The downside to such approaches is that by nature the theories are not designed for the topic that they are applied to and so whilst providing a novel lens to assess a phenomenon, it is also likely to be a narrow lens.

5.3.2 Conceptual Structured Approaches

Conceptual Structured approaches enable the development of theory into working models. In the field of SCRES, such approaches are particularly orientated towards developing and validating models in the absences of empirical data. Two broad approaches enable this: Mathematical Modelling and Simulation. Mathematical Modelling concerns the use of abstract mathematical language to describe the behaviour of a system with specified parameters [212]. Simulations are a way in which a model can be tested in an artificial environment by manipulating a range of key variables. These approaches are now considered in more detail.

5.3.2.1 Mathematical Modelling of Resilience

Mathematical modelling offers an attractive method of simplifying the complexity of resilience in real world supply networks and investigating the relationship between a select number of resilience variables of interest to the researcher. As such, it is unsurprising that a number of mathematical approaches to modelling resilience have been investigated in the academic literature. At their simplest, they involve first generation multivariate techniques such as multiple linear regression to predict the value of a 'dependent' variable (i.e. resilience) based on the value of two or more other 'independent' variables (such as resilience elements). For example, Skipper and Hana (2009) [141] used this approach to identify the contribution of various strategies aimed at enhancing flexibility in order to increase resilience. They identify management support, resource alignment, information technology usage, and external collaboration as being the top contributors although the R^2 indicated that there were likely additional variables of interest and that this may have been influenced by limited survey responses. One of the major limitations of this approach is that all variables are assumed to be independent which may not always be the case with resilience elements because employing one, such as holding surplus inventory, may limit the effectiveness of another, for example flexibility.

Given the limitations of first generation multivariate methods, newer, second generation multivariate methods such as Structural Equation Modelling (SEM), have been increasingly used in resilience studies, not as predictive tools (as in the case of multiple linear regression) but as a way of testing theoretical models for their fit to the variables they describe [84, 131]. One of the major advantages of SEM is that it is well suited to handling large, quantitative data sets, sometimes including dependent variables and analysing multiple variables simultaneously rather than individually. It is also well suited to identifying the presence and effect of latent variables (variables that are previously unknown or difficult to measure) on known, measured, variables and vice versa [214].

For example, Chowdhury and Quaddus (2016) [48] use SEM to test a resilience model, consisting of three phases (readiness, response and recovery) and 9 resilience elements based on data gathered from interviews with 15 apparel manufacturing companies in Bangladesh (See Figure 5.2). Results validate the three phases of disruption and affirm that supply network orientation, learning and development and supply network risk management culture significantly influence resilience. However, the range of resilience elements considered is very small compared to the 34 identified in this thesis (See Chapter 3). Additionally, the model is best suited to considering just the effect of resilience elements and not the causal pathways, nor the relation with specific vulnerabilities.

One approach which can accommodate the relationship between resilience variables and vulnerabilities is Graph Theory. Graphs have two basic elements: the node (or vertex) and the edge (or link) which together, form a highly visual (and therefore useful to mangers) way of modelling the two-way relations between objects.

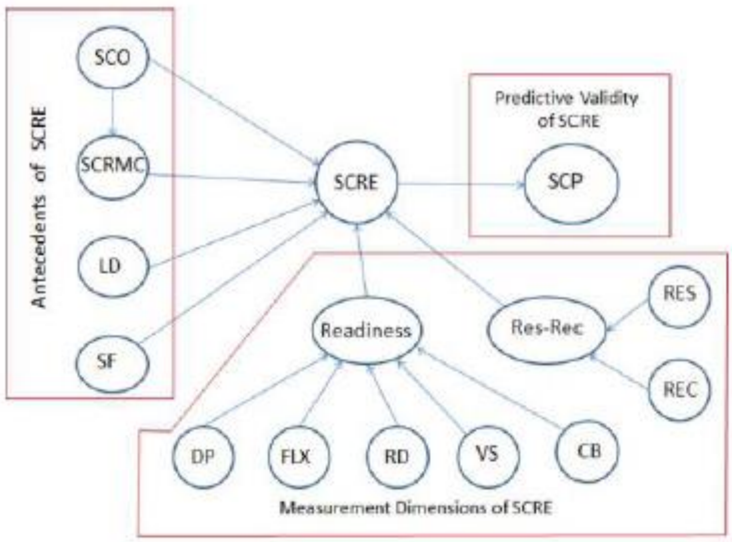


Figure 5.2: Resilience research model provided by Chowdhury and Quaddus (2016). Note: SCO=Supply Chain Orientation, SCRMC=Supply Chain Risk Management Culture, LD=Learning and Development, SF=Support Factors, DP=Disaster Planning, FLX =Flexibility, RD=Redundancy, VS=Visibility, CB=Collaboration and SCP= Supply Chain Performance.

For example, Wagner and Neshat (2010) [172] use graph theory to aid in the calculation of a supply network vulnerability index. By considering vulnerability drivers as vertices and the interdependencies between them as edges, a graph can be plotted for a specific supply network. As the relations between different vulnerabilities can be measured quantitatively, the graph can be weighted to prioritise higher significance vulnerabilities. Whilst useful for intuitively representing actual links between various aspects of resilience on a network scale, it must be considered that the huge range of empirical data required to represent an entire supply network is difficult to obtain in an industry setting (the majority of the authors cited have used surveys which effectively limit usefulness to academia only).

5.3.2.2 Simulation Modelling

Like the mathematical models considered in Section 5.3.1.1, simulation models are simplified representations of reality. However, unlike mathematical models, which are well suited to predicting the relations between variables under highly specific circumstances, simulation models focus on being able to test the response of the model to much more varied circumstances. As such, they are commonly used to model system wide modifications for resilience that would otherwise be infeasible in real life due to the range of companies involved and the long time periods required to observe effects. Furthermore, because simulations proceed step by step using numerical approximation, as opposed to mathematical models which often have a very specific optimal solution, simulation is better suited to 'soft variables' such as resilience [215]. Simulation approaches used to model resilience include Systems Dynamics, Discrete Event Simulation, Agent Based Modelling, Monte Carlo Simulation.

Systems Dynamics Simulation is based on initial pioneering work by Forrester (1961), which involved translating the interactions between key system components into a causal loop diagram, converting these relations into differential equations, subjecting the system to a disturbance and then studying the output responses to understand the cause and effect relations [216]. For example, Yang and Xu (2015) [86] take a broad approach to systems dynamics and consider the dyadic relationship between grain suppliers and customers in China and how a variety of factors, including robustness and recovery time, determine resilience specifically in response to natural disasters. Their response is based on the commonly utilised concept of the 'Resilience Triangle' which is a disaster research concept developed by Bruneau (2003) [144] (See Figure 5.3).

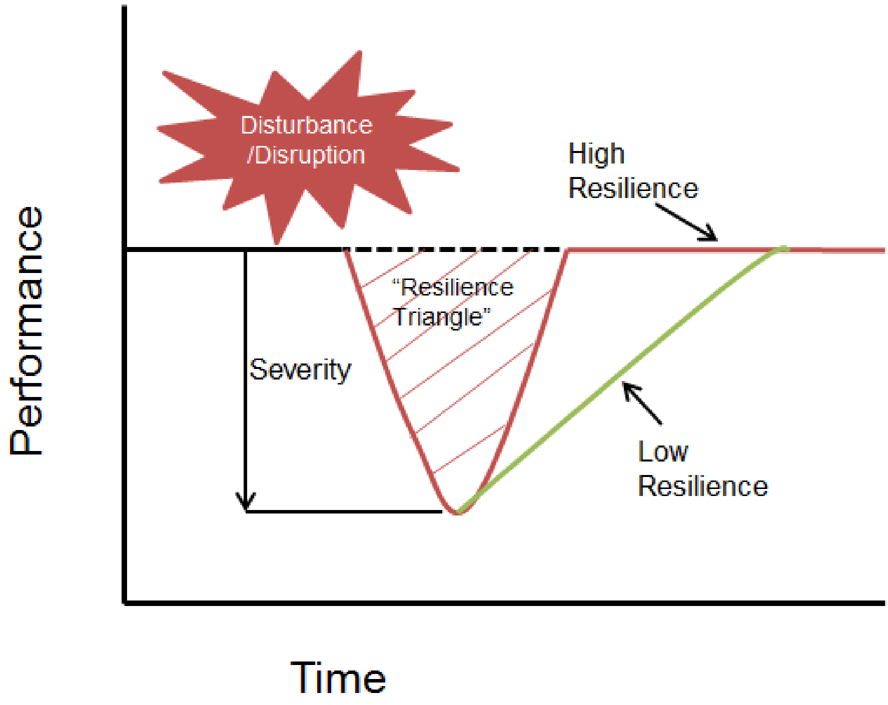


Figure 5.3: Resilience Triangle

The depth of the triangle shows the disturbance severity, and the length of the triangle shows the recovery time. The smaller the triangle is, the more resilient the system is and as such, it is one of the simplest and most common methods of visualising the impact of resilience strategies and variations have been used by a number of other authors [36, 131, 211].

However, there are limitations to the concept of the resilience triangle itself and systems dynamics approaches more broadly. Regarding the resilience triangle concept, is best suited to measuring singular resilience 'elements' at a time and it is poorly suited to measuring multiple elements simultaneously [217]. Another is that because it associates resilience with time and performance it tends to be biased towards resilience elements that favour profit and competitiveness rather than elements that enhance adaptively. For example, a key criterion in Yang and Xu's work was the identification of the most profitable response route. Indeed, it is unable to measure resilience actions which result in a net gain or loss in performance.

In terms of systems dynamics models in general, a key limitation is that they are based on physical laws which must be obeyed [218]. As such, they often assume central control of all variables in addition to the fact that the variables studied tend to be highly aggregated which can hinder the resolution of results. As such, they are not suited to consider random individual actions (such as a worker within a factory) or volatility originating sources outside of the controlled system, such as extreme weather or governmental policy changes. This means that they are best suited to systems that can be modelled centrally, and which only include a single actor or “echelon”, for example, factory process control rather than an entire AFSN.

An alternative to systems dynamics is Discrete Event Simulation, which models the working of a system as a temporal sequence of step by step ‘events’ across one or more sample pathways, the interactions and reactions of which, characterise overall system behaviour and performance [43]. It has two major advantages over systems dynamics models, the first being that individual model variables can be tracked over time thus increasing system resolution and secondly that this in turn allows queuing behaviour from demand and supply to be better visualised.

For example, Schmitt and Singh (2012) [219] have constructed a Discrete Event Simulation model using Arena software. It modelled two products across multiple manufacturing/ packaging plants and distribution centres, capturing flow and allowing for disruption at multiple nodes and links. This involved the design of risk profiles for each node and link outlining the likelihood (e.g. 1 in 10 years) and duration of each possible disruption based on a literature review. It then studied the effects of altering placement of buffers such as inventory, capacity and time, between varying stages of the supply network on customer fill rate as a proxy for resilience. However, as with earlier systems dynamics models, an observed shortcoming of this approach was that it assumed centralised control of model variables which would not realistically be true given that it would be people, rather than machines, making decisions at each of the buffer points. It was also observed that the level of detail in discrete event simulation in terms of multiple time points and pathways means that adding a large number of variables can make the simulation highly time intensive which is potentially a limitation when considering the broad range of resilience factors identified in Chapter 3 [126].

In response to perceived shortcomings of Systems Dynamics and Discrete Event Simulation models, a number of researchers have applied Agent Based Simulation to supply chains [99, 215-216]. This more complex simulation effectively involves the accumulation of several Systems

Dynamics models in order to allow the integration of the entire supply network in the form of a linked system of independent echelons. These echelons can be used to represent individual actors each with an independent, measurable, decision making procedure. One advantage therefore is that actors can interact, negotiate and learn from each other and disruptions. It can also enable a more granular understanding of actors, such as individual consumers.

For example, Datta et al. (2007) [220] scale up the Agent Based Simulation approach to take into account supply networks spanning multiple countries and including multiple products all whilst being influenced by diverse influences including demand variability and production/distribution capacity constraints. Each actor is programmed with a set of response rules to react to these influences, based on real world information and stock flows (obtained from publicly available data), giving a baseline model. Performance is measured by customer service level, production change over time, average inventory at each distribution centre and total average network inventory across all distribution centres. Despite the obvious advantages, this model is still limited by boundaries that do not represent full complexity of supply networks. For example, one assumption is the infinite supply of raw materials at manufacturing level, which is obviously a limitation in terms of organic resources such as food. It also does not represent the costs, financial or otherwise of the different resilience enhancing actions proposed and this hinders comparative study. However, as the author correctly points out, such problems could be incorporated into future works.

Another widely used simulation approach which shares many similarities with Agent Based Simulation is Monte Carlo Simulation, which models the actions and interactions of autonomous agents. However, unlike agent based approaches, it assumes that a global system control does not exist thus making it ideally suited to modelling complex, real life systems such as AFSNs [222]. Broadly speaking, Monte Carlo Simulation works by using random numbers to solve mathematical problems, hence the name which refers to the gambling Casinos of the Monte Carlo Principate [223]. Monte Carlo Simulation methods tend to be used when there is considerable uncertainty regarding how a system will respond to future scenarios based on contemporary available data and which therefore makes it unfeasible to compute exact results using the types of deterministic algorithm used in other simulation approaches such as discrete event simulation. There is no single Monte Carlo Simulation method; instead, the term describes a large and widely used class of approaches. Recent advances in the availability of powerful and affordable computers mean that not only is the processing power required to run the potentially thousands of simulations available, but there is also a range of software available for non-experts, thus explaining the huge growth in publications using this method. This is particularly true in SCRES where using Monte Carlo methods enables the impacts of different supply network disruption scenarios and the impact of various mitigating resilience elements to be evaluated.

For example, Caschili et al (2015) [104] develop a spatial, multi-layer model of international trade networks and their reaction to disruptions which is assessed via Monte Carlo Simulation. The model considers three major layers which are economical (GDP, trade and exchange rate), social (population, migration and cultural ties) and infrastructural (borders distance and quality) and which are based on Ecological Systems Theory and the ways in which complex systems adapt after a disruptive event. In a steady state, the layers are linked by algorithm and Monte Carlo approaches are then used to model the effects of disruption, for example, rises in GDP in various nations in order to identify key nodes which facilitate the spread of disruption. However, possible mitigation techniques and their impacts are not simulated.

The advantage of using Monte Carlo approaches is that they are not deterministic and so when identifying potential disruptions, do not rely on known system risks alone but can also incorporate random variability, thus helping to offer insights that are better suited to dealing with projected future supply network volatility. A downside however, is the huge amount of data required to design the initial model and rules. Whilst Caschili et al. (2015) [104] were able to obtain this from relevant global authorities such as the World Bank, in more industry specific examples, the relevant data is often difficult to obtain empirically. Therefore this data often must be generated artificially, requiring a number of assumptions to be made on relations between variables which may not hold true in real world settings [224].

5.3.3 Conceptual Empirical Approaches

Conceptual Empirical analysis concerns the collection of real world quantitative or qualitative data to support existing conceptual models. The advantage of such approaches over using artificially generated data is that it can avoid assumptions made in aggregated models. Furthermore, by collecting data specific to the model at hand, rather than using publicly available supply chain data, it can be specifically tailored to the research question, thus increasing reliability. However, the disadvantage to is that data regarding key resilience components such as vulnerabilities, the resilience elements that best mitigate them, and the relations between the two, cannot be measured in a laboratory. Instead, they can only be obtained by talking to numerous supply chain experts across multiple companies, which is both incredibly time and resource intensive. For this reason, empirical methods predominantly use surveys for quantitative data (i.e. observations that are representative of a statistically significant number of organisations) and Case Studies, Focus Groups and Interviews for data that requires qualitative details, for example, the relationships between resilience components. These two empirical approaches are now explored in more detail.

5.3.3.1 Quantitative Empirical Approaches: Surveys

The majority of quantitative empirical approaches to measuring resilience observed in the literature were questionnaire based. Questionnaire surveys are useful when the research goal is to provide a description of the incidence or prevalence of a phenomenon and hence survey approaches in SCRES often reach out to thousands of participants. Findings are then frequently analysed using mathematical approaches. For example, Brandon-Jones et al. (2014) [98] explore the three way relationship between the resilience element of visibility, its impact on resilience, and the resources (in terms of information sharing and connectivity) that enable visibility. This is facilitated by data collected from a survey of 264 manufacturing plants in the UK which they assess using principle component and factor analysis to establish the fit of empirical data to their pre-established hypothetical model.

A major limitation to survey-based approaches is the often low response rate and potential bias of respondents who may respond according to pre-conceived beliefs. Furthermore, whilst data obtained is broad, it is often shallow, focussing on just one or two variables (e.g. just visibility in the case of Brandon-Jones) partly due to the non-expert nature of respondents and the need to keep questions simple to facilitate this audience. Another issue when studying supply network level resilience presented by use of surveys is that they represent the views of only a single respondent and not their wider supply network, thus restricting the ability to explore network wide moderating factors.

5.3.3.2 Qualitative Empirical Approaches: Case Studies, Focus Groups and Interviews

Qualitative approaches differ from quantitative approaches in that they consider meanings behind concepts that could not otherwise have been adequately understood using numerical representation. Here the goal is to build in-depth of knowledge, particularly in terms of context and relationships that typically could not be obtained through surveys due to time and respondent expertise considerations. Typical analytical approaches may include focus groups (group interview facilitated by the researcher to elucidate salient qualitative factors from a broad range of expert stakeholders), case studies (the investigation of a phenomenon in its real-life context with the objective being generalizable findings) and interviews (similar in purpose to focus groups but often with one participant).

A case study can be generally defined as the investigation of a single phenomenon in real world settings in order to gain in-depth knowledge, in particular, concerning the boundaries and interactions between the phenomenon in question and surrounding related factors [225]. Case studies can be historical (using publicly available historical data) although this approach may not offer as precise a fit to the research question (s) as bespoke, contemporary case studies. Case studies can also be singular or comparative and can also involve the collection of supplementary quantitative data. Whilst interviews are often the predominant way of collecting data, data is frequently supplemented by a range of documentary evidence from the industry in question (such as internal strategy or process documents, supplier evaluation tools and supplier questionnaires or business continuity plans) [49, 112].

For example, Leat and Revoredo-Giha (2013) [75] develop a framework for enhancing resilience in the Scottish pig meat industry. This is validated using a case study approach which consisted of 7 semi-structured interviews involving producers, processors and retailers. Peck et al. (2005) [77] take a different approach to the case study methodology and conducted the case studies before the theoretical model was developed. This meant that the purpose of the model was to explain the empirical findings, i.e.an inductive rather than deductive approach. In both cases, a key advantage of the case study approach was identified as its ability to analyse a concept qualitatively and quantitatively in its natural setting. A downside to the case study approach more generally therefore, is that because findings are case specific and not always easily transferred/generalizable. It is therefore important that case study selection is made based on the unique, extreme or revelatory nature of the situation [226].

Another type of qualitative conceptual approach is the focus group. Focus group-based approaches are effectively interviews carried out with multiple interviewees simultaneously. Focus groups often consist of 3-15 participants, moderated by a group leader (often the researcher) with data collected in a semi-structured fashion and often in multiple, cumulative sessions around a carefully defined topic. A key strength is that interviewees can build on each other's answers thus adding depth that could not have been gained from individual interviews as well as drawing out issues that the researcher may not have been aware of [46].

For example, Carvalho et al. (2013) [217] use focus groups which follow the Delphi Technique, which consists of an iterative series of two to three ‘rounds’ of carefully structured questions designed to extract the maximum amount of information from participants. These are then analysed using a variety of approaches including statistical methods, Likert scale ratings, degree of importance, bibliometric analysis, SWOT analysis or standard deviation. Anonymous feedback is then provided to the participants after each round and helps guide the next round of questions which continue until group consensus is agreed (thus offering a level of focus and depth that other qualitative approaches could not offer). The Delphi Technique is particularly suited to situations where it is important to define areas of uncertainty or disagreement and to assess this in a quantitative manner. Carvalho et al. (2013) [217] successfully employ this technique to help populate and validate their conceptual ‘ecosilient index’ which contained a series of linked, weighted, greenness and resilience management strategies in from both organisational and supply chain perspectives.

Focus groups can be highly time effective in comparison to interviews and they are also relatively flexible in that they can be applied in an inductive and deductive manner. A downside is that they can take considerable effort to arrange and care has to be taken to ensure that interviewees are representative of the population in question. In particular when focus groups consist of potential business rivals, there may be reluctance to share certain information (even if Chatham house rules are followed) and or certain participants may dominate the discussion.

The final qualitative empirical approach is to use interviews. Interviews are particularly useful when research is explorative in nature as they can often uncover broader meanings, linkages and explanations than quantitative techniques such as surveys are able to. In comparison to surveys, interview response rates are often higher and the two way nature of dialogue often helps ensure that interviewees fully understand the questions they are answering [227]. There are three different types of interview which are, structured, semi-structured and unstructured. Structured interviews are essentially verbally administered questionnaires/surveys in which a list of predetermined questions is asked with no scope for follow-up questions to responses that warrant further elaboration. As such, this approach is quick and easy to administer and is useful if a very large number of interviews are required but less well suited if depth of response is important.

For example, Elleuch et al. (2016) [47] use structured interviews in combination with the use of Ishikawa diagrams to identify the key vulnerabilities facing a large food manufacturing organisation. The benefit of using a structured interview with vulnerability factors scored on a scale (typically 1-9) is that it allows easier comparison of variables. In this way, Elleuch et al. (2016) [47] use Analytic Hierarchy Process to identify binary links between different vulnerability factors thus enabling them to identify the top 23 priority vulnerabilities facing the organisation. However, it should be noted that because Analytic Hierarchy Process is based on pair wise comparisons, it can become quite time consuming if a large number of vulnerabilities/elements need to be compared [228].

Unstructured interviews on the other hand do not have any organised sequence of pre-prepared questions and typically begin with a single opening statement (e.g. "tell me what you know about resilience in your organisation") and allow conversation to develop naturally. As such, this type of interview best suits an inductive research approach which seeks to avoid the influence of any pre-conceived theories, or, when very little is known about the research area. The drawback is that such interviews can be highly lengthy, and because there is no common format, results can be hard to codify. Semi-structured interviews are effectively a middle ground approach which consist of several key questions that help to define the areas to be explored, but which are open ended and allow the interviewer or interviewee to diverge in order to pursue an idea or response in more detail [229].

5.4 Tools used to practically enhance Resilience

The tools that exist to practically enhance resilience are significantly different to conceptual methods to measure and model resilience because the end product must be practically implementable. Such tools therefore predominantly originate from Government and Industry as these are often the only actors with the influence to practically make changes to resilience at a national scale or company/value chain level respectively. Whilst these actors often do use some of the previously described conceptual resilience methods to influence their tools, the priority is always on being able to identify and mitigate risk, rather than to develop theory, and so tools must offer a tangible benefit to performance. However, indicators of impact on performance vary between Government and Industry, with Government priorities being to mitigate major disruptions affecting key public services and industry priorities being to minimise or altogether avoid the damage to economic viability from a disruption. It was identified earlier that FDM resilience must consider the potential for business resilience solutions to have ramifications for wider societal and the natural environment and so for this reason, both Government and Industry tools are explored in this review. Whilst the indicators used by Government and Industry differ, both use versions of ERM and BCM programmes and these are now explored in detail.

5.4.1 Enterprise Risk Management

ERM refers to a broad series of practices in place to help businesses to identify all risks that confront an organisation, project the likely impact of these risks on KPIs, and mitigate the risks in a systematic and coordinated way [230]. In the context of UK FDMs, ERM is strongly driven by a need to mitigate the risk of health and safety breeches. Whilst what constitutes ERM varies significantly on a company by company basis, ISO 31000 is generally accepted to represent best practice and whilst there are alternatives, such as the Supply Chain Councils SCOR model, they include risk management as a sub-component of a wider supply chain management model and so are less rigorous, particularly in terms of not considering the monitor and review/communicate and consult stages of ISO 31000 (see Figure 5.6).

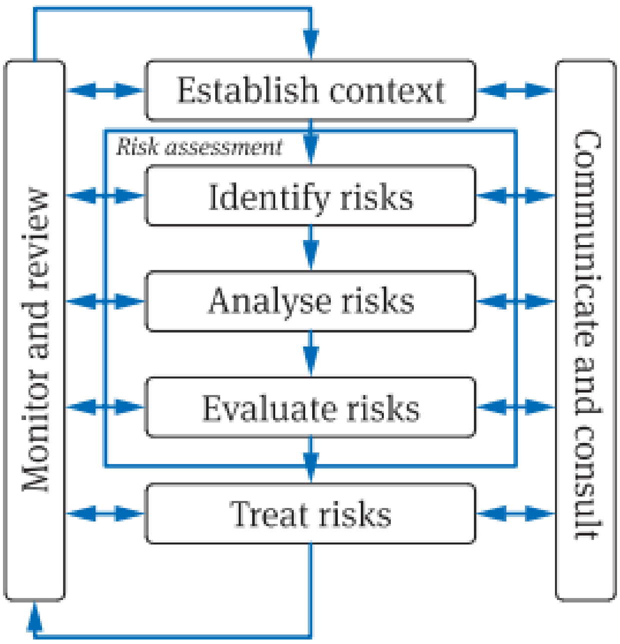


Figure 5.6: The ISO 31000 risk management process. Source: ISO 31000 Risk Management: a Practical Guide for SMEs [231]

Therefore, using ISO 31000 as a benchmark for industry ERM, the main principles are:

1. **Establish Context**: The context stage concerns the establishment of an organisation's objectives, broadly spanning operations, reporting and compliance. It also considers the wider supply network environment in which it is pursuing these objectives, including its stakeholders (and associated relationships), geography and processes.

2. **Risk Assessment:** The systematic identification of risks across the legal, social, political and cultural environment in which the organisation operates. Findings suggest that a number of global companies predominantly identify risks based on either "fault tree analysis" or "event tree analysis". Both are logic diagrams that represent the sequences of failures that may propagate through a complex system. Other approaches can include expert surveys and supply network mapping [232]. Risk analysis is commonly based on Value at Risk principles which are generated via the multiplication of a risks probability by its monetary impact [114, 228-229]. Probability is determined based on the nature of the threat itself and historical occurrence as well as the exposure of the supply network at risk. Indicators are often both qualitative and quantitative and often relative rather than absolute [23]. Impact is often assessed based on revenue lost, brand damage and impact on corporate social responsibility. An example of this categorisation is shown in Figure 5.7. The evaluation stage involves the assessment of existing protocols based on their ability to contain the identified risks and if necessary, the generation of new protocols.

3. **Treat Risks**: the treatment of risks stage involves the development of mitigation strategies (or adaptation of existing strategies) to deal with identified priority risks. One approach might be to avoid the risk altogether by changing the high-risk activity. Alternatively, contingency plans and modifications to operational procedure can allow an actor to reduce risk. A final option is to transfer risk to a third party via outsourcing or insurance.

4. **Communications and Consultation**: This stage concerns ensuring that the right people are aware of their responsibilities based on the treatment option selected previously. This is commonly achieved through an constantly updated risk register that includes details of the current controls and details of any further actions that are planned [235].

5. **Monitor and Review**: Responses to actual disruptions as well as crisis management exercises are formally evaluated, in terms of both cost and effectiveness against and the risk register protocol list updated accordingly.

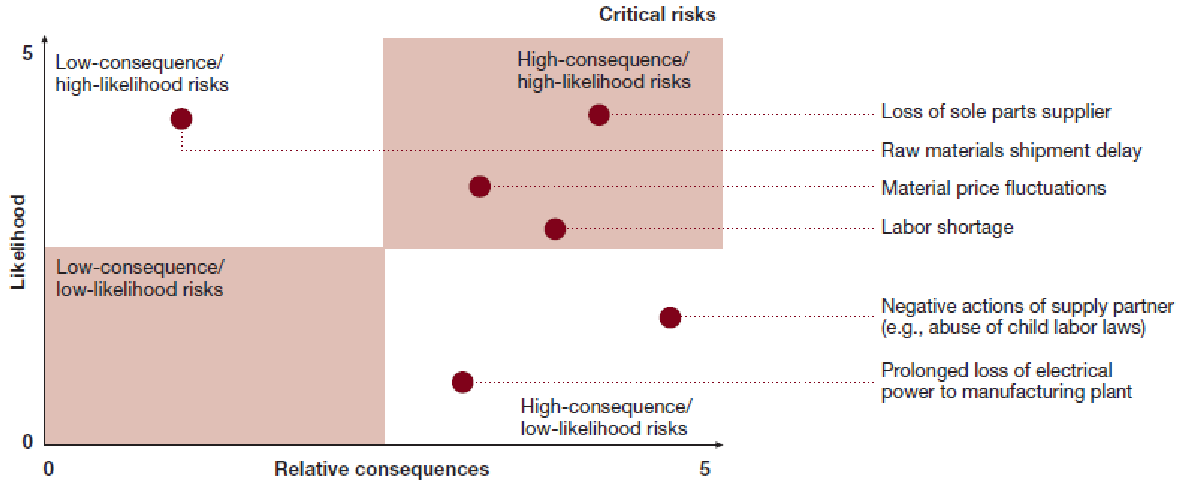


Figure 5.7: Standard Industry risk assessment matrix. Source: Source: PWC, Building a resilient supply chain [234]

The monitor and review stage in particular is a key distinguishing component of ERM which ensures that mitigation strategies are up to date against the latest evolving threats. Cisco achieve this through focusing on products rather than risks, because, as is the case in many companies, relatively few products often account for a relatively large percentage of the company revenue [233]. These are visualised through a bespoke dashboard consisting of feeds from an external provider (NC4) which is combined with a Google Earth interface to visualise key nodes, critical components and TTR for the top 100 revenue providing products (See Figure 5.8).

In addition to their standing risk management team, they have a number of ‘standing incident managers’ who are employees from key product groups and functional teams who join the crisis team to aid planning and dissemination of response strategies to colleagues if a disruption occurs. To aid this, the team has developed ‘playbooks’ which provide a framework for how to respond to various incident, key contacts, and supporting materials to assist the broader workforce in responding to a disruption. In order to more accurately characterise impact, many organisations use ‘wargames’ to identify supply networks risks. These are broader than interviews and challenge participants form a range of supply network stakeholders against specific scenarios to identify deep rooted risks and dependencies, often requiring collaborative efforts in order to overcome disruptions.

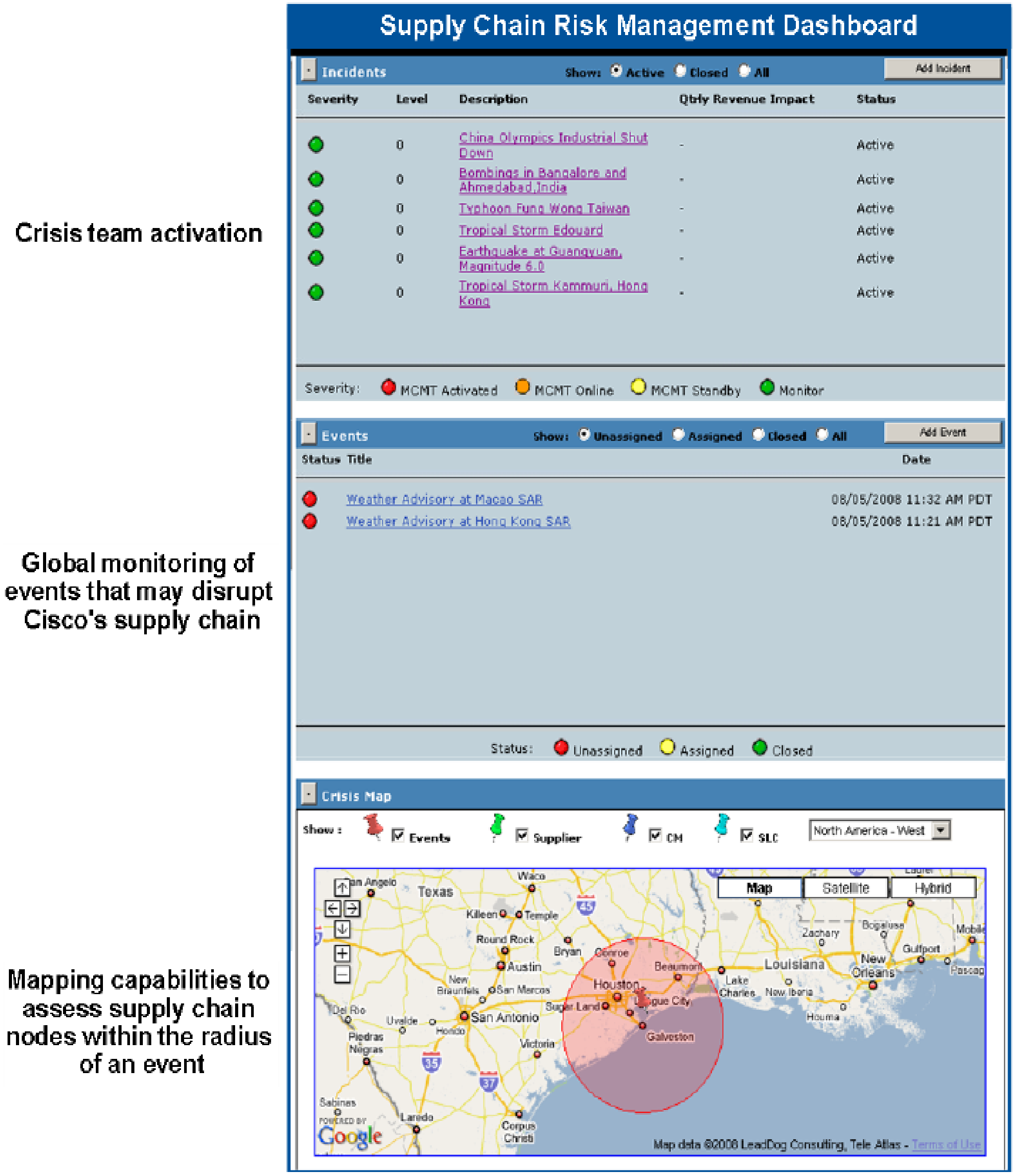


Figure 5.8: Cisco real time risk identification dashboard. Source: Miklovic and Witty (2010) [236].

Despite its popularity, one of the shortcomings of the IS031000 approach is that the priority tends to be placed on the high likelihood/high impact events (top right hand quarter in Figure 5.7) rather that the high impact/low probability disruptions which are the ultimate target of resilience [1,46]. To address this concern Pettit et al. (2010) developed The SCRAM™ (Supply Chain Resilience Assessment Model) in what is to the authors knowledge, the only commercially validated academic tool that goes beyond modelling resilience as a theory and actively seeks to enhance resilience [45]. The tool makes use of cross-industry validated taxonomies of 7 vulnerabilities and 14 different capabilities (analogous to resilience elements) as shown in Table 5.1.

Each of the categories V1-7 and C1-14 has numerous sub-factors and the tool works as a questionnaire by which senior management rank each of the sub factors on a Likert scale of 1 (strongly disagree) to 5 (strongly agree). The averages of each of the sub factors are then used to calculate the ranked average of each of the main categories. This information allows a simple calculation, $R = \frac{\mathrm{C{-}V{+}4}}{8}$ which, provides a resilience score for the organisation. Such an approach is useful, as rather than relying on staff knowledge of past disruptions, likelihood and impact, it allows respondents to think more broadly about potential vulnerabilities and the potential of the organisation to counter. However, the SCRAM™ tool does not actually link specific capabilities and vulnerabilities, thus it does not help and organisation to arrive at 'balanced' resilience, it simply uses averages to give a relative idea of a company's balance of risks to countering options. This means a company could record a 'false negative' whereby it is assumed resilience capabilities are sufficient when, in actual fact, they are the wrong ones to deal with the vulnerabilities faced.

Table 5.1: SCRAM ™ Vulnerabilities and Capabilities[45]

Variable	Vulnerability Factor	Variable	Capability Factor
V1	Turbulence	C1	Flexibility in Sourcing
V2	Deliberate Threats	C2	Flexibility in Order Fulfilment
V3	External Pressures	C3	Capacity
V4	Resource Limits	C4	Efficiency
V5	Sensitivity	C5	Visibility
V6	Connectivity	C6	Adaptability
V7	Supplier/Customer Disruptions	C7	Anticipation
		C8	Recovery
		C9	Dispersion
		C10	Collaboration
		C11	Organisation
		C12	Market Position
		C13	Security
		C14	Financial Strength

The SCRAM™ tool also cannot measure resilience metrics from outside of the organisation in question and so it cannot capture external vulnerabilities, externally focussed capabilities, or the impact of the focal company's resilience choices on their supply network stakeholders. Lastly, none of the resilience elements or vulnerabilities considered in the SCRAM™ tool are AFSC specific.

In contrast to industry risk analysis efforts, Government approaches to ERM tend to be national in scope and attempt to measure and enhance the ability of whole sectors to be able to absorb and react to disruptions whilst maintaining a set level of service. This can still be achieved if individual businesses succumb to a disturbance, provided other organisations can fill their place. For example, research by DEFRA notes that the resilience of the overall UK AFSN is underpinned by "the number of different supply chains and manufacturing and retail businesses." It empathises that food resilience is about "ensuring that critical elements of our food supply chain work, including maintaining communication, transport and energy networks". As such, whilst the framework for identifying and mitigating risk at a national level still broadly follows similar steps to those outlined in IS0 31000, the nature of risk variables changes significantly in comparison to an individual organisation's perspective [17, 140, 237]. For example, at a National level, exposures may include strategic energy imports, population exposure to pandemic diseases, regional extreme weather, and large scale economic downturns. An example of how the ERM methodology may be applied to identify the state of national food resilience is summarised in Figure 5.9.

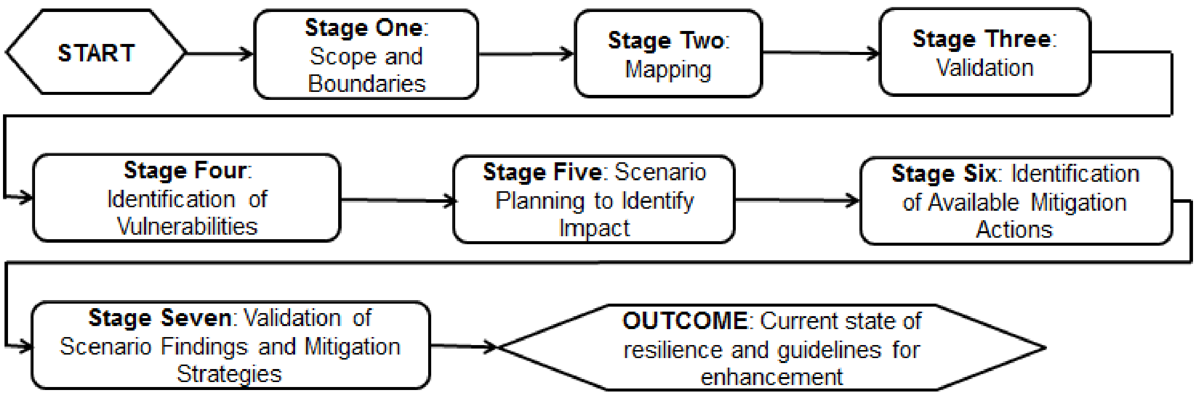


Figure 5.9: Outline of the risk analysis procedure for evaluating current resilience at a national level and developing mitigation strategies. Based on information provided by Weir (2009) [237].

Such processes are usually undertaken periodically or when distinct new risk sources emerge. The first step is often to identify perceived key food items (for example, products that are important for health and wellbeing and required frequently but which may show production bottlenecks or be import reliant, such as infant milk formula, milk and bread). The second step is often mapping, which can be visual, using Geographic Information System methodologies, and which aims to describe the scale and significance of each key foodstuff within the wider FSN, including its downstream dependencies, transport and control nodes and route to market. Validation is commonly achieved via stakeholder steering groups representing key supply chain actors important in delivering the types of products in question. Identification of vulnerabilities and their mitigation is often facilitated via wargaming activities, involving multiple internal and external stakeholders. In these wargames, likely high probability or particularly high impact scenarios are considered and the causal events and pathways are analysed in order to associate the most effective mitigation strategies. These are then validated via workshops of internal and external stakeholders for feasibility and effectiveness before being released as a final report of key vulnerabilities, pressure points and recommendations for mitigation strategies.

5.4.2 Business Continuity Management

Unlike ERM approaches which focus on identifying, mitigating and regularly reviewing all threats, BCM approaches prioritise only the protection of 'mission critical assets' and are used by both industry and Government in the UK [20]. BCM therefore can offer a much deeper analysis of specific disruptions but at the expense of the range of risks it encompasses. As with ERM this section of the review first considers Industry BCM approaches before turning attention to Government BCM approaches.

For UK FDMs, concerns about compliance, health and safety and brand reputation are major driving factors for BCM activities. The objective of BCM efforts in industry is to protect the well-being of the business, its customers, employees and shareholders. It is not undertaken for the wider public good as is the case in Government BCM approaches. BSI PAS 56 forms the main template for BCM in the UK AFSN, being used by a third of all stakeholders [20].

Evidence gathered by Peck (2006) [20] suggests that in a food industry context, this model would begin with the identification of key assets and activities and the identification of top risks facing those factors. Key assets are then assessed on their key performance indicators in the event of one of the identified risk scenarios in a wargaming style. The outcome of this process in line with PAS56 standards ideally includes the introduction of risk registers, the establishment of flexible response crisis management team and yearly BCM audits. Such teams would likely source members from those involved already in the Health & Safety and product traceability areas of major product lines.

BCM is also widely used by Government and in the UK, responsibility for managing substantial AFSN disruption falls primarily with the Local Government Authority (LGAs) in whose boundaries the disruption occurs in line with the Civil Contingencies Act 2004. BCM at an LGA level typically takes the form of five stages: Assessment, Prevention, Preparation, Response and Recovery Management [238].

1. Assessment

The assessment stage concerns identifying high probability risks for key services as well as worst case scenario events but is designed with flexibility in mind so that following stages are more easily transferrable.

2. Prevention

This stage cross references current practice with legislation, regulations, codes of practice and guidance documents, in order to ensure compliance and in doing so, aims to prevent many dangerous occurrences or reduce their severity.

3. Preparation

Preparation begins with the development of clearly defined response procedures to different scenarios to enable stakeholders at both an individual and organisation level to respond in a concerted manner. Training is then provided to all stakeholders and responses are regularly rehearsed.

4. Response

The aim of this stage is to establish the conditions by which the plan will be activated for each involved stakeholder. This is important because, disruptions might not always be catastrophic, but may instead be ‘creeping’ in onset (as described in Chapter 3) and so it might not always be statutory emergency services who determine when a contingency plan should be enacted.

5. Recovery Management

This stage encompasses the physical, social, psychological, political and financial responses to a disruption and how they can be anticipated and dealt with, particularly through the promotion of self-help activities for key local private and voluntary organisations.

This section concludes the review of methodologies used to measure and enhance resilience. The final section compares the strengths and limitations of the research methodologies identified in this chapter, alongside the conceptual and real-world research needs identified in Chapters 3 and 4 respectively, in order to set out a vision for the research methodology, conceptual framework and practical tool required to fulfil Research Objectives 2 and 3 of this thesis.

5.5 Resilience of UK FDMs-Conceptual and Practical Research Opportunities

The review chapters have identified a number of conceptual and practical considerations which are important if resilience is to be enhanced effectively from a FDM point of view. This section now presents the limitations in existing resilience theory from a FDM perspective (identified in Chapters 3 and 4) and the opportunities for the conceptual framework described in Thesis Research Objective 2 to address these. It also describes the limitations in approaches to measuring and enhancing resilience (identified in Chapter 5) and the opportunities for the practical tool outlined in Thesis Research Objective 3 to overcome these.

5.5.1 Limitations of Existing Conceptual Research and Opportunities for a Novel Food and Drink Manufacturer Conceptual Framework of Resilience

A number of works in the literature have proposed resilience definitions and the core components that should feature, such as the type or resilience (engineering, ecological or adaptive), the scope of what is being made resilient to what, and the phases of disruption that are being targeted (readiness, response, recovery and growth). However, definitions were often inconsistent and prioritised the economic performance of individual companies. For UK FDMs, a consistent definition which considers the importance of food at a food security level, as well as a company level, would be a useful starting point for developing a resilience strategy.

Based on careful analysis of the contemporary scope of operations of UK FDMs, Chapter 4 identified five categories of metrics, that when applied to an organisations supply network, can provide an indication of potential failure modes. These failure modes can then be used to provide a bespoke indicator of the vulnerabilities facing that company. However, few authors in the literature have proposed using failure modes to identify vulnerabilities as part of a resilience strategy and none have focussed on the food sector in specific. Therefore, there is a need for a FDM specific taxonomy of vulnerability sources, associated failure modes and metrics which can gauge an organisations exposure.

There is also considerable inconsistency in the literature concerning the resilience elements that would be used to mitigate these vulnerabilities. It would appear that many of those from disciplines such as ecological systems science and community resilience studies would be useful in an FDM context, but these are often inconsistent and do not have practical action associated with them. Therefore, there is a need of synthesis of the 34 identified resilience elements to remove inconsistency. There is also a need for the identification of measurable, FDM specific, actions for each. Furthermore, there is an opportunity for the development of a set of FDM specific KPIs in order to measure the impact of resilience elements, not just against their target vulnerabilities, but also on wider sustainability so as to ensure that the right resilience elements are being selected.

Finally, there is a need to conceptually link failure modes to specific vulnerabilities and vulnerabilities to resilience elements in a FDM context. This has been attempted by a small number of authors in the literature, but they only considered the relationships between resilience elements and vulnerabilities, and they were not systematic. More so, they were also not orientated towards food (which would have very specific vulnerabilities and corresponding resilience actions as befits its nature as unique organic resource with significant concerns for societal wellbeing).

5.5.2 Limitations of Existing Resilience Measurement/Enhancement Tools and Requirements for a Food and Drink Manufacturer Specific Practical Tool

Chapter Five identified that many of the methods described in the literature focus on modelling and validating resilience as a theory and are not designed to practically implement resilience strategies at an FDM level. Due to difficulties in obtaining data regarding resilience at a supply network level, it has been common to focus on mathematical and simulation modelling, but these often do not take into account the diverse conceptual background of resilience. Many tend to focus on a small number of resilience elements and their impacts on economic driven performance measures such as cost and time without consideration of environmental and social performance measures.

This is a major limitation, as much of the value of being able to map out bespoke vulnerabilities, link them to specific and appropriate resilience elements and then evaluate their impact on sustainable KPIs is lost. In terms of practical tools for implementing resilience, across both Government and Industry, the predominant approach was to incorporate resilience into existing BCM/ERM approaches. However, whilst both are extremely well established and standardised approaches, they also suffer from a simplistic approach to resilience consisting of using historical risk to identify primarily high likelihood vulnerabilities which is a limitation in conditions of volatility such as those being experienced by FDMs in current times. It would seem therefore, that there is a need to empirically identify which resilience elements, supply chain metrics vulnerabilities are and failure modes are relevant in describing a FDM's resilience and how they relate to each other in a novel conceptual framework. Following this, a known format such as BCM/ERM could be adapted to use this framework, thus adding conceptual specificity to a proven implementation method. This research opportunity is visualised in Figure 5.11.

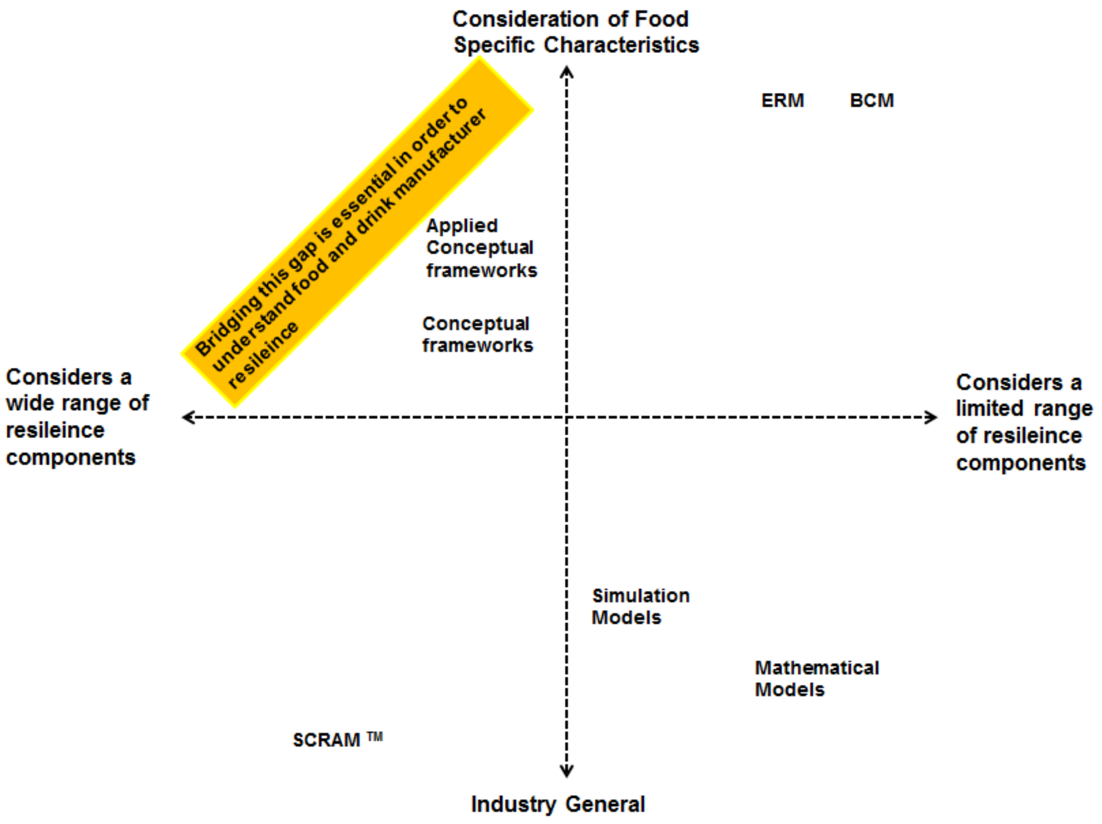


Figure 5.11: Limitations of current resilience modelling and enhancement techniques and opportunities for a novel practical tool

5.6 Chapter Summary

This chapter has addressed Thesis Research Objective 1C by reviewing the methods used by academia, industry and government to model resilience conceptually and to practically enhance resilience. The chapter also served to compare the limitations of the practical tools identified in this chapter, alongside the conceptual and real-world research needs identified in Chapters 3 and 4, to define the research gaps which Research Objectives 2 and 3 should aim to address. At a conceptual level, it was identified that there was a need clearly define UK FDM resilience and to empirically identify which resilience elements, supply chain metrics, vulnerabilities and failure modes are relevant and how they relate to each other. This will be achieved as pat of Thesis Research Objective 2 in Chapter 7. At a practical level it was identified that most tools were designed for academic modelling purposes, with the few practical tools being variations of ERM/BCM approaches. These typically use historical risk to identify high likelihood vulnerabilities and this is a limitation in conditions of volatility such as those currently being experienced by FDMs. Therefore, it is imperative that the practical tool developed as part of Thesis Research Objective 3 builds on tools like ERM/BCM by incorporating the food supply chain mapping approach outlined in Chapter 4, alongside the FDM specific conceptual underpinnings of resilience described above.

Chapter 6: Methodology

6.1 Introduction

This chapter describes how, building on the review chapter findings, a suitable methodology was constructed in order to allow this thesis to meet its research aims and objectives. It begins by describing the "Research Onion" framework which guided the design of the research methodology in this thesis. It then describes in detail the Research Philosophy, the Research Approach, the Research Strategy, the Research Choice and the Research Techniques. The chapter then describes the different phases of the research and represents these graphically. The chapter concludes by outlining the strengths and limitations of the chosen methodology.

6.2 Research Methodological Design

The research methodology in this thesis was based on the research onion developed by Saunders et al. (2009) [239]. Whilst the research onion originated in the social sciences, it can accommodate quantitative as well as qualitative goals and is adaptable enough to fit almost any type of research context. A major strength is that it is highly effective at linking broad concepts such as research philosophy impact on extremely precise factors such as research strategies and even data collection [240]. Whilst not commonly included in resilience research methodologies, it is important that philosophy does underpin how resilience is studied, because, as Chapter 5 identified, a key source of information will often be the subjective inputs of supply chain managers in addition to objective observations made by the researcher. Within the research onion, there are five core areas to be considered when developing an appropriate research methodology. These are the research philosophy (i.e. belief about the way in which data about a phenomenon should be gathered, analysed and used), research approach (i.e. whether a deductive vs. an inductive approach was used), research strategy (the practical investigative route chosen, e.g. case study vs. simulation), research choice (How to optimise the chosen strategy, i.e. mixed or mono methods) and ultimately, the research techniques employed (the specifics of how data was collected and analysed). These are represented in the 'Research Onion' shown below in Figure 6.1.

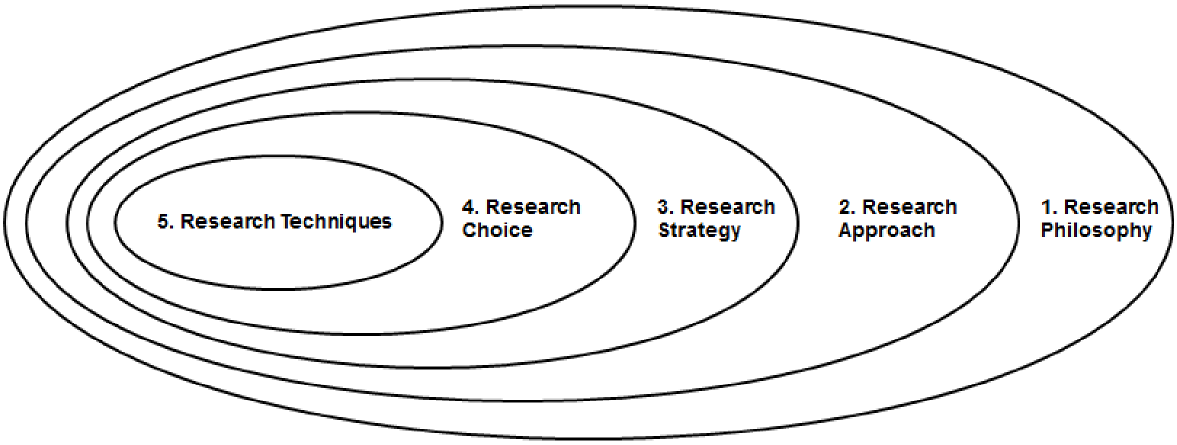


Figure 6.1: Aspects of Research Design. Adapted from Saunders et al. (2009) [239]

6.3 Research Philosophy

The research philosophy concerns both ontology, the branch of philosophy that deals with the nature of the world and its existence, and epistemology which refers to how best the nature of the world can be investigated. Both are important in determining the ultimate methodology a piece of research takes. There are generally accepted to be two opposing philosophical paradigms, positivism and constructivism [38]. The former assumes the existence of a world with properties that can be measured objectively and without associating values of desirability (for example, indicating if a given resilience element is good or bad). Constructivism on the other hand assumes that the world is constructed from the perceptions of myriad individuals. Clearly neither the positivist or constructionist paradigms are suitable platforms from which to approach the aim of this thesis which is to determine how resilience should be viewed as concept and enhanced in practice by UK FDMs. To do so requires an outlook which not only seeks to objectively identify the key physical determinants of resilience (such as supply network design and resilient practices), but which also considers the interactions between such determinants and their ultimate effect on the wider UK food system. For this reason, the research presented in this thesis has been built on a philosophy of ‘pragmatism’.

The Pragmatist core argument is that the research questions are the most important determinant of the philosophical stance taken by the researcher [241]. It proposes that a philosophical stance is only important as far as it is able to practically provide answers to a research question. As a result, tenants of both positivism and constructivism are valid depending on their ability to explain resilience in supply networks which are by nature, human as well as physical systems. Likewise, multiple methods of data collection, contrasting world views and data analysis approaches are all potentially valid depending on their fit to the research objectives.

6.4 Research Approach

The research approach refers to whether the research is deductive or inductive in nature. The most common approach to investigating resilience, at least in the supply chain management literature so far, appears to be deductive approaches whereby the prior literature and understanding of the researcher is used to develop a conceptual model and hypotheses that is tested empirically against real world observations. Examples can be found in the work of Jϋttner and Maklan (2011), Pettit et al. (2010) and Wieland and Wallenburg (2013) amongst others [46, 55, 111]. Deductive research often aims to advance existing theory and proponents argue that it enables the researcher to focus, something that is particularly important when investigating complex constructs such as supply networks where data can otherwise be voluminous [225].

Inductive research on the other hand begins with empirical observations first, in many cases with the researcher deliberately not researching the field beforehand so as to retain an open mind. Findings are then used to build new theory. Good examples can be found in the work of Peck (2005) and Carvalho et al (2013) [77, 217]. Proponents claim that it is useful in identifying perspectives on complex topics (such as SCRES) that are not considered in the existing theory [154]. For example, in the context of SCRES where the majority of research is from a supply chain management perspective which prioritises organisational competitive advantage in the form of time and money, perspectives about what makes the network resilient on wider social and environmental scale are often overlooked.

Based on the identified research gaps in Chapter 5, it was decided that a deductive approach was important because of the broad range of resilience definitions, elements and strategies which appeared to be useful for understanding food manufacturer resilience, but which also suffered from interdisciplinary inconsistency. However, a key aspect of the research aim in this thesis is also to understand not just what resilience is, but how and why an entity is, or is not, resilient. This required the freedom to accept that there might be contributing factors that are not presented in the existing literature/resilience theory. As such, whilst the design of this thesis is heavily deductive in the sense that the review chapter findings contributed heavily to the design of the conceptual framework in Chapter 7, findings from the Case Studies conducted in Chapter 9 were subsequently used to modify the framework retrospectively. Thus the approach used in this thesis is Abductive, in other words, a combination of inductive and deductive approaches to best tackle the identified research challenges, as outlined by the choice of Pragmatist philosophy in Section 6.3 [242].

6.5 Research Strategy and Choice

Following the principles of the research onion, research strategy can be guided by the research questions, the researcher's existing knowledge as well as the previously established research philosophy and approach. The review in Chapter 3 indicated that there was not only considerable inconsistency in the existing academic literature regarding resilience components and definitions, but that little research had focussed on UK FDM specific resilience. Furthermore, there was a need to develop resilience as a concept beyond models and frameworks into a practical tool that could be used by UK FDMs.

As such, there was a need for the research strategy to be multi-pronged, with the ability to not only systematically identify and synthesise existing knowledge on resilience as a concept, but to also to develop understandings of how resilience concepts interact with each other and the wider supply network in a real-world setting. Based on the review of suitable research strategies in Chapter Five, the most appropriate method for capturing the multidisciplinary breadth of the academic literature on resilience in a way that is thorough and replicable was the "Systematic Literature Review" (SLR) methodology. The SLR approach differs from more general literature reviews in terms of comprehensiveness (ensuring that all relevant material is included), specificity (identification of salient points through fit to carefully selected review questions), and transparency and replicability (adding reliability to findings)[211]. Crucially, the SLR approach also enables synthesis of ideas which not only aids wider scholarly dissemination of key concepts and advances the research field, but also effectively creates new knowledge, thus being of equal value to new research [61, 243].

In terms of the 'research choice' selection, it was identified in Chapter 5 that there was a need to not only to synthesise inconsistent resilience components such as failure modes, vulnerabilities and elements into FDM specific taxonomies, but also to identify the links between each pair of these components. Chapter 5 also highlighted that the nature of FDM organisations as a unit of study, meant that data could only be obtained by questioning industry experts [244]. This leant itself to the conceptual empirical approaches described in Chapter 5. However, quantitative approaches in the form of surveys were rejected on the grounds that there were too many variables between which relationships needed to be established to fit into a reasonable survey length. It was also recognised that given the complexity of the research topic, without the researcher present to guide the participant, it was unlikely that responses would provide the required qualitative depth. Out of the qualitative approaches available, the case study approach was chosen because it was most suitable for exploring a concept in its ‘real-world’ setting. This is because whilst interviews and focus groups are entirely dependent on the subjective opinions of the interviewee(s), case studies can be supplemented by a range of documentary evidence from the industry in question (such as internal strategy or process documents, supplier evaluation tools and supplier questionnaires or business continuity plans)[55, 135].

6.6 Research Techniques

This final section of the research onion concerns the way in which data was collected and analysed, both at a theoretical level in the initial review and hypothesis formation, and then later at the empirical validation stage of the research.

6.6.1 Theoretical Research Techniques

The conceptual methodology focussed around the SLR approach and largely followed that of Denyer and Tranfield (2009) [59], consisting of five distinct steps which are outlined in Figure 6.2. These steps are discussed in detail in Chapter 3. A key aspect of Steps 4 and 5 in the SLR approach is synthesis. Synthesis is typically employed when the source material range is heterogeneous, for example, stemming from multiple disciplines and with inconsistencies in terminology, and enables the identification of whether multidisciplinary sources are convergent, divergent or co-evolving. Findings can either be used aggregately to summarise a field, perhaps by enumerating common core concepts and using statistical methods to identify averages, or integratively, where similar but differently termed concepts are merged understandings to build a synergistic conceptual framework of the study subject. The research in this thesis was based on integrative, as opposed to aggregative synthesis, as evidence suggests it better suits heterogeneous source material [243].

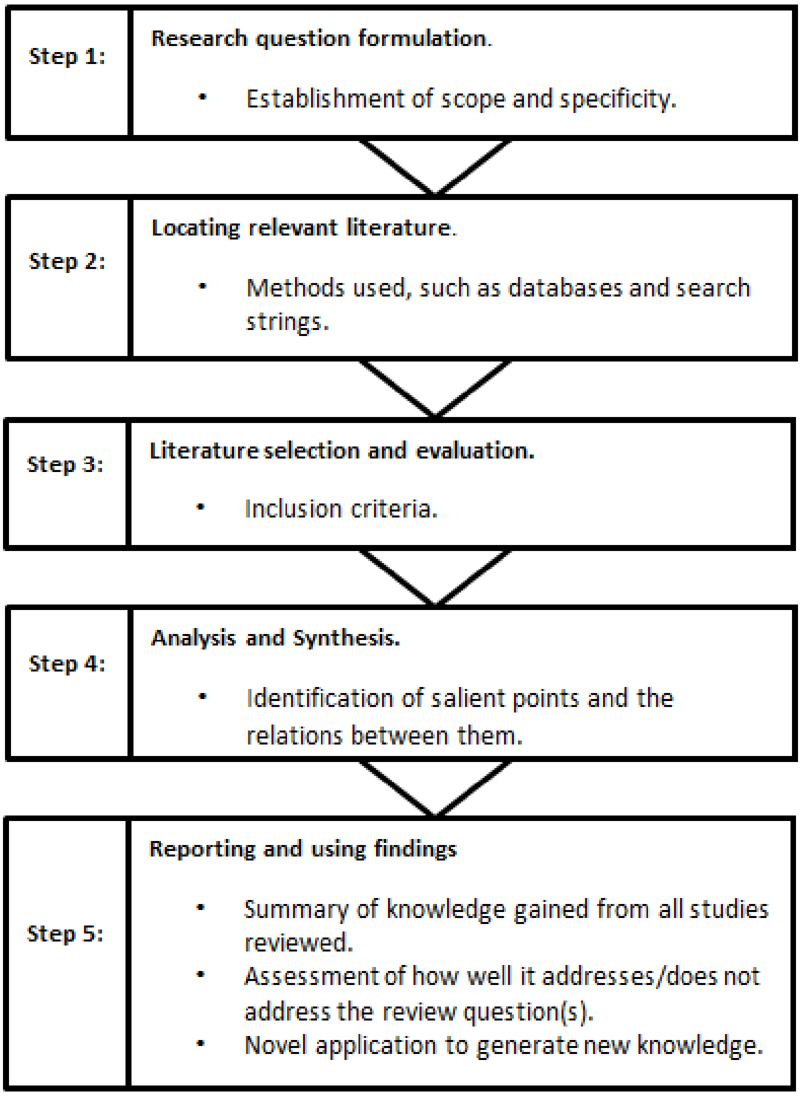


Figure 6.2: Systematic Review Methodology Adapted from Denyer and Tranfield (2009) [59].

6.6.2 Empirical Research Techniques

Case studies were selected based on a number of criteria. The first was the principle that multiple case studies (as opposed to one) should be performed on the basis that they reduce observer bias, necessitate a replicable process (thus enhancing the reliability of the findings) and finally, they aid analytical generalisation of findings which is a key aim of this research [239-240]. Moving beyond this, a key selection criterion was that FDMs must demonstrate significant production activities in the UK. As the aim was to represent the diversity of the UK Food and Drink Manufacturing Sector, cases were selected to provide a diverse mix of small to international scale manufacturers. Furthermore selections were made based where possible, on the criticality of foods produced to UK Food Security as identified in a recent House of Commons Select Committee Report [17]. Once these criteria had been taken into account, a shortlist of Food and Drink Manufacturers within the Engineering and Physical Sciences Research Council Centre for Innovative Manufacturing in Food (of which the author of this thesis is a member) and broader industry contacts of the author was constructed and companies were approached.

In terms of research ethics, the author deferred to the Loughborough University ‘research ethics checklist’ which contained detailed guidance on protecting human subjects from harm and deception, gaining informed consent from potential respondents, protecting vulnerable groups, and protecting privacy and confidentiality of information. As such, participant information sheets and consent forms were sent to potential participants prior to data collection. However, the main concern in this research was demonstrating to industrial collaborators that the potentially commercially sensitive information the case study sought would be well protected. This was achieved via the signing of non-disclosure agreements and the establishment of steps to ensure the secure storage of all data obtained in an anonymised form.

In terms of data collection itself, a semi-structured interview approach was developed on the premise that it enabled comparison between different case study findings but also that it allowed the opportunity for participants to contribute information, particularly on the relationships between framework constructs that the researcher might not otherwise have considered [247].

6.7 Research Phases

This section describes the way in which the aforementioned methodological design was applied to this research. Whilst it was established in Section 6.6 that a mix of less common research techniques were required to achieve both the necessary synthesis of concepts and the need for empirical exploration and validation, the methodology by which these techniques were actually applied was much more conventional. It was based on the four stage approach established by Greenfield (2016) [248] which consists of:

a) Formation of the research hypothesis and its conversion into specific aims and objectives.

b) Theoretical research where the existing theory is applied or adapted to provide a conceptual framework and possibly more specific models of the research problem and its components respectively.
c) Testing and validation of the theoretical framework via appropriate empirical means.
d) Analysis of findings, adjustment of theory accordingly and presentation of findings.

These four stages are now described individually and are represented in Figure 6.3. As Figure 6.3 highlights, this research was iterative and developments at each stage were constantly cross compared with earlier assertions, aims and objectives so as to ensure that the synthesised conceptual underpinnings of the research reflected real-world empirical observations.

6.7.1 Phase A: Research Hypothesis, Aim and Objectives

Following the recommendations outlined by Greenfield (2016) [248], the research hypothesis was based on a set of carefully formed research questions based on the author's previous knowledge and initial reading around the concept of AFSN resilience. These questions concerned what the unique causal vulnerabilities and actual failure modes facing UK FDM were in a globalised, lean setting and how they could be measured. They also concerned the various underpinnings of resilience as a concept, such as definitions, elements and strategy formulation that might be applicable to UK FDMs and how they were individually linked to the aforementioned vulnerabilities and failure modes. The final question area generated concerned the relationship between UK FDM resilience and their sustainability, not only as an individual organisation, but also as part of a wider supply network. The research aim and supporting objectives were developed to address these research questions.

The overall aim concerns the generation of a synthesised conceptual framework that is specifically tailored to UK FDMs and from this, the development of a set of practical tools which can guide UK FDMs in enhancing their resilience against specifically identified vulnerabilities. This is facilitated by a number of Thesis Research Objectives, the first of which concerned three linked literature reviews on resilience as a concept, its real-world considerations for UK FDMs and existing methods for its measurement and enhancement. The second Thesis Research Objective built on the findings from these reviews, in combination with industry interviews, to produce a comprehensive and synthesised conceptual framework to support UK FDM resilience.

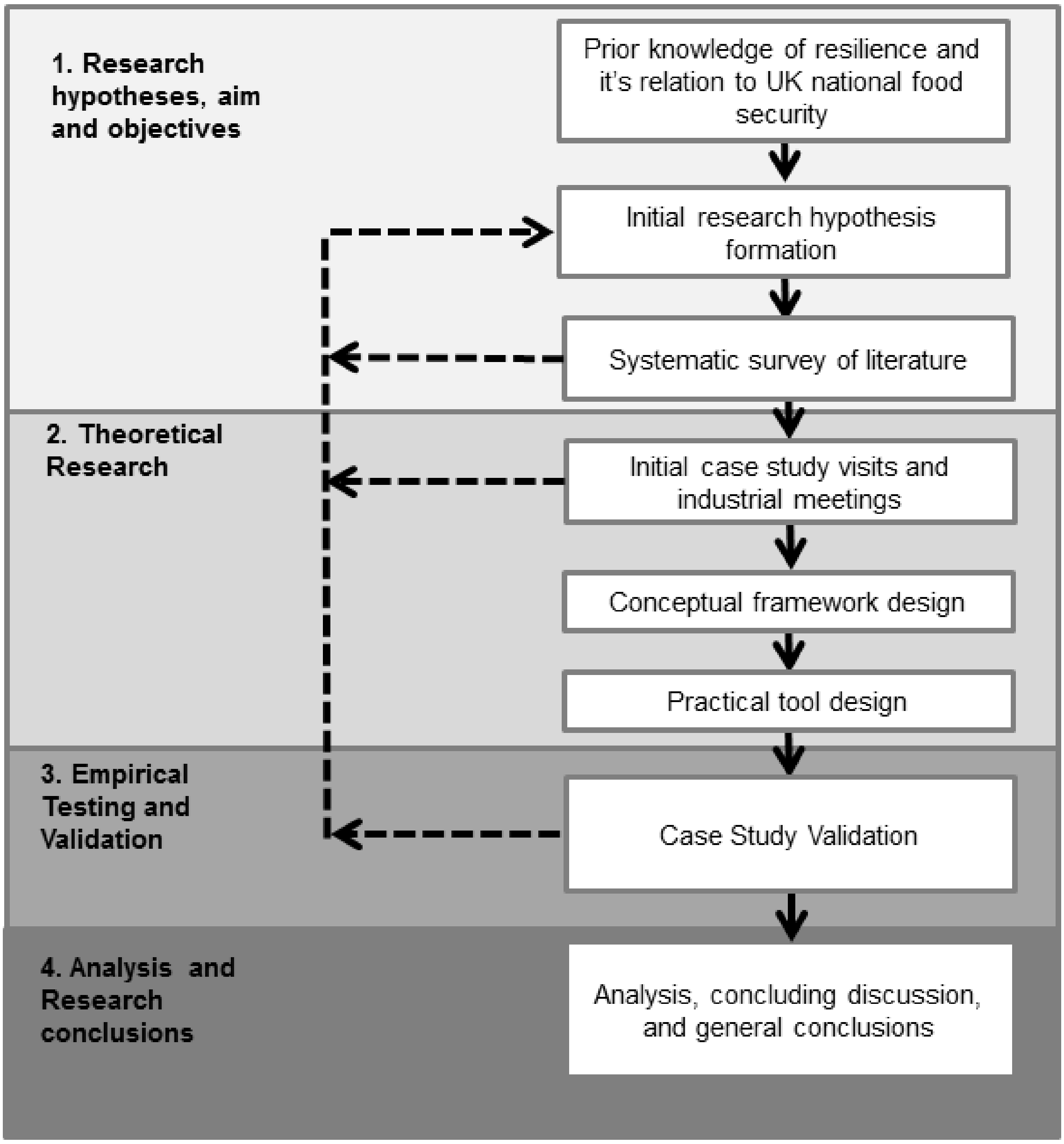


Figure 6.3: Outline of research phases involved in this thesis.

The third Thesis Research Objective expanded on this framework to develop practical tools, complete with relevant qualitative and quantitative metrics to guide UK FDMs in formulating resilience strategies. The final Thesis Research Objective involved the validation and development of this framework and tools via industrial case studies. The last component of phase A of the research was therefore to perform the three reviews, thus fulfilling Thesis Research Objective One. In line with the pragmatic research philosophy established in Section 6.3, the findings from each of the reviews not only ensured that the research questions, aim and supporting objectives were in line with the latest research in the field, but also were invaluable in identifying the appropriate methodological approaches and research opportunities for this thesis to pursue.

6.7.2 Phase B: Theoretical Research

The theoretical research occurred in two stages. The first was the development of a conceptual framework which described all of the key theoretical components of resilience (i.e. definition, failure modes, vulnerabilities, exposure metrics, resilience elements, and evaluation KPIs) and their inter-relations. Notably, it used the synthesis research technique described in Section 6.5.1 to address inconsistencies in defining resilience and in UK FDM appropriate resilience elements. By incorporating real-world UK FDM exposure metrics identified in Chapter 4 and also state of the art principles concerning resilience modelling and enhancement tools from Chapter 5, particularly in the form of the ISO 310000 framework, the conceptual framework formed the basis of the practical tool developed in Chapters 8 and 9. In parallel with the framework development, a number of private industrial visits were conducted to discuss the framework concepts and gain industry insight. This also acted as a trial run of the case study questionnaire, aiding in its refinement as recommended by Yin (2013) [225]. The second stage of the theoretical research concerned the development of a practical tool in the form of a workbook which provides the reference charts and relational matrixes, along with instructions on the collection of associated data, to enable the framework to be practically implemented by an industrial user.

6.7.3 Phase C: Empirical Testing and Validation

The third phase of the research involved the empirical validation of the conceptual framework and its derivative workbook tool kit via case studies with two carefully selected UK FDMs. This was achieved with semi-structured interviews and email requests for supporting data required by a questionnaire that was designed to mimic the workbook tool as closely as possible. The exception was that rather than the participant completing the questionnaire on their own as they would in the actual workbook, the researcher was able to probe for more information on many of the concepts, in line with the principles of the semi-structured interview process. The results generated were analysed and used to refine the proposed framework as well as to provide bespoke reports suggesting resilience priorities for each of the participants.

6.7.4 Phase D: Analysis and Conclusions

The final phase of the research methodology focused on analysis of the findings from the case studies and the use of these findings to evaluate the real-world applicability of the conceptual framework and practical toolkit (Thesis Research Objectives 2 and 3 respectively). Where possible, the conceptual framework and practical toolkit where enhanced based on these findings, in line with the abductive research approach of this thesis. Findings were also used to provide a number of key research conclusions regarding the nature of resilience in UK FDMs, as well as research limitations and opportunities for future work.

6.8 Limitations

A number of steps have been taken to ensure that the research contained within this thesis is both rigorous and replicable. In terms of the theoretical research, particularly the SLR process, established best practice in the form of the methodology developed by Tranfield and Denyer et al. (2003) was followed [211]. This involved thorough, multiple researcher validated selection of key words and search strings, across a thorough list of databases and time points so as to ensure the fullest possible range of literature was captured. Synthesis also followed established best practice in the form of Denyer and Tranfield (2006) [249]. This was integrative rather than additive in approach and involved the breakdown of different definitions of resilience and descriptions of resilience elements into coded keywords in an excel spreadsheet so as to enable cross comparison and merger where concepts were the same in practice but different in title, thus helping to overcome inconsistency.

For the empirical research, the case study technique selected also carefully followed the established doctrine laid out by Yin (2013) [94, 220, 243]. Part of this doctrine calls for the establishment of construct validity which is a measure of how accurately the measurements selected by the researcher actually reflect the problem being investigated. In the context of this research, this was achieved by developing an interview protocol based on a systematic review of the literature, piloting the protocol with colleagues who had relevant experience in the food and drink manufacturing industry, using multiple firms to reflect different perspectives of the UK FDM industry, as well as triangulation of data sources i.e. interviews, literature observation and company records. In addition, the transcribed case study findings were sent back to the interviewees for validation and where possible, multiple respondents were used to minimise bias in each company.

Further key aspects of this doctrine are internal validity (ensuring that relationships recorded between framework constructs are real) and external validity (ensuring that findings are generalizable). In both cases, this was achieved via the use of multiple industry interviews, pilot studies and case studies to enable cross referencing.

However, whilst the aforementioned measures have been put in place to ensure the reliability of this work against the context of its specific aim and objectives, it must be stressed that this is at heart an explorative piece of research aimed at providing understanding and guidance rather than an absolute tool. It is therefore anticipated that further quantitative investigations, based on the relational findings of this research, would help develop the applicability of this research at an industry level and pave the way for a more precise mathematical or statistical tool.

6.9 Chapter Summary

Based on the research aim and objectives of this thesis, supplemented by review findings in Chapters 3-5, this chapter has detailed the methodological approach used in this thesis. It has explored in detail the research philosophy, approach, strategy, choice and techniques used before describing the phases of research and limitations. The remainder of this thesis now proceeds to document the research findings, as described in phases Two, Three and Four of the research model presented in Section 6.6.

Chapter 7: A Conceptual Framework of Resilience in the UK Food and Drink Manufacturing Sector

7.1 Introduction

This chapter addresses Thesis Research Objectives 2 and 3, namely, development of a conceptual framework describing key conceptual components of FDM resilience followed by the development of a practical toolkit which can be used to apply this theory in a real-world setting. The initial section presents an overview of the entire framework, describing the purpose of each of the four component stages. Following this structure, the chapter then describes in detail the process involved in Stage 1 of the framework, concerning synthesis of a conceptual FDM definition of resilience and generation of a taxonomy of FDM specific KPIs by which resilience activities can be measured. This is mirrored by Stage 1 of the tool kit which describes practically how the conceptual definition and KPIs can be implemented in an industry context. The remaining stages of the framework and tool kit, which represent significant portions of the research in this thesis, are described in subsequent chapters.

7.2 Framework Purpose and Design

The framework primarily serves to fulfil Thesis Research Objective 2: "To synthesise the findings from Research Objective 1, in combination with industry interviews, to produce a comprehensive conceptual framework to support UK FDM resilience". However, the framework is more than just a summary of relevant resilience components as it also addresses a number of the research gaps described in Chapter 5 (Section 5.5), specifically:

- Synthesis of a novel definition of resilience for UK FDMs which considers the type of resilience sought (i.e. engineering, ecological or adaptive), what is being made resilient to what, and the stages of a disruption that will be targeted, with consideration for positive impacts on both company performance and its impact on wider food security.
- Synthesis of the 34 multidisciplinary resilience elements in Chapter Three into a UK FDM orientated taxonomy complete with practical actions for each element and the phase of disruption in which they should be employed.

- Integration of the food specific failure modes, vulnerability sources and exposure metrics identified in chapters 3-5 into a FDM sector specific vulnerability identification tool to overcome existing reliance on Enterprise Risk Management/Business Continuity techniques.
- Identification of the linkages between the each of the vulnerabilities that the above tool seeks to identify and specific countering resilience elements.
- Generation of a range of KPIs required to effectively evaluate the resilience elements based on their economic, environmental and social performance, thus helping to align resilience strategies with sustainability.

The second purpose of this Chapter is to achieve Thesis Research Objective 3: “To develop practical tools based on the framework, complete with relevant qualitative and quantitative metrics to guide food and drink manufacturers in formulating resilience strategies”. The discussion of current research limitations in Chapter 5 (Section 5.5) identified how existing methodological approaches to studying resilience were either not practical for implementation within an FDM (e.g. mathematical modelling and simulation) or lacked the required conceptual underpinnings to fully cover resilience (e.g. BCM and ERM). It also identified that, whilst some aspects of resilience could be objectively measured, others would be heavily dependent on the experience of industry experts. To achieve these requirements, the conceptual framework and toolkit were developed in parallel, with the tool taking the form of an empirical questionnaire, mirroring each of the stages of the conceptual framework. To aid this objective, the structure of the framework was based on the practical and proven design of the ISO 31000 ERM tool. The ISO 31000 tool allowed practical alignment of the conceptual components of resilience in an implementable manner as shown in Figure 7.1.

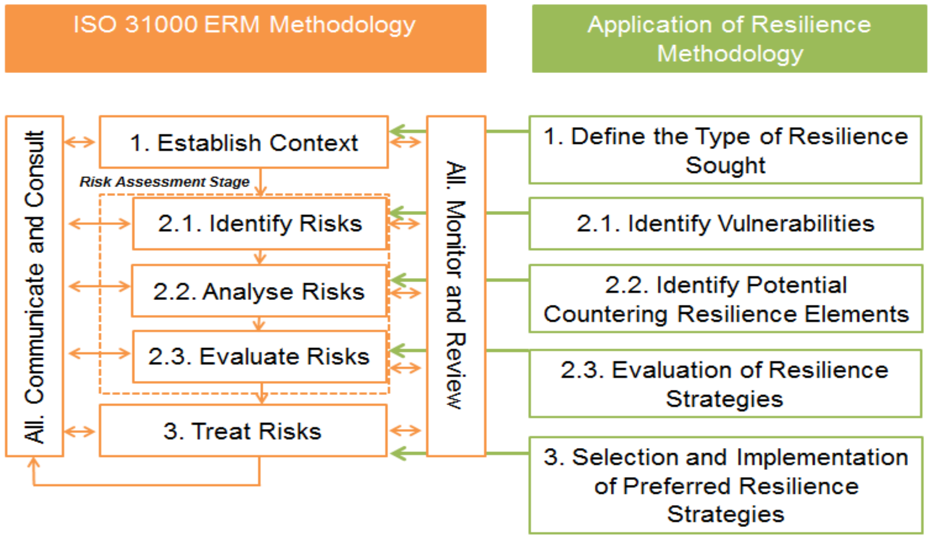


Figure 7.1: The relation between the ISO 31000 ERM framework and the resilience components identified as being important in Chapters 3-5

The ERM methodology was chosen over BCM because whilst both are well established in industry, BCM is focussed on mission critical assets only and whilst providing a highly detailed set of risks and contingency plans, evidence suggests it is also performed less frequently than ERM. It should be stated that the aim of using a similar framework is not to replace ERM processes within an organisation as the purposes of risk management and resilience are different. Risk management is an established field for identifying, characterising and mitigating known risks, whereas resilience is about building in capabilities that provide an organisation with flexibility to dampen the impact of unknown disruptions, as well as hastening recovery and strategic realignment with the post disruption operating environment.

The aim is therefore that the framework and tool kit presented in this thesis will supplement existing ISO 31000 models, enhancing the ability of UK FDMs to adapt to volatility, whilst utilising what is already well-known and effective process. With these considerations in mind, the conceptual framework is presented in Figure 7.2 and will from now on be referred to as The Food and Drink Manufacturer Resilience Framework, abbreviated to FDM-RES Framework.

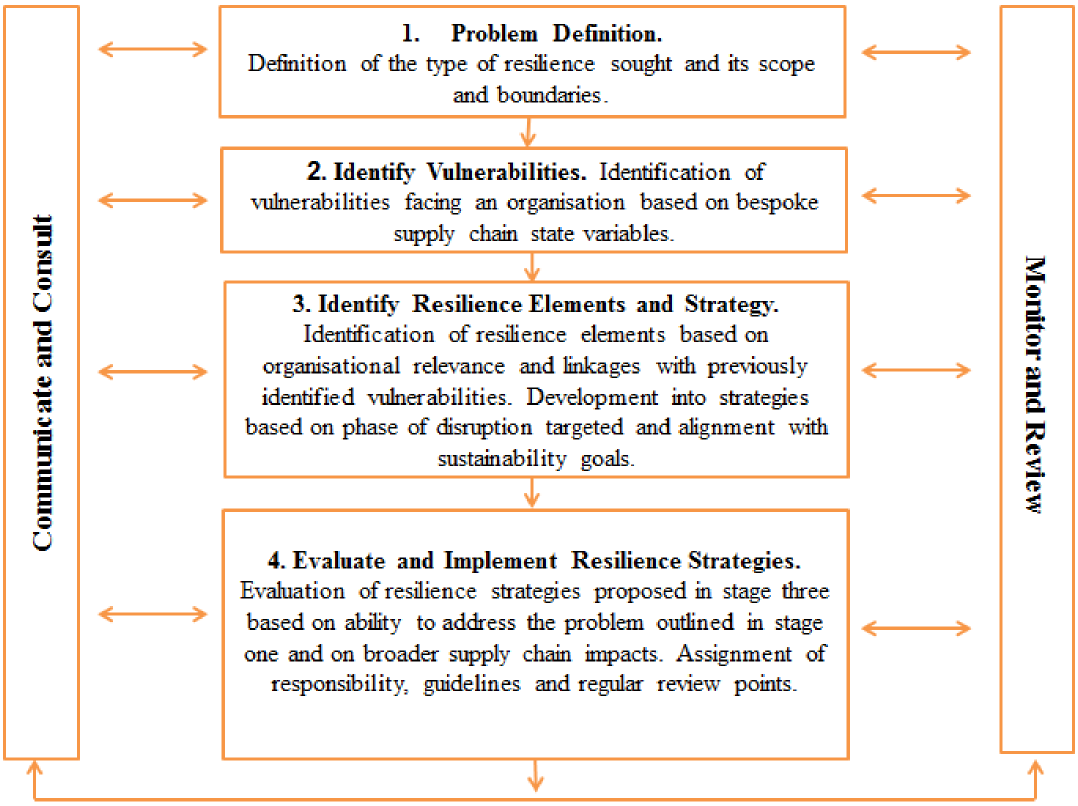
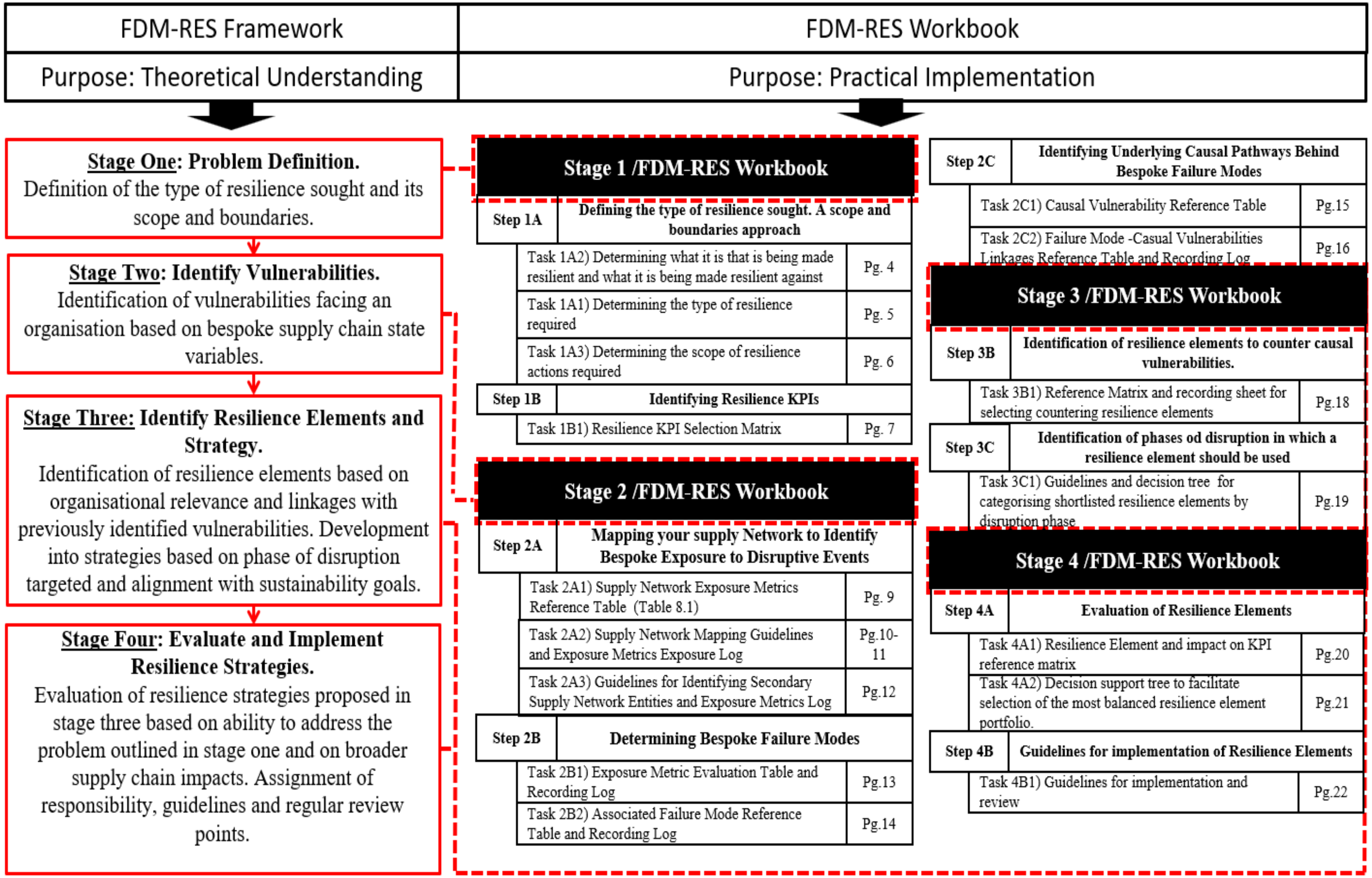


Figure 7.2: Proposed FDM-RES Framework.

The FDM-RES Framework presents the steps necessary to define resilience from a FDM perspective (Stage One), identifies how an FDM can identify specific vulnerabilities in real-time (Stage Two), establishes which Resilience Elements should, in theory, counter the identified vulnerabilities (Stage Three) and outlines the indicators which should in principle provide a measure of the effectiveness of the resilience elements, both in terms of economic performance and wider sustainability (Stage Four). Mirroring the conceptual FDM-RES Framework is the practical tool kit which provides the reference charts and relational matrices, along with instructions on their use and the collection of associated company data, to enable each of the four stages of the FDM-RES Framework to be practically implemented by an industrial user. This practical tool is referred to from now onwards as the FDM-RES Workbook. It's four stages directly mirror each of the four stages of the FDM-RES Framework as shown in Figure 7.3.

Figure 7.3 (Overleaf): Overview of the FDM-RES Workbook, and its parallel relationship to the conceptual FDM-RES Framework.


FDM-RES Framework
Purpose: Theoretical Understanding
FDM-RES Workbook
Purpose: Practical Implementation
Stage One: Problem Definition.
Definition of the type of resilience sought and its scope and boundaries.
Stage Two: Identify Vulnerabilities.
Identification of vulnerabilities facing an organisation based on bespoke supply chain state variables.
Stage Three: Identify Resilience Elements and Strategy.
Identification of resilience elements based on organisational relevance and linkages with previously identified vulnerabilities. Development into strategies based on phase of disruption targeted and alignment with sustainability goals.
Stage Four: Evaluate and Implement Resilience Strategies.
Evaluation of resilience strategies proposed in stage three based on ability to address the problem outlined in stage one and on broader supply chain impacts. Assignment of responsibility, guidelines and regular review points.
Stage 1 /FDM-RES Workbook
Step 1A
Defining the type of resilience sought. A scope and boundaries approach
Task 1A2) Determining what it is that is being made resilient and what it is being made resilient against
Pg. 4
Task 1A1) Determining the type of resilience required
Pg. 5
Task 1A3) Determining the scope of resilience actions required
Pg. 6
Step 1B
Identifying Resilience KPIs
Task 1B1) Resilience KPI Selection Matrix
Pg. 7
Stage 2 /FDM-RES Workbook
Step 2A
Mapping your supply Network to Identify Bespoke Exposure to Disruptive Events
Task 2A1) Supply Network Exposure Metrics Reference Table (Table 8.1)
Pg. 9
Task 2A2) Supply Network Mapping Guidelines and Exposure Metrics Exposure Log
Pg.10-11
Task 2A3) Guidelines for Identifying Secondary Supply Network Entities and Exposure Metrics Log
Pg.12
Step 2B
Determining Bespoke Failure Modes
Task 2B1) Exposure Metric Evaluation Table and Recording Log
Pg.13
Task 2B2) Associated Failure Mode Reference Table and Recording Log
Pg.14
Step 2C
Identifying Underlying Causal Pathways Behind Bespoke Failure Modes
Task 2C1) Causal Vulnerability Reference Table
Pg.15
Task 2C2) Failure Mode -Casual Vulnerabilities Linkages Reference Table and Recording Log
Pg.16
Stage 3 /FDM-RES Workbook
Step 3B
Identification of resilience elements to counter causal vulnerabilities.
Task 3B1) Reference Matrix and recording sheet for selecting countering resilience elements
Pg.18
Step 3C
Identification of phases od disruption in which a resilience element should be used
Task 3C1) Guidelines and decision tree for categorising shortlisted resilience elements by disruption phase
Pg.19
Stage 4 /FDM-RES Workbook
Step 4A
Evaluation of Resilience Elements
Task 4A1) Resilience Element and impact on KPI reference matrix
Pg.20
Task 4A2) Decision support tree to facilitate selection of the most balanced resilience element portfolio.
Pg.21
Step 4B
Guidelines for implementation of Resilience Elements
Task 4B1) Guidelines for implementation and review
Pg.22

The justification for choosing a workbook format, as opposed to, for example, a software database process, was that the linkages between the underlying vulnerabilities a company might identify in their supply chain and the countering resilience elements that company might select (as well as what to prioritise in their evaluation) would always be highly dependent on the individual knowledge and requirements of the user. This is more easily facilitated in a physical workbook than a software database where the options for input choices are constrained by the author's knowledge.

Section 7.3 now proceeds to provide an overview of the FDM-RES Framework and each of its four stages. After this, Chapter 7 will present Stage 1 of the FDM-RES Framework and the corresponding Stage 1 of the FDM-RES Workbook in full. Stage 2 of the FDM-RES Framework, which represents more substantial research, is covered in Chapter 8, along with the associated FDM-RES Workbook Stage 2. Stages 3 and 4 of the FDM-RES Framework are covered in Chapter 9, along with the associated FDM-RES Workbook Stages 3 and 4. The entire FDM-RES Workbook is practically applied to case studies with two UK FDMs in Chapter 10.

7.3 Framework Overview

The FDM-RES Framework consists of four principle stages, problem definition, identification of vulnerabilities, identification of countering resilience elements, and evaluation, selection and implementation of the preferred resilience strategies. In line with ISO 31000 principles, running parallel to the four core stages are the stages of 'communicate and consult' and 'monitor and review' which represent the fact that findings from each of the four stages must be effectively communicated and reviewed regularly. For simplicity, the stages of 'communicate and consult' and 'monitor and review' are effectively internalised within stages 1-4 of the FDM-RES Framework.

7.3.1. Stage 1: Problem Definition.

At a conceptual level, this stage serves to synthesise considerations regarding the type or resilience sought (engineering, ecological or adaptive), the scope of what is being made resilient to what, and the phases of disruption that are being targeted (readiness, response, recovery and growth). These are combined with considerations of the broader importance of food at a societal level to generate a unique FDM specific definition of resilience. This stage also serves as a foundation for Stage 1 of the FDM-RES Workbook because by defining the type of resilience they are seeking at a conceptual level, a company can establish what KPI's reflect this practically.

7.3.2 Stage 2: Identify Vulnerabilities

This stage concerns the identification of the vulnerabilities which the object of resilience (ranging from an entire company to individual assets) is most exposed to. This requires the ability to infer exposure from supply network surroundings and this is facilitated via the use of the supply network exposure metrics identified in Chapter 4. These are used to identify points at which a disruption could prevent any one of the KPIs identified in Stage 1 from being achieved- known as failure modes. From these failure modes, a profile of company specific underlying vulnerabilities can be identified.

7.3.3 Stage 3: Identify Resilience Elements and Strategy

This stage addresses how countering resilience elements can be selected to counter the priority vulnerability sources identified in the previous stage. Identification of potential resilience elements is guided by a comprehensive FDM specific resilience element taxonomy constructed using synthesis of the findings from the SLR in Chapter 3. Selection is further aided by established linkages between specific resilience elements and vulnerabilities observed in the literature. The resulting shortlisted resilience elements are then formulated into different strategy options based upon the phase of disruption in which they are intended to be implemented.

7.3.4 Stage 4: Evaluate and Implement Resilience Strategies

This stage concerns the evaluation of all of the identified potential resilience elements based on their impact on the KPIs identified in Stage 1 and therefore their ability to deliver the type of resilience sought. In this way, not only are the resilience elements selected the most appropriate for the actual vulnerabilities faced, but they are also the ones that are most cost effective for the company, and best aligned with existing sustainability objectives. This stage also concerns implementation of the chosen resilience strategy, involving the assignment of responsibility, the provision of guidelines and the implementation of reliable communication channels and regular review points. This helps to ensure the resilience process is adaptive, allowing stages 1-4 to be updated in line with the changing supply network operating environment.

This chapter now proceeds to detail stage 1 of the FDM-RES Framework and the mirroring FDM-RES Workbook section in full.

7.4 FDM-RES Framework Stage 1: Problem Definition

This stage of the framework consists of two steps, the first of which concerns the conceptual synthesis of a FDM definition of resilience and the second the development of a bespoke KPI taxonomy as shown in Figure 7.4.

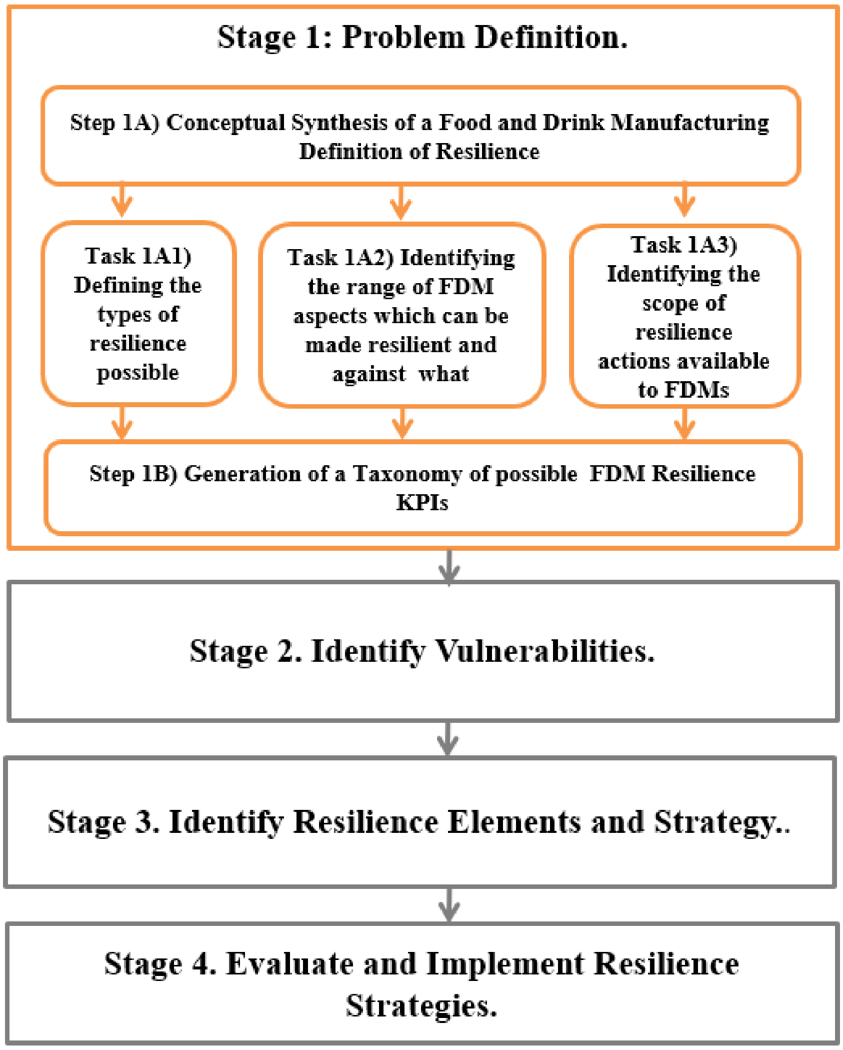
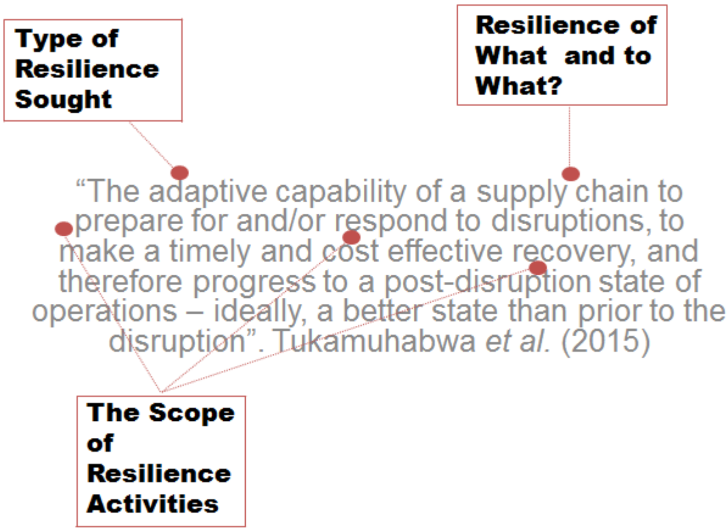


Figure 7.4. Stage one of the FDM-RES Conceptual Framework.

7.4.1 FDM-RES Framework Step 1A

Systematic comparison of 48 definitions of resilience in Chapter 3, from across multiple disciplines, identified three core components central to the majority of definitions. These were the type of resilience sought (i.e. Engineering, Ecological or Adaptive), the entity that is being made resilient (i.e. a product line, a facility, a company or a value chain) and the scope of resilience activities (i.e. in preparation for a disruption, in response, in recovery or in adaptation). These are captured in the comprehensive definition, provided by Tukamuhabwa et al. (2015) [38]:



7.4.1.1 FDM-RES Framework Step 1A1: Type of Resilience

What is meant by the type of resilience a definition refers to is to which of three paradigms, either the engineering, ecological or adaptive paradigm, that the definition adheres to.

In the Engineering definition of resilience, resistance to disturbance and the speed by which the system returns to its pre-disruption state are the main objectives [83]. This definition is often used to describe systems which have a single relatively static function. From a food manufacturer's perspective, this this definition could be applied to a highly specialised production line, producing only a very narrow range of products to tight specifications and for which there is very limited potential to change the input material, process or product [87]. Therefore, resilience is only concerned with reducing the risk of disruption in the first instance and minimising the cost and time of recovery.

The Ecological definition of resilience on the other hand, considers that in some situations, a disruption might be significant enough that it forces a company to change its operations if it is to maintain core functions [25]. For example, it might force a change in raw material or production process depending on whether the disruption knocks out a key supplier of whether it occurs in the manufacturers factory. Whilst this disruption might be negative, for example by reducing product margins, it might also be positive, for example, replacement machinery for an old production line disrupted by fire might actually be more efficient [77]. Therefore, the priority of ecological resilience is to be able to identify potential disruptions in advance and plan to adapt operations smoothly rather than being forced to change on the spot by an unanticipated disruption.

The Adaptive definition of resilience proposes that interactions between different scales (for example, from individual species, to forests, to entire ecosystems), time periods and geographic distances all drive constant change [86]. In AFSCs these different scales are analogous to interactions between actors at different stages of a value chain (e.g. producers, retailers and even suppliers of suppliers or providers of infrastructure), acting at different time points (for example, the growing season is often far out of synchronisation with manufacturing cycles) and at different global locations, creating significant complexity and uncertainty [75]. As such, disruption is constant and there is unlikely to be an optimal one-off fix that brings resilience as in the engineering and ecological definitions. Rather, resilience is achieved by a series of constant, smaller scale adaptations in response to ongoing disturbances. The principle is that such a system will be inherently more synchronised with changes in its external supply network and much more effective in its own responses to disruptions, so that when disruptions do occur, they are likely to be less severe. In other words, an adaptive definition emphasises that resilience must be seen as a cumulative response, increasing in line with experience gained from continuous disruptions, whilst the engineering and ecological definitions see resilience as one-off fixes (See Figure 7.5).

7.4.1.2 FDM-RES Framework Step 1A2: Resilience of What and to What?

Distinguishing what is the subject of resilience and what negative event it needs to be made resilient to, is a key aspect of defining resilience.

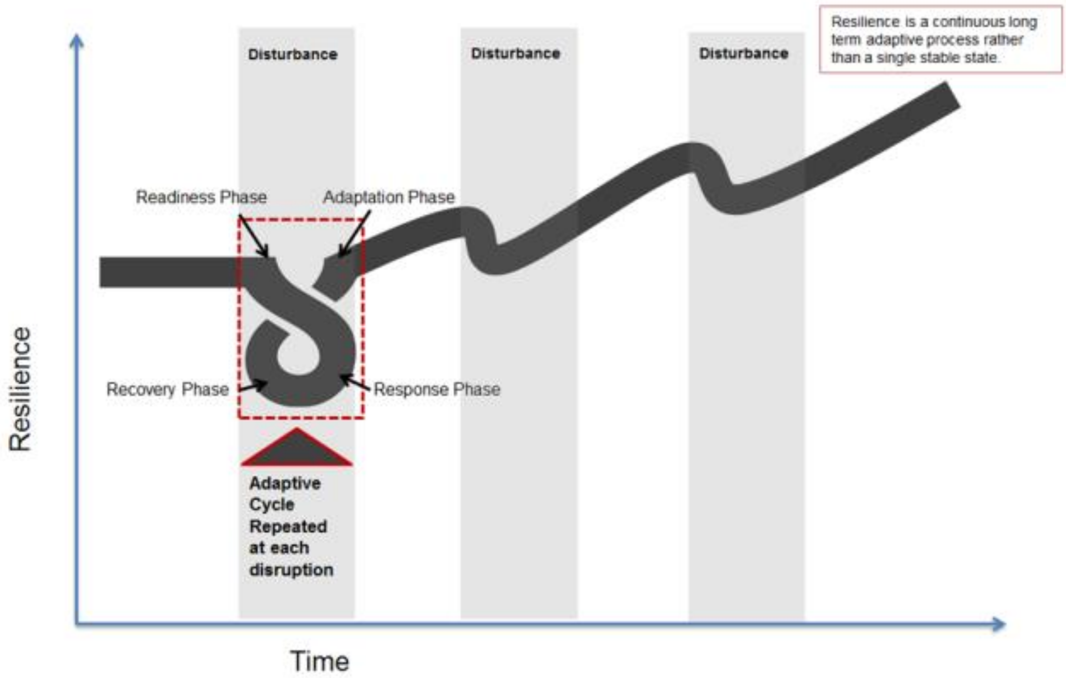


Figure 7.5. Resilience as a cumulative concept

Nearly all of the definitions reviewed in Chapter 3 made some reference to what it was that was being made resilient and what the perceived antagonist was. However, many were very general, commonly citing "supply chain" and "disruption" respectively. However, when considering FDMs, "supply chain" could refer to various scales, from a single product line, to a single site within an organisation, all the way up to an organisation itself, its entire value chain, or even a national food system. Similarly, "disruption" may refer to anything from a common fault in a product run with relatively minor impacts that are more of a nuisance than a major threat all the way up to catastrophic events such as site fires and terrorist incidents. There is therefore a real need for an actor to precisely define what it is that they wish to make resilient and to what.

7.4.1.3 FDM-RES Framework Step 1A3: Scope of Resilience

The types of resilience elements that are used in the event of a disruption can be categorised in terms of when they are best used in relation to a disruptive event. Some resilience elements are used in 'readiness' to anticipate disruption and either prepare for it or avoid it. Others are used in 'response' to mitigate the impact of a disruption as it happens. 'Recovery' elements prioritise ability to repair losses caused by a disruption and return to meeting core priorities. 'Growth' elements focus on learning from and adapting core priorities post disruption so that competitiveness actually improves compared to pre-disruption levels. From this point forward, the ‘Growth’ phase will be referred to as the ‘Adaptive Phase’ to reflect the principle that resilience in FDMs is primarily concerned with the ability to retain the core function of food provision in an ever-changing operating environment rather than economic ‘growth’ alone.

Defining which phases you need to target as an organisation is useful, because many resilience elements can only be used in certain phases, for example, the resilience element of ‘early warning detection systems’, can only be used in the preparation phase of a disruption. Whilst Chapter 3 identified that it was common for authors to consider the response and recovery phases only, these phases are limited to the engineering definition of resilience. For the ecological and adaptive definitions of resilience, a company has to be able to anticipate disruptions and to adapt to the new post-disruption operating environment respectively, thus necessitating the use of the readiness and adaptive phases.

7.4.1.5 Synthesis of a conceptual FDM Definition of Resilience

Based on the discussion so far, a definition of resilience from a food and drink manufacturer perspective must consider the type of resilience which best suits the company’s current priorities, the object(s) which is being made resilient and the scale of vulnerabilities targeted (internal, value chain, or wider operating environment) and also where in the timescale of a disruption resilience interventions should be targeted. These considerations will also be heavily influenced by economic pressures such as tight margins resulting from fierce inter-value chain competition, in addition to social pressures, such as the need to maintain supply of key commodities such as bread and infant milk formula, regardless of disruption, because they are so vital to public health and wellbeing. This presents the potential for conflict. For example, if a product is of national importance in its current formulation yet economic viability calls for substantial reformulation.

Furthermore, because modern AFSCs so complex, involving myriad bio-geophysical, social, economic and political drivers and feedbacks, they are effectively constantly evolving, presenting ever changing vulnerabilities and opportunities. As such, resilience can only be obtained by constant and cumulative interventions, as opposed to one off solutions.

Therefore, the following definition of FDM resilience is proposed:

The ability of Food and Drink Manufacturers to evolve in line with constantly changing operating environments, to the effect that the core functions of economic advantage and also the continued provision of key public food supplies, of the correct quality and volume and at the required times and locations, are buffered against all disruptions, whether anticipated or not. Depending on what aspect of a food manufacturers operations are to be made resilient, this may be achieved via resilience elements which facilitate the accurate anticipation of disruptions and postponement of their impact, and which enable rapid recovery in addition to the ability to actively learn from each disruption so that resilience is cumulative rather than reactive.

This definition incorporates the three key concepts of resilience which were: a) resilience of what to what, b) the type of resilience sought and c) the scope of resilience activities. It does this by specifying the core functions to be made resilient, emphasising the need for an adaptive type of resilience and also detailing the different phases of disruption against which resilience actions should be directed. In particular, the 'what' that is being made resilient can reflect both economic competitiveness and food security, thus offering a much more specific fit to UK FDMs than traditional 'growth' focussed definitions of resilience.

7.4.2 FDM-RES Framework Step 1B

The final aspect of stage 1 of the FDM-RES Framework is to establish the metrics by which the identified resilience is measured. In line with findings in Chapter 3 (Section 3.4.4.2) such metrics should also act as the "state variables" that allow the impacts of "Capacity to Respond" (i.e. resilience elements) on system performance and crucially, sustainability, to be assessed [90]. The performance measures must therefore capture more than simply economic impact and instead, should cover social and environmental performance too and be specific enough to be useful at an FDM setting (unlike the broader systems level sustainability KPIs discussed in Chapter 3).

Therefore, there was a need for consolidation of non-sector specific industry resilience KPIs identified in Chapter 3, with FDM specific KPIs identified in Chapter 4 and private discussion with industry partners. The resulting taxonomy of FDM resilience KPIs presented in Table 7.1 and its later application in the case studies in Chapter 10 therefore represents a novel development in the field of SCRES.

The aim of this taxonomy is not to be a comprehensive synthesis of all FDM relevant KPIs and nor is it to be a measurable tool. This is because many FDMs will already have highly comprehensive lists of KPIs which are specific to their operations. Rather, the purpose of the taxonomy presented in Table 7.1 is serve as thorough yet high level guide to which companies can align their own more specific KPIs. The advantage is that following this guide will allow framework users to see how the commonly used economic indicators align with associated sustainability indicators, thus helping to ensure that resilience goals and broader sustainability are aligned. As such, the framework is not intended to guide physical measurement of KPIs, rather it is designed to guide organisations in identifying which of their own KPIs are priorities for the entity being made resilient so that in Stage 3 of the FDM-RES Framework, when resilience elements are selected, they can be evaluated on their ability to deliver these KPIs as well as, crucially, their wider sustainability impact.

The taxonomy was constructed using the common economic KPI categories of Cost, Service Level, Efficiency and Quality [88, 128, 251]. Each of these four categories can be considered in an economic, social and environmental sense. For example, the cost of utilities (such as water, energy and waste disposal) can be considered in financial terms as well as the societal impact of how these resources are generated and disposed of, and the environmental impact. As such, where possible direct links between economic, social and environmental KPIs have been indicated by locating them next to one another (reading left to right). However, it is broadly intended that any KPI chosen in one category, such as cost, would consider all of the cost associated KPIs in the remaining two pillars.

When designing the sub-pillars of KPIs for each category in the taxonomy of KPIs in Table 7.1, a number of well-known industrial standards such as the IS0 series, i.e. quality (ISO 9000) [252], environmental (ISO 14000) [253] and occupational health and safety (ISO45001) [254] management systems and the Global Reporting Initiative sustainable indicators reference list were used [255]. The aim is that this will increase the familiarity and relevance of KPI categories for FDMs. Furthermore, by cross referencing these against a range of FDM specific works in the literature on sustainable KPI's, the taxonomy in Table 7.1 is also FDM specific too [13–18].

Table 7.1(Overleaf): Food and Drink Manufacturer Resilience Key Performance Indicators

KPI	**KPI Pillar: Economic (E)**	**Metric**	**KPI Pillar: Social (S)**	**Metric**	**KPI Pillar: Environmental (ENV)**	**Metric**
Cost (C)	**(CE1**) Raw Material Cost	Price (£) per unit	**(CS1)** Human Rights Standards of Suppliers	Presence of policies prohibiting slave/child labour and preventing discrimination	**(CENV 1)** Environmental Standards of Suppliers	Investigation of suppliers for adherence to third party accredited environmental standards.
	(CE2) Utilities cost (water, electricity, gas, waste disposal)	Price (£) per unit	**(CS2)** Social impact of utility generation and disposal	Impact of water extraction and air emissions on local communities, , jobs created, aesthetic impact on local communities	**(CENV 2)** Environmental legislation compliance	Maintenance of sourcing and emissions compliance with all relevant legal standards.
	(CE3) Inventory Carrying Cost	Price (£) per unit	**CS3)** Job Satisfaction	Hours spent doing repetitive work		
	(CE4) Spare Capacity Cost	Price (£) per unit				
	(CE5) Staff Cost	Cost (£) per our overtime	**(CS4)** Fair Salary	Measured by **(£)** above minimum wage equivalent	**(CENV3)** Natural Capital Valuation	The presence of policies which, in addition to economic value of raw materials, also consider ecosystem services.
	(CE6) Gross Value added	Value (£) added to finished goods compared to raw material total value	**(CS5)** Labour Relations	Presence of strategies for good relations with bodies representing labour, where applicable.		
	(CE7) Market Concentration	% market share per product type.	**(CS6)** Regional employment	Measured by % regional employment	**(CENV4)** Environmental risk management procedure	Measured by the presence and implementation of environmental risk factor checks.
	(CE8) Profit margins	Value added minus overheads.				
	(CE9) Net Profit	Annual profits (£)	**(CS7)** Philanthropy and Local Community Investment	Scope (£ invested) and effectiveness of in-kind contributions, volunteer initiatives, knowledge transfer and partnerships that enhance local communities		

Service Level (SL)	**(SLE1)** Order Fulfilment Time	Measured by average hours taken for order to be fulfilled.	**(SLS1)** Regular Review of Worker Rights	Measured by the presence of regular audits to ensure compliance with worker rights legislation and third-party accreditation	**(SLENV1)** End of Life Planning and Circular Economy	Measured by the presence of sustainable design initiatives (for example, % renewable resources used), environmental impact through production, distribution, use and recycling of the product (for example emissions) and planning for end of life (e.g. recyclable and biodegradable materials, redistribution schemes and manufacturer take back schemes).
	(SLE2) Contract Fulfilment	Measured by the number of units delivered in relation to the contract requirements				
	(SLE3) Customer Responsiveness	Measured by the speed in hours at which a manufacturer can respond and complete customer requests for changes to order types/volumes	**(SLS 2)** Occupational Health and Safety	Measured by the number of avoidable accidents in a single year		
			(SLS 3) Employee Diversity: and Equal Opportunities	Measured by the ratios of Ethnicity and male to female employees (%)		
	(SLE4) Customer Satisfaction	Number of complaints as a ratio of completed deliveries per year	**(SLS 4)** Corporate Attitude to risk management	Measured by the presence of organisational Enterprise Risk Management and Business Continuity programmes and their consistency with recognised accredited schemes (i.e. ISO)		
	(SLE5) Traceability of incoming raw materials and outgoing produce	Measured by the granularity with which deliveries, both inbound and outbound can be tracked				
Efficiency (E)	**(EE1)** Raw Material to Finished Product Conversion Rate	Measured as percentage of raw materials by volume that are present in the finished product	**(ES1)** Employee Appraisal and Development Systems	Measured by training and evaluation schemes for employees that match the likely rotations of that staff member and present clear progression routes	**(EENV1)** Energy, Water and Raw Material Efficiency During Manufacturing	Measured by the average intake per ton of product
					(EENV2) Emissions Related to Manufacturing	Measured by the average air, water and disposal emissions released per ton of product and packaging
	(EE2) Employee productivity	Measured as a percentage compared to average employee productivity	**(ES2)** Average Employment Retention Rate	Average stay length (months)		
			(ES3) Corruption	Measured by surveys investigating internal tolerance		

				levels		
Quality (Q)	**(QE1)** Safety of Goods	Measured by the percentage of restricted substances per product.	**(QS1)** Health and Nutrition of Goods	% products manufactured in sites certified according to internationally recognized food safety management system standards. % total sales where efforts have been made to lower saturated fat trans-fats, sodium and sugars.	**(QENV1)** Animal Welfare	Measured by the presence of independently accredited supplier guidelines for animal husbandry and response protocols to animal illness
	(QE2) Shelf Life	Suitability of shelf life in relation to customer demands. Measured by units that pass their shelf life without being sold				
	(QE3) Product Reliability and Convenience	Measured as percentage defects per 1000 units as well as by the % profits reinvested in R&D	**(QS2)** Private labelling standards that go beyond legislative requirements	Active communication to consumers about ingredients and nutritional information beyond legal requirements	**(QENV2)** Production Certification Schemes that go beyond legislative requirements	Measured by soil degradation, biodiversity loss and deforestation associated with all company activities beyond immediate suppliers.
			(QS3) Societal benefit of product	% products that contain increased fibre, vitamins, minerals, phytochemicals or functional food additives		
			(QS4) Smell and Noise Reduction	Measured by the presence of engagement with local communities and efforts to act upon feedback to reduce problem issues such as smell and noise if necessary	**(QENV3)** Presence of emissions reduction and resource efficiency enhancement targets	Measured by the presence of written and binding targets to reduce emissions (pollutants and GHGs) and enhance resource efficiency (water, raw materials and energy) by an achievable % compared to baseline emissions

7.4.3 FDM-RES Workbook Step 1A

Step 1 of the FDM-RES Framework has facilitated the generation of a conceptual definition of resilience for FDMs and created a taxonomy of FDM specific KPIs needed to measure resilience effectiveness. Step 1 of the FDM-RES Workbook now considers how these concepts would be practically applied in a workplace setting with the goal of enhancing company resilience, following the process outlined in Figure 7.6.

7.4.3.1 FDM-RES Workbook Step 1A2

From the scope of FDM activities discussed in Chapter 4, it can be inferred that there are five broad types of entity which a FDM may wish to enhance the resilience of. These are:

a) A specific product line within an organisation

b) A specific asset owned by the company, such as a factory.

c) A specific operation within a company, for example, chilled fresh foods

d) The entire organisation

e) A collaborative venture with strategic partners to enhance the resilience of an entire value chain

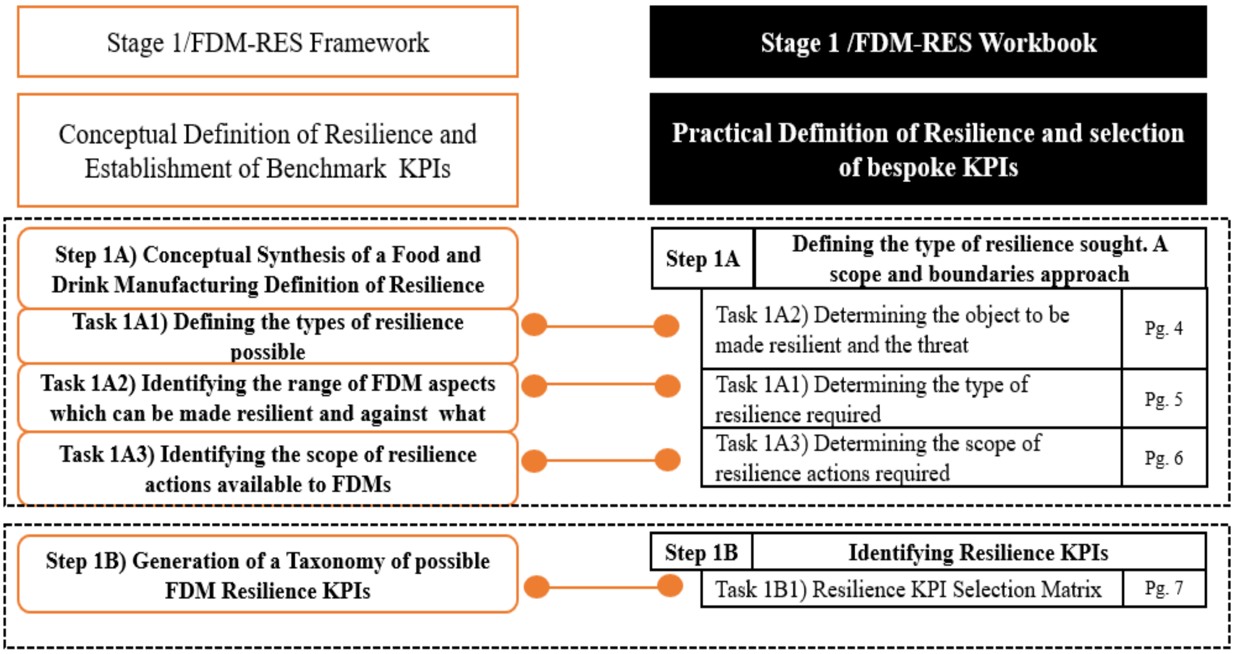


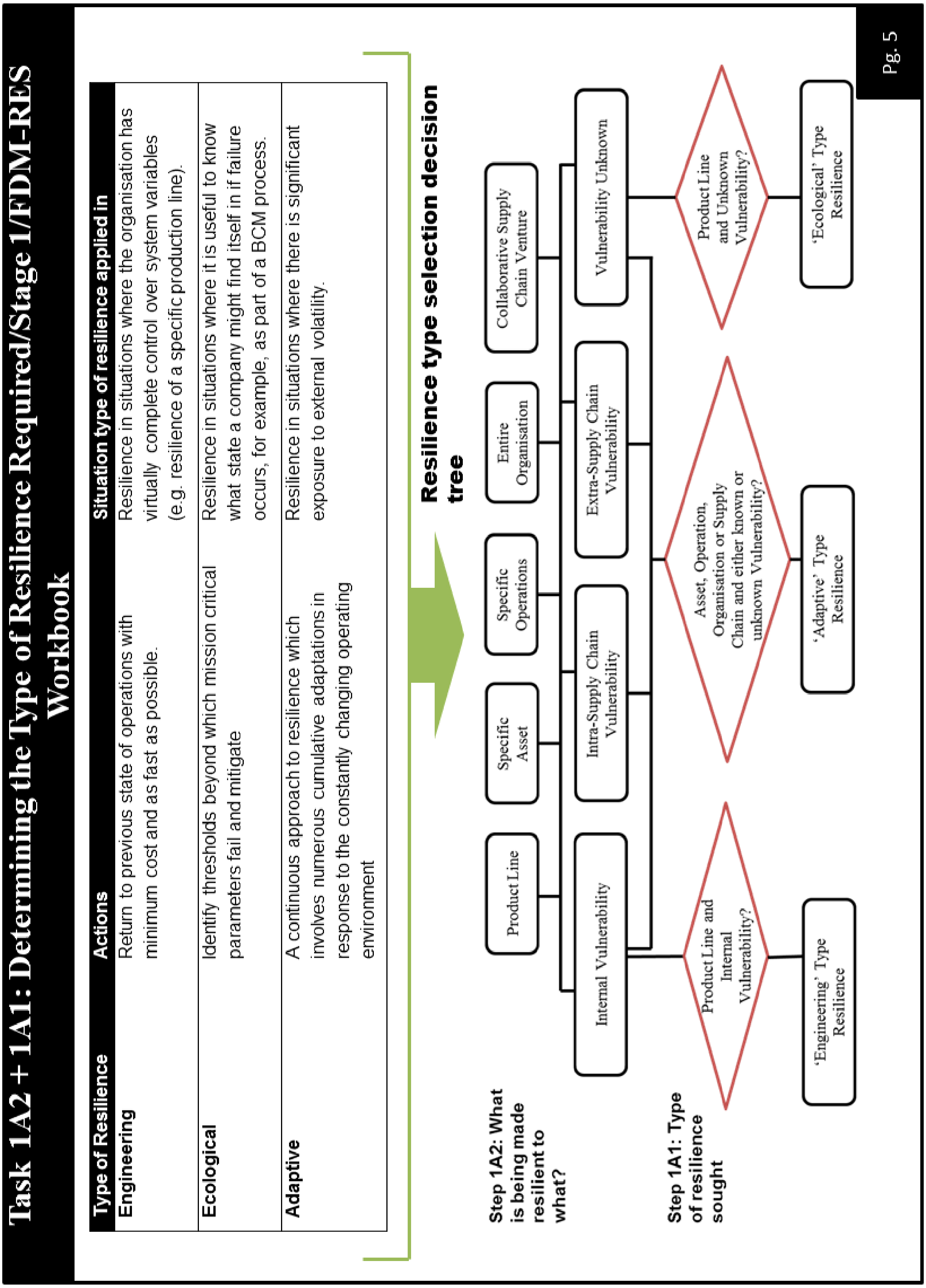
Figure 7.6: FDM-RES Workbook Stage 1 Overview.

It is feasible, even at this early point in the framework implementation, that the FDM in question may have a good idea about the type of negative event that they are attempting to address. For example, it might be a known disturbance (more mundane than disruptions and unable to cause serious failure alone, e.g. persistent fault rates) that is potentially costly, inefficient and even indirectly exacerbating exposure to disruption elsewhere. It might then be possible to filter the source of vulnerability so as to assist the process in Stage 2. Such sources may be either internal sources (problems within the organisation itself), value chain sources (vulnerabilities arising from a specific value chain) or wider operating environment sources (vulnerabilities stemming from indirect company exposures such as market forces, government policy and environmental events.

7.4.3.2 FDM-RES Workbook Step 1A1

Step 1A1 concerns which of the ‘Engineering’, ‘Ecological’ or ‘Adaptive’ types of resilience are most appropriate given the circumstances of the FDM completing the FDM-RES Workbook. For example, if the object to be made resilient is a production line and the vulnerability sources are internal to the company, for example, machine fault rates, and therefore relatively controllable, a company may decide the engineering definition of resilience is appropriate. Equally, if the object being made resilient is relatively shielded from exposure, again, such as a production line and the company does not have a clearly identified vulnerability in mind, then they may choose the ecological definition of resilience. However, it is likely that for any item being made resilient that is more exposed to the outside operating environment, such as facilities and whole operations, regardless of whether the vulnerability is known or not, that an adaptive definition of resilience will be most effective. These decisions are summarised in the workbook example provided in Figure 7.7, which highlights the decision process involved in identifying the type of resilience required.

It must be stressed that whilst theoretically there might be situations where a company feels it has high enough level of control over external influences that the engineering definition is favourable; in practice it can blind an organisation to changing operating environments. Using a simple example, if a company has a highly efficient production line for making potato fries and it encounters a supply disruption, the engineering definition would prioritise finding another supplier as quickly as possible. However, in the meantime, much more efficient varieties of potatoes might have entered the market making the manufacturers process sub-optimal compared to competitors.



Task 1A2 + 1A1: Determining the Type of Resilience Required/Stage 1/FDM-RES Workbook

Type of Resilience	Actions	Situation type of resilience applied in
Engineering	Return to previous state of operations with minimum cost and as fast as possible.	Resilience in situations where the organisation has virtually complete control over system variables (e.g. resilience of a specific production line).
Ecological	Identify thresholds beyond which mission critical parameters fail and mitigate	Resilience in situations where it is useful to know what state a company might find itself in if failure occurs, for example, as part of a BCM process.
Adaptive	A continuous approach to resilience which involves numerous cumulative adaptations in response to the constantly changing operating environment	Resilience in situations where there is significant exposure to external volatility.

Figure 7.7: FDM-RES Workbook example of the decision tree guiding the practical identification of the type of resilience sought by a user.

The same principle underpins the ecological definition too, in that clinging to one way of doing things can eventually lead to a catastrophic disruption because the external environment has changed that significantly. The reality is that even seemingly internal process such as the production line example are likely more intertwined with wider supply networks than might be immediately perceived and so the author would always recommend the adaptive definition of resilience.

7.4.3.3 FDM-RES Workbook Step 1A3

FDM-RES Workbook Step 1A3 describes how the choice of resilience type can influence the phases of disruption that a FDM resilience strategy should target. In the case of an organisation which has selected an engineering type of resilience, the priority is simply to return to how things were before the disruption, in which case the focus is on identifying the most effective response and recovery resilience elements. A company selecting an 'ecological' type of resilience is prioritising the ability to detect disruption that could fundamentally change the way a company operates and to mitigate it. Therefore, the focus is on resilience elements that aid preparation as well as response and recovery. However, a company that has selected the 'adaptive' resilience type has identified that day to day operations are constantly being shaped by external influences. By a constant process of preparation, response, recovery and adaptation, resilience gains are increased cumulatively so that the impacts of future disruptions, even if not previously experienced, are lowered. This is summarised in Figure 7.8.

7.4.3.4 FDM-RES Workbook Step 1B

The type of resilience identified in FDM-RES Workbook Step 1A3 can help to refine selection of KPIs as indicated in the decision tree in Figure 7.9. However, it should be noted that this is only intended as a guide based upon theoretical best practice and the real-world circumstances of the user will always take precedence. For example, based on analysis of what is being made resilient, confirmation of whether the vulnerability source is already well known, and decision on the type of resilience sought, logically a company arriving at the engineering 'type' of resilience would effectively be employing resilience as a one-off fix and would likely be considering KPIs that affect core company viability in that one off, immediate situation. For a FDM, it is proposed that these are safety of goods, compliance with appropriate legislation and fulfilment of contracts as these are almost instantaneous company-wide failure modes.

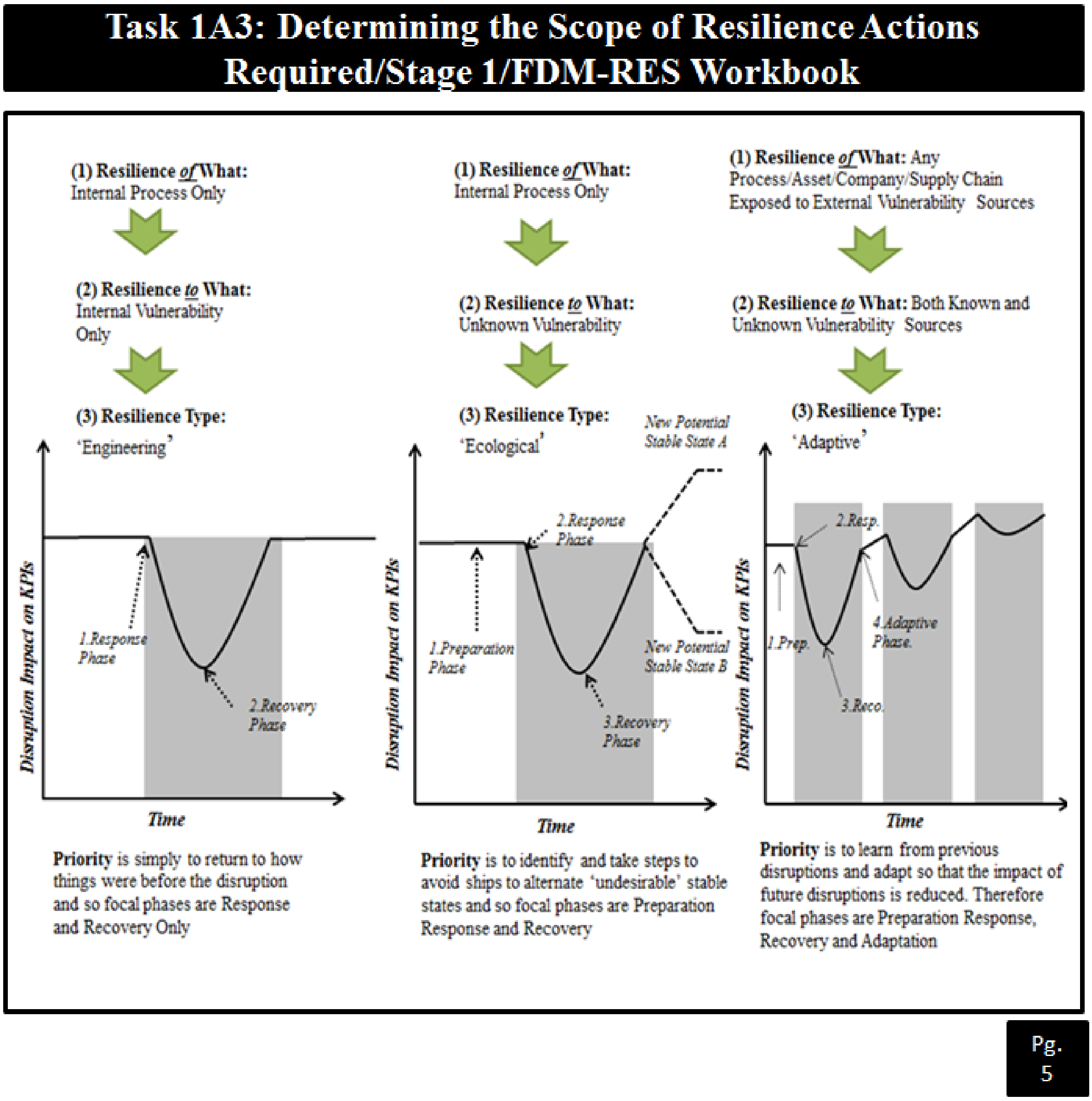


Figure 7.8: The process by which the identification of what is being made resilient to what and the type of resilience sought can influence the phases and therefore scope of resilience efforts.

Equally, a company arriving at the ecological 'type' of resilience will be keen to preserve their current business model and so will likely consider slightly longer term KPIs but which are still important for company viability. These would include factors such as long-term customer satisfaction, and product quality and reliability from which a short-term failure may be recoverable although chronic failures will affect company viability. These factors are suggested to include: Raw Material Cost, Profit Margins, Net Profit, Labour Relations, Environmental Legislation Compliance, Order Fulfilment Time, Contract Fulfilment, Customer Responsiveness, Customer Satisfaction, Traceability, Regular Review of Workers Rights, Occupational Health and Safety, Raw Material Conversion Rate, Safety of Goods and Shelf Life.

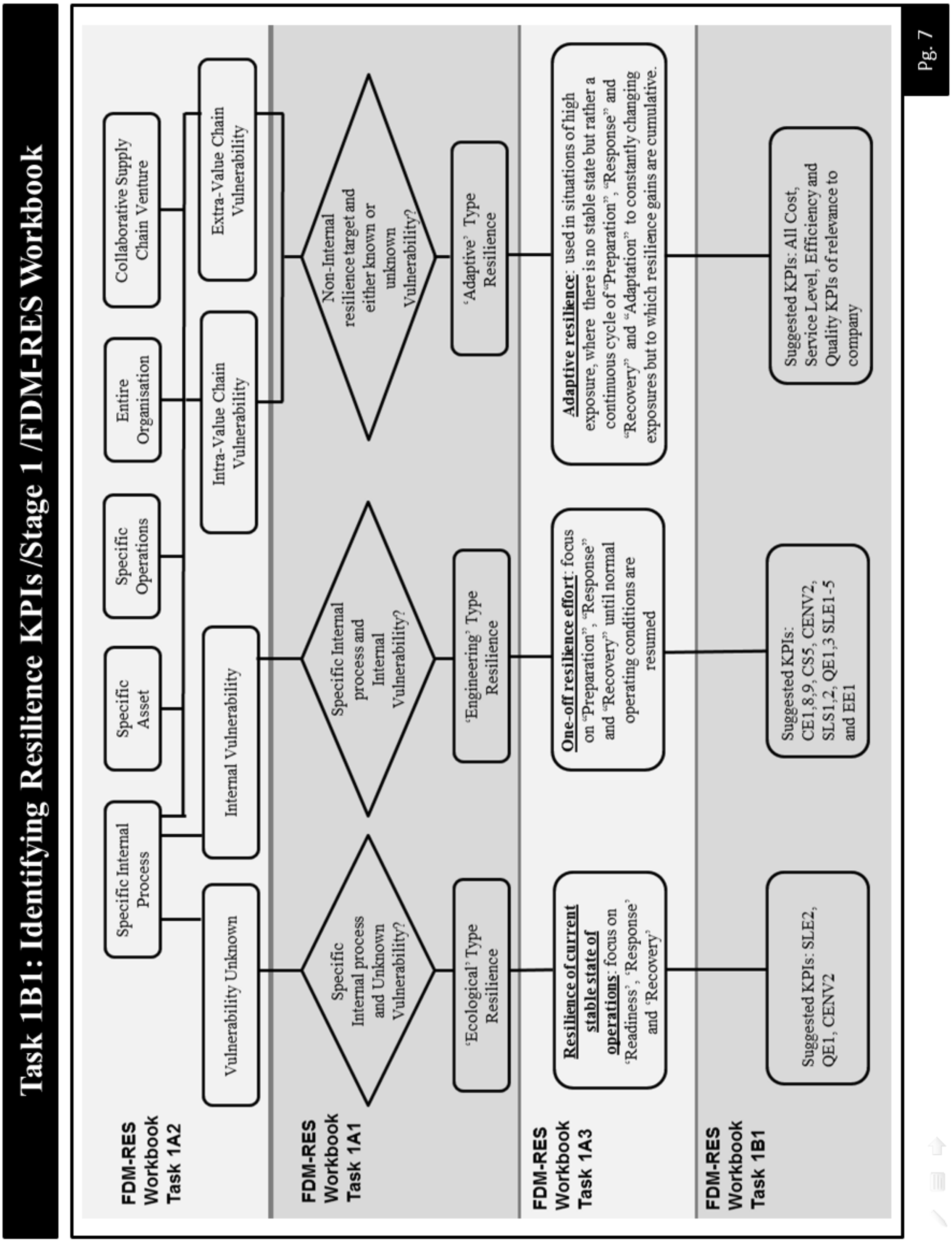


Figure 7.9: FDM-RES workbook snapshot, showing decision tree guiding selection of resilience KPIs.

Finally, in the adaptive ‘type’ of resilience, KPIs should reflect constant long-term scanning of potential viability threats in the medium to long term. At this point it is very much up to the company in question to apply and prioritise their own KPIs using the taxonomy in Table 7.1 based on their perspective of the overlap between resilience goals and wider sustainability priorities.

7.5 Chapter Summary

This Chapter has presented the FDM-RES Framework which conceptually unifies a number of previously inconsistent and isolated resilience considerations into a FDM specific context. The FDM-RES Framework was designed from the outset to be the basis for a practical tool kit, referred to as the FDM-RES Workbook. For this reason, it was modelled on the extremely widespread and standardised ISO 31000 ERM model, using this to shape the resilience concepts identified into the review chapters into four stages: Problem Definition, Identification of Vulnerabilities, Identification of Resilience Elements and Strategies and Evaluation and Implementation. The chapter continued to provide a brief overview of each stage, explaining how the conceptual work involved in each stage in the FDM-RES Framework was exactly mirrored by the tasks of the FDM-RES Workbook. The remainder of the chapter then focussed on detailing in full the first stage of the FDM-RES Framework, involving the conceptual synthesis of an FDM specific definition of resilience and the creation of a taxonomy of FDM specific KPI by which resilience efforts could be measured. Stage 1 of the FDM-RES Workbook then described the practical steps by which the definitions of resilience and the KPIs could be implemented by a user. Chapter 8 now proceeds to build upon Stage 2 of the FDM-RES Framework and FDM-RES Workbook by identifying resilience elements and describing their formulation into effective resilience strategies.

Chapter 8: Vulnerability Identification Tool

8.1 Introduction

This Chapter describes Stage 2 of the FDM-RES Framework/Workbook and presents a novel process for the identification of bespoke vulnerabilities. After a brief introduction detailing the requirements of the vulnerability identification process from a food and drink manufacturer's perspective, the Chapter proceeds to describe the generation of a conceptual process for identifying bespoke vulnerabilities within the FDM-RES Framework. In doing so, it presents the process by which high priority exposure metrics are identified, details the creation of a novel taxonomy of FDM specific Failure modes and proposes linkages between each specific high priority exposure metric and the associated Failure Modes. Finally, it describes the creation of a unique FDM specific taxonomy of vulnerabilities and proposes links between individual vulnerabilities and Failure Modes. Each conceptual step of the FDM-RES Framework is followed by the corresponding FDM-RES Workbook step which focusses on practical as opposed to conceptual application.

8.2 Framework Stage 2: Identification of Vulnerabilities

The review in Chapter 3 identified that accurate measurement of vulnerability, rather than risk (as is commonly used in ISO 31000 ERM methodologies), was potentially a more precise approach for isolating probable disruptions and designing countering resilience strategies. This is because whilst risk management focusses on assigning likelihood to disruptive events, often based on past occurrence, vulnerability management prioritises the analysis of possible causal pathways as a marker for current exposure. This means that vulnerability is more useful if the goal is to counter volatility, which is a key objective of resilience, whereas risk is potentially better suited for more stable and predictable operating environments [260]. It was identified in Chapter 3 (Section 3.4.4.6) that measurement of vulnerability in a FDM context can be achieved through the use of supply chain exposure metrics to identify weak points, which can in turn be linked to ultimate consequences if that weak point was to become a break in the value chain, known as failure modes. Each Failure Mode will have a range of unique potential causal vulnerabilities against which countering resilience elements can then be assigned. These observations and the relations between them are displayed visually in Figure 8.1 and have formed the basis for Stage 2 of the FDM-RES Framework as shown in Figure 8.2.

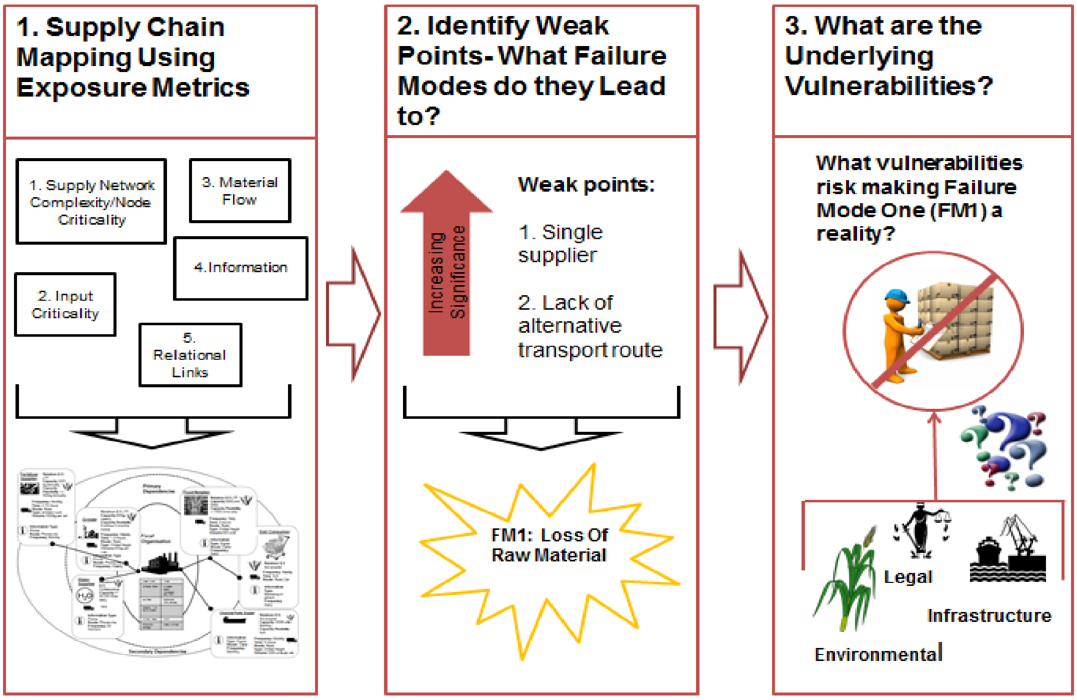


Figure 8.1: Proposed novel vulnerability identification process.

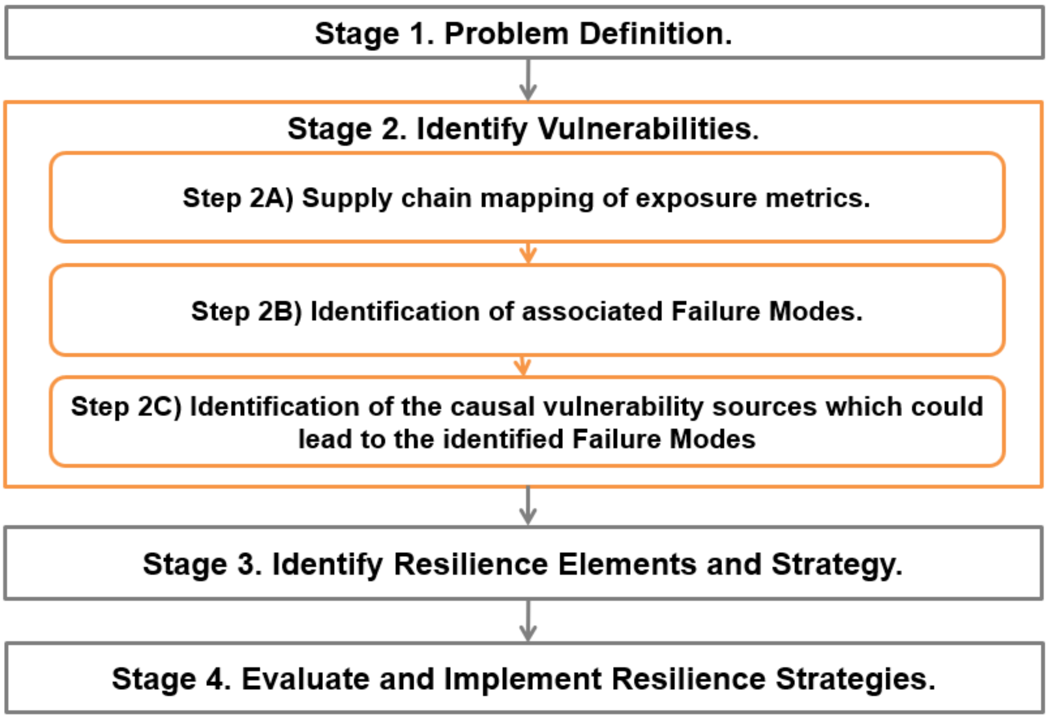


Figure 8.2. Stage 2 of the FDM-RES Framework

However, there are conceptual challenges involved in applying the methodology outlined in Figure 8.2. One such challenge is that whilst the relationship between supply chain exposure metrics and failure modes has been established previously and used to form a novel supply chain mapping tool [84], none of the metrics/failure modes were specific to Agri-Food Supply Networks (AFSNs) and certainly not FDMs. Furthermore, the referenced work did not proceed to associate specific underlying vulnerabilities with the failure modes, although this has been achieved by others using Ishikawa diagrams and Failure Mode Effect Analysis (FMEA) which are both very well established tools [47].

Therefore, FDM-RES Framework Stage 2 adds to the field of FDM resilience by consolidating FDM specific exposure metrics (FDM-RES Framework Step 2A), by developing a detailed taxonomy of FDM specific Failure Modes (FDM-RES Framework Step 2B) and by establishing FDM specific vulnerabilities (FDM-RES Framework Step 2C). Through a systematic review of the literature as well as empirical investigation thorough industry interviews, links between all three components are also proposed. As in Chapter 7, each of these conceptual steps are mirrored by practical steps in the FDM-RES Workbook. Unlike the FDM-RES Framework which develops the necessary conceptual taxonomies and relationships required to identify a company's disruption vulnerabilities, Stage 2 of the FDM-RES Workbook provides instructions and workspace to facilitate the practical collection of supply network information, the identification and evaluation of key exposure metrics, establishment of failure modes and ultimately, the determination of underlying vulnerabilities. An overview of Stage 2 of the FDM-RES Workbook is provided in Figure 8.3 and compared with the conceptual stages of the FDM-RES Framework (i.e. Figure 8.2).

8.2.1 FDM-RES Framework Step 2A

One of the key challenges faced when attempting to identify a company's bespoke vulnerabilities is the complex network of primary (direct operational role in producing a given product) and secondary actors (resources, utilities, knowledge or assets) that make up modern value chains. Therefore, this complexity needs to be accurately captured by appropriate metrics if threats to the KPI's identified in Stage 1 of the FDM-RES Framework are to be adequately identified. A number of possible metrics were discussed in the review in Chapter 4 and Table 8.1 consolidates these, proposing specific measurable attributes for each. These metrics capture the whole range of entities directly and indirectly involved in a FDMs value chain, the way in which raw materials enter that value chain, in which material is moved through the chain, the way that supporting information flows throughout the chain and the relationships between all of the entities in the chain.

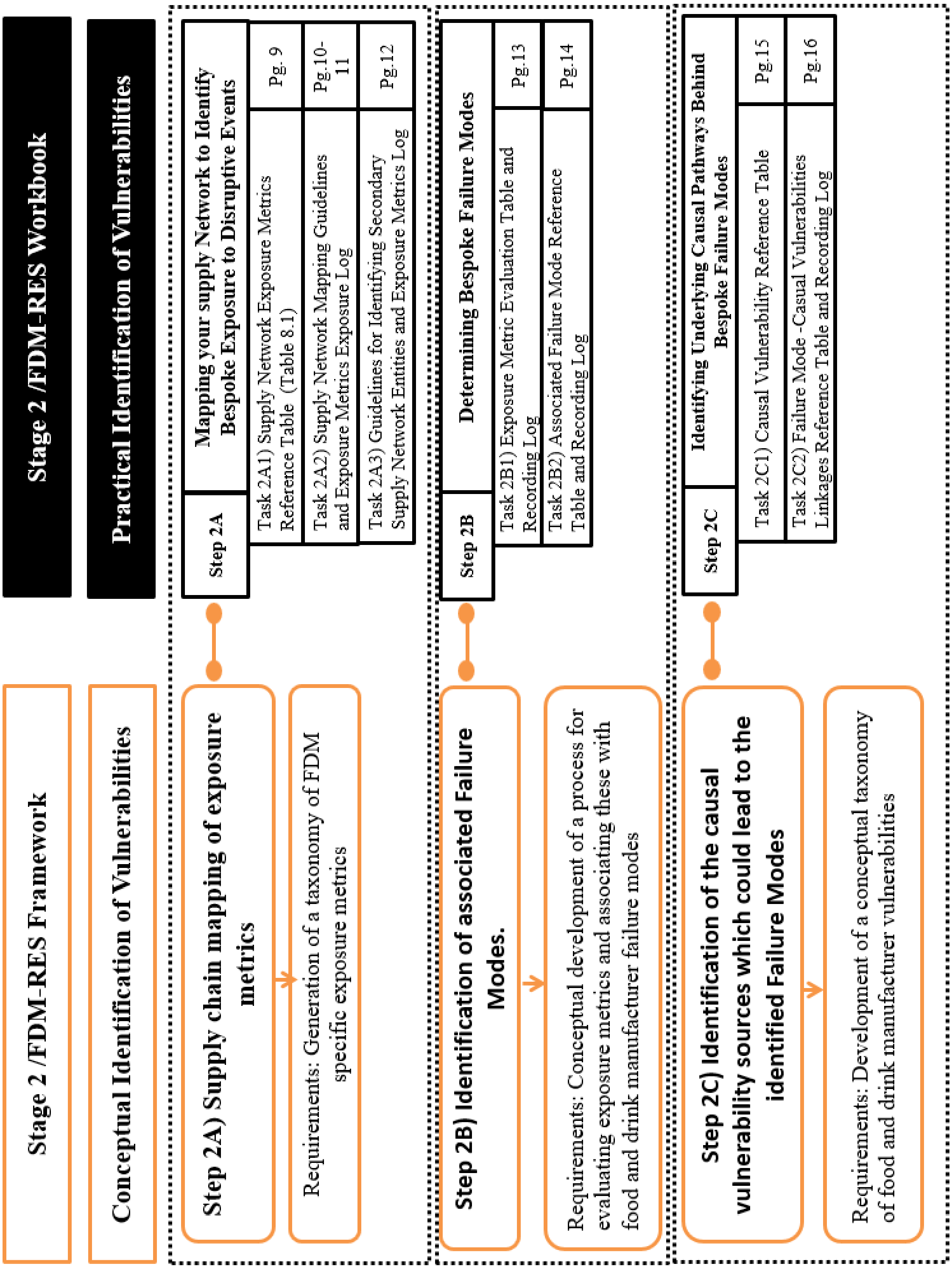


Figure 8.3 Overview of the practical steps involved in Stage 2 of the FDM-RES Workbook (black) and comparison with the conceptual steps of Stage 2 of the FDM-RES Framework (orange).

Table 8.1 Proposed taxonomy of FDM specific supply chain exposure metrics

Class	Sub-Class	Object of Measurement	Metrics
Supply Network Complexity	Primary Entities	All Immediate Suppliers	a) Total number of each type b) Geographic location(s) c) Number of potential alternatives (i.e. node criticality) d) Level of auditing of procedures and financial security (high/low)
		All Internal Assets	a) Total Number of each type b) Geographic location(s) c) Number of interoperable sister sites (i.e. node criticality) g) Level of auditing of procedures and financial security (high/low)
		All Immediate Customers	a) Numbers b) Geographic location(s) c) Level of auditing of procedures and financial security (high/low)
	Secondary Entities	Suppliers of Suppliers	a) Numbers b) Geographic location(s) c) Number of potential alternatives that meet product specifications d) Level of auditing of procedures and financial security (high/low)
		Waste removal	a) Numbers b) Geographic location(s) c) Alternatives that match product specification d) Ability to change collection capacity at short notice (high/low)
		3rd party logistics	a) Numbers b) Geographic location(s) c) Alternatives that match product transport requirements d) Ability to change collection capacity at short notice (high/low)
		Water and energy suppliers	a) Location of supplier/infrastructure b) Presence of alternatives (i.e. companies that use different infrastructure routes to supply utilities)
		Government (both UK and international)	a) Numbers b) Geographic location(s) c) Political stability (high/low) d) Corruption (high/low)
		NGOs	a) Numbers b) Geographic location(s) c) Suitable alternatives
Input Criticality		Raw Material	a) Location (if different to supplier) b) Growing constrictions (i.e. specific geographic range or growing conditions) c) Inbound lead time (hours) d) Supplier reserves (hours) e) Supplier capacity to alter supply volumes (% no. units)
		Energy	a) Peak capacity of supplier vs most extreme requirements of FDM
		Water	a) Peak capacity of supplier vs most extreme requirements of FDM
Material Flow		Raw Material	a) Inbound/outbound transport type/requirements (i.e. road, rail, ship vs. ambient or chilled) b) Inbound/outbound volume (unit no./weight/volume) c) Inbound outbound frequency (hours) d) Inbound/outbound transport route. e) Presence of alternative types/routes (no. and for each, the relative ability to satisfy the volume, condition and frequency requirements?)
		Energy Water	a) Physical route b) Locations of reserves (i.e. spare generators/water tanks) across

		value chain
	Internal Movement of Goods within Focal FDM	a) Transport type/requirements (i.e. road, rail, ship vs. ambient or chilled) b) Volume (unit no./weight/volume) c) Transport frequency (hours) d) Transport route. e) Presence of alternative transport types/routes f) Raw material to outbound warehouse Lead time (hours) g) Raw material and finished inventory reserves (hours) e) Internal flexibility to alter supply volumes (% no. units)
	Outbound Delivery of Goods	a) Transport type/requirements (i.e. road, rail, ship vs. ambient or chilled) b) Volume (unit no./weight/volume) c) Transport frequency (hours) d) Transport route. e) Presence of alternative transport types/routes
Information Flow	Raw Material	1. Inbound and outbound information type (i.e. paper or digital) 2. Inbound and outbound information route (infrastructure required and repositories) 3. Inbound and outbound information frequency (hours)
	Energy	
	Water	
	Internal Movement of Goods	
	Outbound Delivery of Goods	
Relational Links for each Primary and Secondary Entity Identified in 'Supply Network Complexity/Criticality Step One'.	Horizontal relationships	1. Presence of Buying–Selling relationship (Yes/No) a) Level of adversity (high/low) b) Interdependence (high/low) c) Level of collaboration (high/low) 2. Presence of long-term partnership (Yes/No) a) Nature of partnership b) Power imbalance (high/low) c) Integration of operations (High/Low) d) Willingness of partner to invest in supplier quality and sustainability (High/Low) e) Willingness of partners to collaborate on cross-value chain issues (High/Low) f) Contractual restrictions on supplier sourcing (High/Low) g) Contractual penalties for late/sub-standard delivery (High/Low)
	Vertically Integrated Relationships	1. Intra-organisational competition (High/Low) 2. Intra-organisational collaboration (High/Low) 3. Level of intra-organisational integration (High/Low)
	Relationships with Actors Outside of Direct Value Chain	Type of Relationship: 1. Buyer /Seller (see above metrics) 2. Advisory/Regulatory a) Direct impact on operations (i.e. ability to impose fines and suspend operations) (High/Low) b) Ability to indirectly impact operations (i.e. consumer influence) (High/Low) c) Value added to product (i.e. certification, product development collaboration) (High/Low)

The exposure metrics were sourced from a variety of supply chain management works which provided supply network performance metrics [200, 259–262] and supplemented by food specific performance metrics where possible [122, 263]. By nature, some metrics are quantitative, measuring volumes, frequencies and times (for example, many of the input criticality, material flow and information flow metrics) but others are more qualitative, such as metrics regarding relational links. However, even such qualitative metrics are designed to elicit yes or no responses to facilitate easier evaluation and identification of failure modes (see Section 8.1.2).

These exposure metrics can be represented in the form of a map of the operating environment of the entity being made resilient. The visibility created reduces reliance on historical risk scenarios because not only are exposure markers effectively real-time, but they also consider a range of exposures that go far beyond the initial value chain and monitor a supply networks broader environmental, societal, and government exposure sources.

8.2.2 FDM-RES Workbook Step 2A (Describing Tasks 2A1, 2A2 and 2A3)

Figure 8.4 is a simplified visualization of how the FDM-RES Workbook guides users in completing each of the three tasks within Stage 2A. This was chosen over a direct screenshot from the workbook due to the fact that the actual workbook contains the full exposure metrics questionnaire making it quite lengthy and also a repeat on information provided in Table 8.1. FDM-RES Workbook Task 2A1 is a paper exercise where a FDM identifies all of their primary supply chain partners (as described in Table 8.1). For each of these, input criticality, material flow, information flow and relational links details are completed. One reason for solely focusing on the primary entities is that these are likely to be well known within the FDM and therefore data for the metrics is likely to be available. Once primary entities are identified in the workbook, they can be mapped out using the guidelines in Figure 8.4. Unsurprisingly, given the complexity of real-world vulnerability sources this techniques is designed to unearth, the resulting maps often look more like uprooted trees than the standard pipeline supply chain map [205].

The mapping procedure proposed in the FDM-RES Workbook follows the well-established procedure of Lambert et al. (2000), which breaks down supply chain entities into primary and secondary tiers. However, in the interests of visual simplicity the mapping process focusses just on the metrics of supply network complexity and relational links. Metrics that are difficult to represent visually (such as input criticality, material flow and information flow) are captured in tables (see Task 2A3 in Figure 8.4).

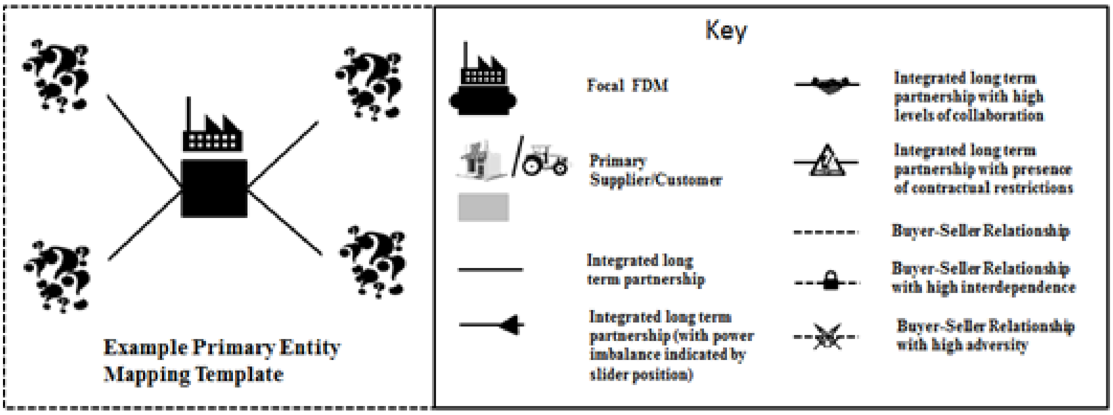
Step 2A: Mapping Your Supply Network to Identify Bespoke Exposure to Disruptive Events/Stage 2 /FDM-RES Workbook

Task 2A1: Identify Primary Supply Chain Entities

Primary Supply Network Entities	Input Criticality	Material Flow	Information Flow	Relational Links
Primary Entity One…	Include inbound lead time/supplier reserves in hours and the number of alternatives	Include transport type/requirements/volume/frequency/route/ alternatives for the above	Include type/route/frequency	Indicate whether buyer-seller/long term partnership) Vertical or Extra Supply Chain Relations
Primary Entity Two…				

Task 2A2: Map Primary Supply Chain Entities

1. Map out the primary entities identified in Task 2A1 following the guidelines provided below



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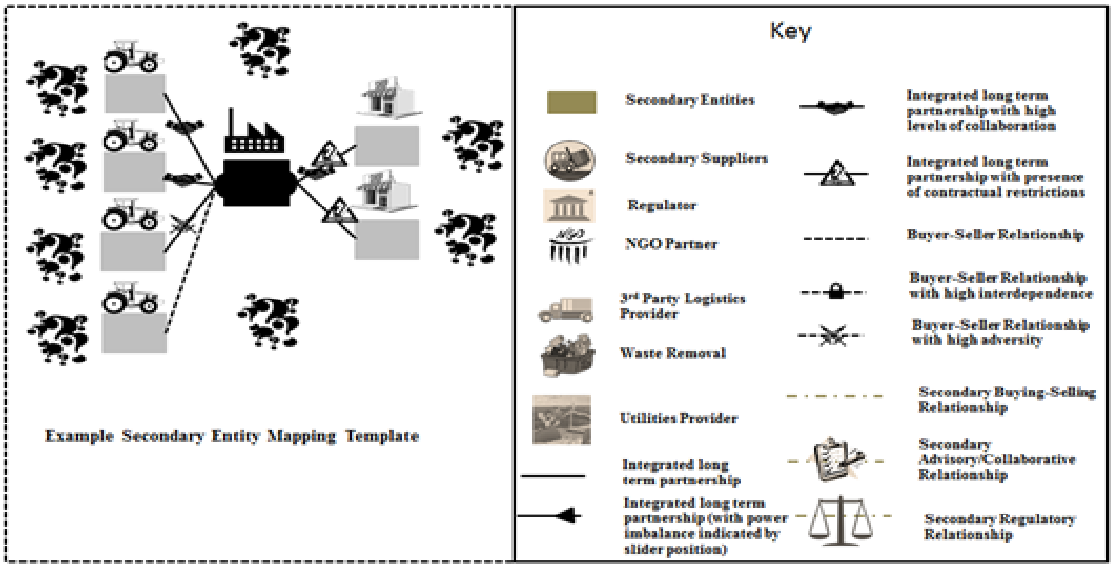
Step 2A: Mapping Your Supply Network to Identify Bespoke Exposure to Disruptive Events/Stage 2 /FDM-RES Workbook

Task 2A3: Guidelines for Identifying Secondary Supply Network Entities and Exposure Metrics Recording Log

1. Using the guideline criteria provided below, map out secondary entities around the primary entities identified in Task 2A2.



Task 2A3: Guidelines for Identifying Secondary Supply Network Entities and Exposure Metrics Recording Log

For each of the Secondary Entities identified in Step Three, please record the following metrics:

Name of Secondary Entity	Input Material Criticality	Material Flow	Information Flow	Relational Link
Name and type: (e.g. seed supplier of primary grower) One of how many? How many geographic sites are associated with this entity?	**For raw materials please provide the following:** a) Location b) Growing constrictions c) Inbound lead time (hours) d) Supplier reserves (hours)	**For raw materials please provide the following:** a)Inbound/outbound transport type/requirements b)Inbound/outbound volume c) Inbound outbound frequency	**Please provide the following:** a)Inbound and outbound information type b)Inbound and outbound	**For buyer-seller relationships :** a) Level of Adversity (high/low) b) Interdependence

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Figure 8.4: Example Workbook application of FDM supply network vulnerability exposure metrics in a supply chain mapping process.

One of the advantages of the mapping process described in Figure 8.4 is that it does not rely purely on the users pre-existing knowledge of secondary entities. Instead, where the user can see from the framework that there should be a supporting secondary entity, but does not have the data to hand, it encourages them to obtain this information. The mapping procedure therefore builds a real–time map of true exposure and thus helps avoid the limitations of relying on risk scenarios based on historical disruptive events and supply network understanding that is skewed towards the immediate value chain. Not only does the secondary mapping stage reveal the complexity of supply chains in terms of numbers of supporting secondary entities, it also shows the interactions between secondary entities.

This is emphasised in the illustrative example provided in Figure 8.5, in which the mapping guide is practically applied to an example FDM. In this example, some of the primary producers supplying the focal FDM, despite being geographically separated by some distance, are still dependent on similar fertilizer and machinery suppliers, something that might not have been apparent based on analysis of primary entities alone. The same can be said for some of the regulatory (e.g. DEFRA and the Environment Agency) and advisory bodies (e.g. the Forestry Commission) which advise multiple partners within the value chain and therefore have reach far beyond the focal FDM. Once secondary entities are identified, data related to the metrics of input criticality, material flow and information flow should be collected and stored in table form in the corresponding workbook section, just as was the case for primary entities (See Figure 8.4).

8.2.3 FDM-RES Framework Step 2B: Determining Failure Modes

Step 2B of the FDM-RES Framework concerns conceptually establishing the process for evaluating the supply network exposure metrics (identified in Step 2A) in terms of whether they represent a priority exposure point. The criteria for a metric being a priority exposure were developed from a number of AFSN peer reviewed publications but also private discussion between the researcher and a number of industrial experts, including the Director of leading AFSN logistics consultants, Global 78 as well as Sourcing Managers at four major FDMs. These criteria are displayed in Table 8.2 which is structured in such a way that metrics identified in the mapping process can be cross referenced against the criteria in which that metric would be a high priority. For example, priority suppliers would be considered a high priority exposure point if they a) were highly clustered in a single geographic area, b) if the majority were long distance suppliers producing low volume and/or high complexity products which c) limited the likelihood of finding alternative suppliers at short notice.

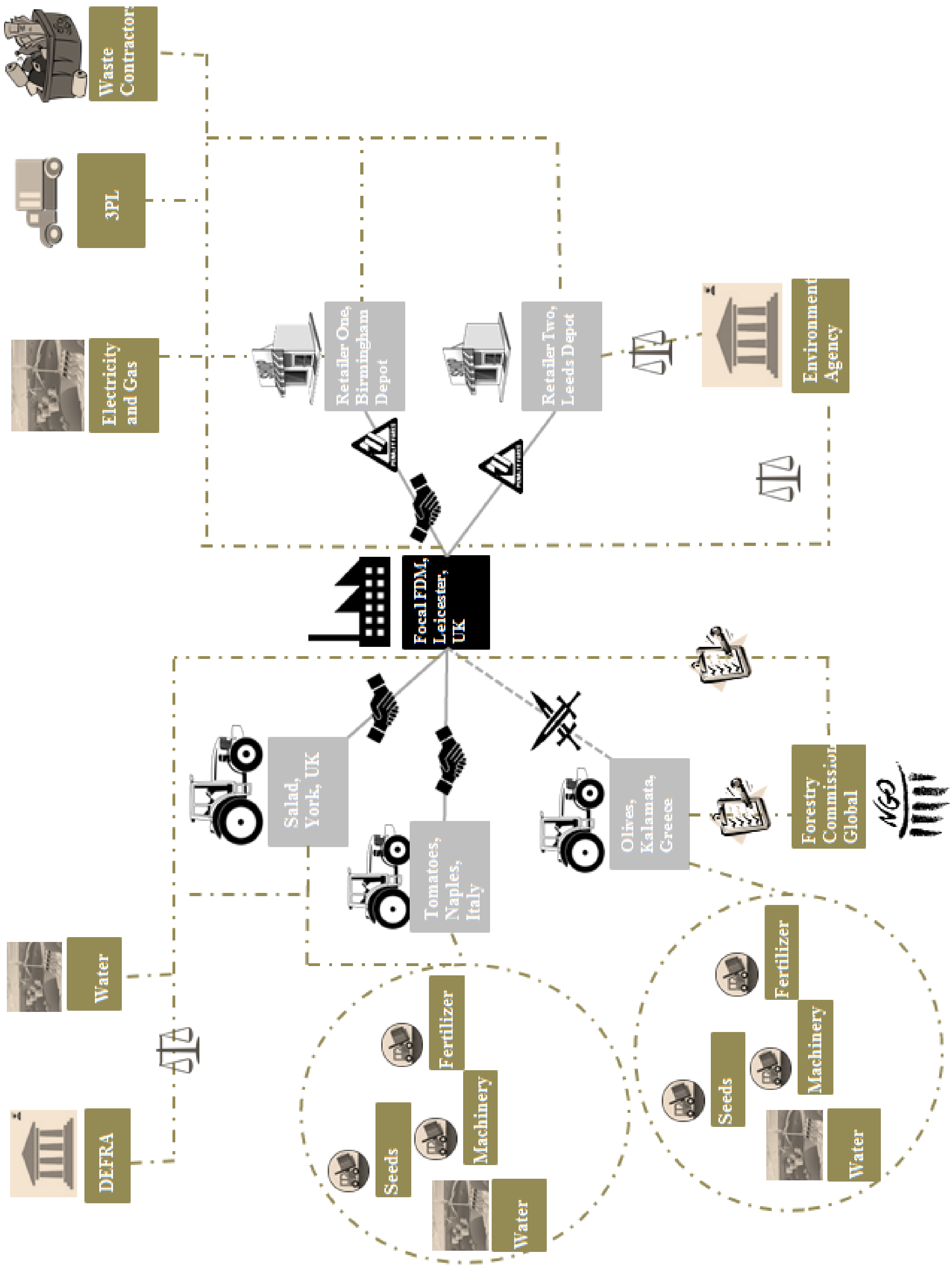

Figure 8.5: Example application of the FDM-RES Framework mapping guidelines to a FDM

Table 8.2: Guidelines for evaluation of supply network metrics recorded in the mapping stage

Metric Class	Object of Measurement	High Priority Exposure If:
Supply Chain Entity	**Primary Entity:** Suppliers	• **PES1**: Geographically clustered • **PES2**: High number of long distance (particularly international) suppliers. Amplified when volumes are low and /or complexity of product is high and the FDM has limited ability to hold raw materials in reserve. • **PES3**: Limited alternative suppliers which could fit product specification
	Primary Entity: Internal Assets	• **PEI1**: Absence of sister sites which could take over production/supply staff/equipment in a disruption situation. • **PEI2:** Inflexible production characteristics that limit ability to change production capacity at short notice and finished inventory stores are low.
	Primary Entity: Customers	• **PEC1**: Significant geographic distance to customer
	Secondary Entity: Suppliers of Suppliers	• **SES1:** Geographically restricted Secondary Suppliers • **SES2:** Limited financial robustness of secondary suppliers • **SES3:** Limited auditing of secondary suppliers • **SES4:** Highly specific product with few alternative suppliers
	Secondary Entity: Utilities (Water and energy suppliers)	• **SEU1:** Limited supplier peak capacity
	Secondary Entity: Waste removal	• **SEW1:** Absence of suitable alternate service providers • **SEW2:** Limited ability of service provider to change collection capacity at short notice
	Secondary Entity: 3rd party logistics	• **SET1**: Absence of suitable alternate service providers • **SET2:** Limited ability of service provider to change collection capacity at short notice
	Secondary Entity: Government	• **SEG1:** High potential impact on operations combined with poorly established communication protocols between Government and the FDM. • **SEG2**: Political instability/inconsistency • **SEG3:** High levels of corruption
	Secondary Entity: NGOs	• **SEN1:** Limited reliability (particularly concerning public image) • **SEN2:** Critical to process (i.e. certification) but without alternative providers available.
Input Criticality	Raw Material	• **ICRM1:** Long production timescale • **ICRM2:** Few growers • **ICRM3:** Tight geographic restrictions on supply • **ICRM4:** Raw material required regularly, combined with low supplier reserves and/or ability to change supply volume.
	Energy	• **ICE1:** Absence of suitable alternate service providers • **ICE2:** Limited ability of service provider to change supply at short

		notice • **ICE3**: Communication routes susceptible to disruption (i.e. single phone line in region prone to strong weather)
	Water	• **ICW1:** Absence of suitable alternate service providers • **ICW2:** Limited ability of service provider to change collection capacity at short notice • **ICW3:** Communication routes susceptible to disruption (i.e. single phone line in region prone to strong weather)
Material Flow	Raw Material	• **MFRM1:** High frequency inbound deliveries using singular transport mode and route with limited ability to switch.
	Energy Water	• **MFE/W1:** Heavy reliance on grid with little in the way of redundant lines or spare capacity (such as generators)
	Internal Movement of Inventory	• **MFI1:** High frequency deliveries using singular transport mode and route with limited ability to switch.
	Outbound Delivery of Finished Goods	• **MFO1:** High frequency outbound deliveries using singular transport mode and route with limited ability to switch.
Information Flow	Raw Material	• **IFRM1:** Lack of communications integration, increasing time taken to act on incoming information.
	Internal Movement of Goods	• **IFI1**: Lack of communications integration/protocols between teams
	Outbound Delivery of Goods	• **IFO1**: Lack of communications integration, increasing time taken to act on incoming information. • **IFO2**: Communication routes susceptible to disruption (i.e. single phone line in region prone to strong weather)
Relational Links.	Horizontal relationships	• **RLH1**: Buying-Selling relationship where interdependence is high (i.e. both parties are, for various potential reasons, very important to each other's viability) and adversity is particularly high, or collaboration is particularly low. • **RLH2:** Long term partnership where there is a strong power imbalance in favour of one party who uses this to impose heavy contractual penalties without efforts to integrate, with, invest in the development of and collaborate with partners.
	Vertically Integrated Relationships	• **RLV1**: Vertical partners are closely integrated on product specifications yet supply each other under circumstances of high competition leading to the risk of monopolisation.
	Relationships with Actors Outside of Direct Value Chain	• **RLO1:** For Buyer-Seller relations see horizontal relations criteria • **RLO2:** Situations where the relationship is advisory or regulatory and where the other party has a large influence on consumer opinion but where collaboration/integration is low

By evaluated supply network exposure metrics in this way, it is possible to shortlist the highest priority exposures and identify the failure modes that could result. By focussing on identifying failure modes (i.e. the consequences of a disruptive event, rather than the causes of the disruptive event) that an exposure point could precipitate, the potential range of underlying causes is narrowed. This is illustrated in Figure 8.6 which highlights how the range of potential causative vulnerabilities that could tip a high priority exposure metric into a failure mode is vast. In the example provided, the high priority exposure is heavy penalties applied by the customer for late deliveries. The causal vulnerabilities that could result in this becoming an actual disruption are large in number and could, for example, involve infrastructure vulnerabilities (e.g. road disruptions), societal vulnerabilities (e.g. criminal acts) or environmental vulnerabilities (e.g. natural disasters).

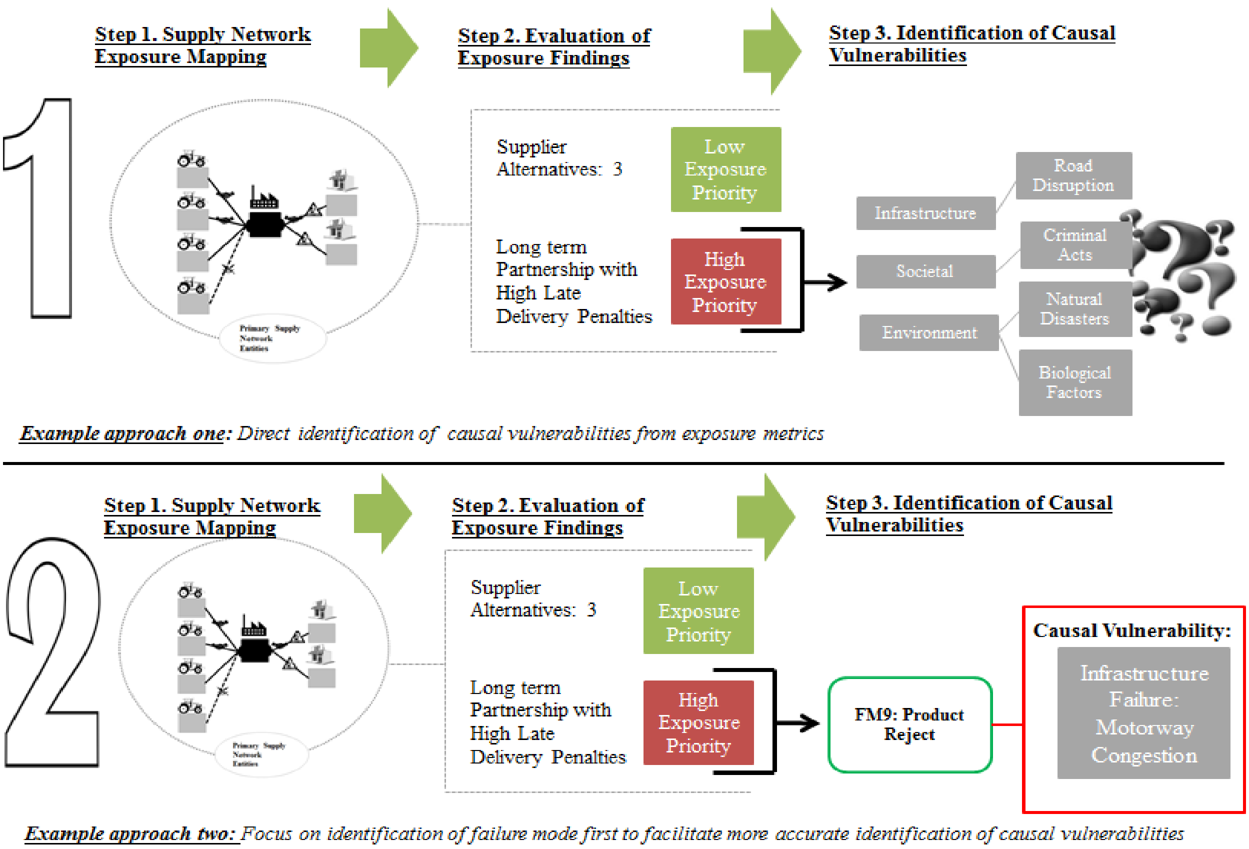

Figure 8.6: Justification for using failure modes to identify causative vulnerabilities rather than just exposure metrics alone.

However, by focusing on the specific consequences of an exposure point turning into a realised disruption, i.e. the Failure Mode, the list of possible causal vulnerabilities should be much lower. For example, in Figure 8.6, the Failure Mode of the high priority exposure is ultimately product rejects and the causal vulnerability is narrowed to infrastructure: motorway congestion [153, 166]. To develop this principle, there is a need for conceptual taxonomies of FDM specific failure modes and linkages between these and the priority exposure metrics proposed in Table 8.2. Yet, it was identified in the research gaps presented at the end of Chapter Five, that no previous work has provided either failure modes or linkages to exposure metrics. In response, Table 8.3 provides a taxonomy of UK FDM specific Failure Modes and Table 8.4 proposes the relational link between each Failure Mode and high priority exposure metric (see Table 8.2) The contents of both Tables 8.3 and 8.4 are based on the review findings from Chapter Four [122, 264-265] in addition to findings from a number of preliminary interviews with senior sourcing managers and operations specialists from four leading FDMs in the UK

8.2.4 FDM-RES Workbook Step 2B (Describing Tasks 2B1 and 2B2)

Step 2B of the FDM-RES Workbook describes the practical process of evaluating the exposure metrics identified in Step 2A (Task 2B1) and of using these to identifying failure modes (Task 2B2). Beginning with Task 2B1, the process of evaluating exposure metrics can be illustrated using Figure 8.7. In this example, an FDM is evaluating a primary supplier (in this case a lettuce grower) and identifies that the grower is relatively local, thoroughly audited for financial robustness and high-quality levels and that there are alternatives who could meet product specifications in the event of a disruption. Therefore, cross reference with the high priority exposure reference list in Table 8.2 returns the supplier as a low priority exposure (i.e. they are not geographically clustered, long distance or a sole available supplier). The same process is applied to the metrics of input criticality, information flow and relational links, all also returning as low priority exposure metrics upon cross-referencing with Table 8.2. However, when considering the final metric of Material Flow, it was identified that because of the short shelf life of lettuce, high frequency deliveries by chilled lorry were required and that these were heavily reliant on major motorways. Due to the high frequency of deliveries, alternate road routes added on significant cumulative time, thus matching the criteria MFRM1 in Table 8.2 for a high priority exposure. Having identified all high priority exposure points in this manner, a FDM-RES Workbook user can the proceed to step 2B2, the cross referencing of high priority exposures with Table 8.4 in order to identify linked Failure Modes.

Table 8.3: FDM Specific Failure Modes

Failure Mode	***Description/Characteristics***
FM1. Raw Material Shortage	All manner of upstream disruptions which limit raw material availability from the focal FDMs perspective.
FM2. Raw Material Sub-Standard Quality	All manner of upstream disruptions, which, whilst not necessarily halting raw material supply to the FDM, significantly affect the quality of raw materials received (e.g. size and credence factors)
FM3. Unable to produce/ Scrap/Rework	Occurs when a product is unable to move beyond the FDM production line, whether because production could not be attempted in the first place, because the final product needed to be reworked, or because the finished product was unfit for any other use thus requiring scrappage.
FM4.Labour Shortage	Refers to any factor(s) which limit labour availability at FDM sites
FM5: Loss of process economic viability	Factors leading to a particular process becoming commercially untenable for the FDM. Examples include raw materials simply not being profitable, wider market saturation or evolving consumer trends.
FM6: Loss of Site	Refers to any number of disruptions which either prevent or severely hinder operations at a particular plant.
FM7: Unable to Deliver	Goods are finished to specification but are prevented from being sold by various internal or downstream disruptions that prevent packing, loading or delivery.
FM8: Legally enforced cessation of specific operations	Situations which could result in a regulatory body forcing the FDM to cease operations in response to major legislative violations, for example, environmental breaches, significant health and safety concerns, or major incidents of food contamination.
FM9. Sub-Standard Product Quality and Possible Reject	Any disruptions which, whilst not forcing a scrap/rework, do impact on the final quality and may result in concessionary rates or penalties being applied by the customer.
FM10: Product Recall	This failure mode refers to any disruption(s) which result in food either being rejected at the retailer depot, or food which has made it onto retailer shelves or consumers' homes, being recalled.

Table 8.4: Relational links matrix between priority exposure metrics and failure modes.

High Priority Exposure Points (Refer to Table 8.2)	Failure Modes (Refer to Table 8.3)									
	FM1	FM2	FM3	FM4	FM5	FM6	FM7	FM8	FM9	FM10
PES1	X	X			X					
PES2	X	X			X					
PES3	X	X			X					
PEI1			X		X	X			X	
PEI2			X		X				X	
PEC1			X				X			X
SES1	X	X			X					
SES2	X	X			X					
SES3	X	X			X					X
SES4	X	X			X					
SEU1			X		X			X	X	
SEW1			X					X		
SEW2			X					X		
SET1	X				X		X			
SET2	X				X		X			
SEG1			X	X				X		X
SEG2	X		X	X						
SEG3	X				X					
SEN1					X					X
SEN2	X	X	X		X				X	X
ICRM1	X	X								
ICRM2	X	X			X					
ICRM3	X	X			X					
ICRM4	X	X								
ICE1			X		X					
ICE2			X		X				X	X
ICE3			X						X	
ICW1			X		X					
ICW2			X		X				X	X
ICW3			X						X	
MFRM1	X	X	X							
MFE/W1		X	X			X			X	X
MFI1	X	X	X							
MFO1							X			X
IFRM1	X	X	X							
IFRM2	X	X	X							
IFI1	X	X	X	X			X		X	
IFO1			X				X		X	X
IFO2			X				X		X	X
RLH1	X	X	X		X					X
RLH2					X					X
RLV1					X					
RLO1	X	X	X		X					X
RLO2					X			X		

Task 2B1: Exposure Metrics Evaluation Reference Table and Recording Log /Stage 2 /FDM-RES Workbook

Supply Network Entity	Input Criticality	Material Flow	Information Flow	Relational Links
Supplier One: One of Two lettuce suppliers in UK. Both in Kent. There are two additional suppliers (UK, Midlands) who meet the retailers standards but they require three months notice The supplier has been thoroughly audited for quality of production and financial robustness before the contract was establishes	**Lettuce:** Location: Kent, UK Growing Length: 3 months, can increase supply by sending smaller plants Growing constraints: None, Greenhouse. The supplier has enough surplus stock to cover 48 hours in excess, other than this there is no surplus capacity without three months notice	**Lettuce:** Inbound via refrigerated lorry Frequency: Every 2 days Route: M1 motorway, alternatives add on 1 hour to journey time	**Lettuce:** Delivery schedules electronic & fully integrated with FDMs scheduling software. Schedules & forecasts sent daily Route: internet, stored on cloud servers	**Relation type**: Long Term Partnership. Supplier is large and supplies multiple manufacturers, therefore power imbalance is low. However, there is a high level of integration and the FDM invests significantly in grower sustainability and efficacy techniques in line with retailer sustainability plan.
Low Priority Exposure	**Low Priority Exposure**	**High Priority Exposure**	**Low Priority Exposure**	**Low Priority Exposure**
Supplier Two:	**Bacon:**	**Bacon:**	**Bacon:**	**Relational Links:**

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Figure 8.7: Example Evaluation of Supply Network Exposure Metrics.

The FDM-RES Workbook therefore presents Table 8.4 as a reference matrix and provides space to record findings, but it is not presented here as it contains no information not already present in Table 8.4 itself. This therefore concludes Step 2B of the FDM RES Workbook and discussion now moves to the final step in Stage 2 of the FDM-RES Framework, Step 2C.

8.2.5 FDM-RES Framework Step 2C

This final section of Stage 2 of the FDM-RES Framework concerns the identification of the causative vulnerability sources that could lead to any of the Failure Modes Identified in Step 2B actually occurring. It is important, because whilst steps 2A and 2B have provided a useful methodology to identify bespoke exposure to disruptive events and their consequences, it is the causative vulnerabilities against which resilience elements must be linked in Chapter 9.

As was identified in Chapter 3, vulnerabilities in the literature are often classified via the "atomistic" approach, focussing on value chain factors or a "holistic" approach which considered broader sources of vulnerability such as Market, Government, Infrastructure, Society and the Environment. Given the complexity of AFSNs, which are also intrinsically linked with the environment via primary production and society via consumption, it was felt that the FDM-RES Framework needed to capture both categories. Using synthesis, 58 distinct vulnerabilities were identified from the aforementioned sources and categorised according to how controllable the vulnerability was, rather than whether the exposure was atomistic or holistic in nature. This is shown in Table 8.5 and care has been taken to include AFSN specific vulnerabilities which are marked in bold italics with an *.

It is proposed that at an organisational level, vulnerability sources originate from four broad areas. These are Raw Materials and Production (concerning inbound materials and internal production processes), Logistics Control (management of the physical movement of goods around the focal actor, both upstream and downstream), Information control (management of the flow of information both upstream and downstream in relation to the focal actor) and finally the Organisational Management Structure (all aspects related to how an organisation is strategically managed). In theory, at an organisational level, all of these vulnerability sources are mostly controllable provided that they are directly related to the choices and actions of an organisations management [173]. However, that is not to say that every vulnerability source at an organisational level is completely controllable, for example, product quality issues related to staff error.

Table 8.5: Systematic review of supply chain vulnerability sources and controllability (AFSC specific vulnerabilities are identified by ***bold italics****)

Supply Network Vulnerabilities (Largely Uncontrollable)

Financial (Fin)	*Market (Mar)*	*Governance (Gov)*	*Infrastructure (Inf)*	*Societal (Soc)*	*Environmental (Env)*
1. Market price fluctuation [39-133-249] 2. Currency exchange fluctuations [39-130-133] 3. Interest rate fluctuations [266] 4. Regional economic downturns [68-114-249-266-267] 5. Hostile takeover attempts [133] 6. Product liability [39]	1. Market decline 2. Competitive Innovation [39-245] 3. Competitor undercutting [95-154]. ***4. Seasonal variability in availability of raw materials (growing seasons, profitability of crop)****[134] ***5. Variability in demand (seasonal, promotional and bullwhip)****[39-68-133-134-170-267-268]	1. ***Changes in Public Food Policy (e.g. production efficiency targets, health and nutrition guidelines)****[133-138-154-267-268]. 2. ***Private Food Policy (e.g. strict customer requirements on appearance, colour, shape and delivery time)****[138] 3. Political instability (regime changes, corruption)[70-124-245-267] 4. Import/export restrictions [15,5]	1. Transport infrastructure disruptions (pipelines, ports, roads, railways, airports)[70-95-114-124-154-269] 2. Water infrastructure disruptions [70-154] 3. Energy infrastructure disruptions (oil supply/price, electricity grid, gas supply)[70-154-266] 4. Communications infrastructure disruptions (cables, radio masts, satellites)[70-154][133].	1. Piracy/Terrorism[39-51-57-70-134-245-269–271] 2. War and conflict [3,12,13] 3. Workforce health (e.g. flu pandemic)[39-267] 4. ***Proportion of Consumer income available for food purchase****[266] 5. ***Changing customer attitudes to consumption (e.g. health, lifestyle and fashion foods)****[134-138-267] 6. Criminal acts (such as fraud data hacking and sabotage)[39-114-133-249] 7. Industrial actions (strikes) [39-70-124-134-266-267] 8. Poor relations with consumers and special interest groups (e.g. customer communication, brand image, consumer confidence)[39-267]	1. Natural disasters (both Geological and Meteorological such as earthquakes, drought etc.) [39-68-70-95-114-133-134-138-154-159-245-249-266-269-271] 2. ***Biological factors (e.g. livestock disease, pests)****[70-134-138-249-266] 3. ***Anthropogenic hazards (such as pollution, land contamination)****[39-133-138] 4. ***Unsustainable Primary Production (Land use, loss of biodiversity, climate change)****[266]

Internal and Value Chain Vulnerabilities

	Raw Material and Production (RMP)	*Logistics Control (LC)*	*Information System (IS)*	*Organisational Management Structure (OMS)*
Value Chain Origin Vulnerabilities (VC) (Partially Controllable)	***1. Inconsistent Raw material quality and heterogeneity****[124-133-267] ***2. Raw material and product related hazards (shelf life, cross contamination, handling requirements)****.[39-40]	1. Reliability of external logistics providers[39-70-95-124-130] 2. High levels of geographically distant, outsourcing for which there is no alternative [16,23,24] 3. Strict customer requirements (in terms of lead times and quality) [70]	1. Lack of established, secure and integrated information sharing infrastructure [4,12,13,17,8] 2. Deliberate withholding of information (trust and cooperation)[70-159] 3. ***Lack of ability to trace food across the value chain****[40].	1. Low level of training & experience in other companies employees[70-95] 2. Poor financial robustness of value chain partners (exposure to bankruptcy or takeover) [95-124-154-159-245-267] 3. High concentration in supply chains (i.e. actors serving as both suppliers and competitors in different contexts)[70-124] 4. ***High levels of power imbalance between actors (contractual fairness and level of lock in)**** [70-124]
Organisation Specific Origin Vulnerabilities (OS) (Mostly Controllable)	***1. Challenges related to storing raw materials/finished inventory (for example, storage requirements and ability to maintain ambient conditions)****[40]. 2. Product failure to comply with environmental legislation*[39-130-249] 3. Product failure to comply with Health and Safety Legislation. *[39-130-249] 4. Insufficient capacity to meet changing order requirements [39-70-130-166-170-245-267] ***5. Inability to react to changing circumstances (ability to quickly substitute raw materials or ramp up production/ decrease lead time)****[70-249]	1. Inaccurate forecasting (e.g. subjective decision making) [3,5,7,18] 2. Lack of flexibility in internal distribution capacity (form, volume, transit time, traceability)[39-130-249]	1. Breech in information/data security (espionage, cyberattack, hardware failure)[124-267-271]. 2. Breakdowns in internal information sharing (reports reach correct staff, prompt response to customer complaints)[39-249] 3. Poorly developed early warning detection systems[130-249].	1. Poor protection of intellectual property[271] 2. Flawed strategic decision making (e.g. high level of bias, poor interpersonal skills, lack of cohesion between departments and limited risk awareness)[133-249-271]. 3. Absence of, or ineffective Contingency Planning (backup power, contingency plans)[40-70]. 4. Poor human resource utilisation (suitable staff training, effectiveness of knowledge transfer between staff levels, knowledge retention)[39-40-70-133-249-269-271] 5. Restricted Corporate Social Responsibility Programme [39]

Largely Uncontrollable — Partially Controllable — Mostly Controllable

Food specific vulnerability sources stem from issues regarding the storage of food as an organic resource, the need to adhere to strict health and safety requirements and aspects related to reactivity to consumer demand given short notice changes in orders and particularly in the chilled ready meal sector, the fairly frequent changes in product specifications compared to other supply chains [20].

At a value chain level, vulnerability sources can again be categorised in terms of RMP, LC, IS, and OMS except that the focus changes to factors affecting supply and demand of raw materials, information and finished goods which stem from value chain partners. A given company will have some level of control over suppliers and customers and this will increase in line with levels of supply chain integration and collaboration. Food specific vulnerabilities arise from raw material quality variability, strict customer requirements, and lose contract (something which is particularly true of supermarkets in the UK who often occupy the most powerful positions in AFSCs and use their purchasing power and proximity to consumers to their advantage) [83]. External sources of vulnerability stem from outside the supply chain in question and can be Financial, Market, Governance, Infrastructural, Societal or Environmental in nature. Some are partially controllable, for example, customer perception can be influenced by marketing, but others such as environmental disasters or terrorist attacks are largely uncontrollable [2]. Food specific external vulnerabilities range from seasonal swings in end consumer demand (e.g. ice cream in summer) to changing health and safety legislation, changing consumer opinion (e.g. GMO) and susceptibility of production systems to anthropogenic pollution.

Based on the authors knowledge and interviews with a number of FDM industry experts, linkages between the 58 categorised causal vulnerability sources and their ultimate failure modes are proposed in Table 8.6. For space related issues, vulnerability classes are referred to in the table by their unique codes as shown in Table 8.5. For example, Value Chain Raw Material and Production Vulnerability 1, *Inconsistent Raw material quality and heterogeneity,* is referred to as VCRMP 1.

8.2.6 FDM-RES Workbook Step 2C (Describing Task 2C1 and Task2C2)

Operationalisation of the conceptual vulnerability taxonomy and the Failure Mode-Vulnerability relationships matrix is facilitated in the FDM-RES Workbook by inclusion of Tables 8.5 and 8.6 as reference charts. By cross referencing shortlisted priority exposures and their failure modes with the taxonomy proposed in Table 8.6, a user is able to significantly refine their ultimate causal vulnerability pool.

Table 8.6: Proposed Failure Mode-Vulnerability relational linkages

Failure Mode	Associated Underlying Vulnerably (Class Code- See Table 8.5)	Associated Underlying Vulnerably (Actual)
FM1. Raw Material Shortage	**Mar.**	4. Variability in availability of raw materials
		5. Variability in demand
	Gov.	3. Political instability
		4. Import/export restrictions
	Inf.	1. Disruption to transport infrastructure
		3. Disruption to energy infrastructure
		4. Disruption to communications
	Soc.	1. Piracy/Terrorism
		2. War and conflict
		6. Criminal acts
		7. Industrial actions
	Env.	1. Natural disasters
		2. Biological factors
		3. Anthropogenic environmental hazards
		4. Unsustainable Primary Production
	VCRMP	4. Outsourcing of Processing Procedures
	VCLC	1. Poor reliability of external logistics providers
	VCIS	1. Lack of established, integrated information sharing infrastructure
	VCOMS	1. Low level of training & experience in other companies' employees.
		3. High concentration in supply chains
	OSRMP	1. Challenges related to storing raw materials/finished inventory
		6. Inability to react to changing circumstances
	OSLC	1. Inaccurate forecasting
		2. Lack of flexibility in internal distribution capacity
	OSIS	1. Breech in information/data security
		2. Breakdowns in internal information handling
		3. Absence of early warning detection systems
	OSOMS	2. Lack of strategic decision making
		5. Insufficient Corporate Social Responsibility Programme.
FM2. Raw Material Sub-Standard Quality	**Mar.**	4. Variability in availability of raw materials (growing seasons, profitability of crop)
		5. Variability in demand
	Gov.	3. Political instability
		4. Import/export restrictions
	Soc.	1. Piracy/Terrorism
		2. War and conflict
	Env.	1. Natural disasters
		2. Biological factors
		4. Unsustainable Primary Production
	VCRMP	1. Inconsistent Raw material quality and heterogeneity
	VCIS	2. Deliberate withholding of information
	OSIS	3. Absence of early warning detection systems
	OSRMP	1. Challenges related to storing raw materials/finished inventory
		6. Inability to react to changing circumstances
	VCOMS	1. Low level of training & experience in other companies' employees.

		2. Poor financial robustness of value chain partners
	OSOMS	2. Lack of strategic decision making
FM3. Unable to produce/ Scrap/Rework	**Gov.**	1. Changes in Public Food Policy
		2. Private Food Policy
	Inf.	1. Disruption to transport infrastructure
		2. Disruption to water infrastructure
		4. Disruption to communications
	Soc.	3. Workforce health
		6. Criminal acts
	VCIS	1. Lack of established, integrated information sharing infrastructure
		2. Deliberate withholding of information
	OSRMP	1. Challenges related to storing raw materials/finished inventory
		4. Insufficient capacity to meet changing order requirements
	OSLC	1. Inaccurate forecasting
	OSIS	1. Breech in information/data security
		2. Breakdowns in information handling
	OSOMS	2. Lack of strategic decision making
		3. Absence of, or ineffective Business Continuity Planning
FM4.Labour Shortage	**Mar.**	5. Variability in demand
	Inf.	1. Disruption to transport infrastructure
		3. Disruption to energy infrastructure
	Soc.	3. Workforce health
		7. Industrial actions
	OSLC	1. Inaccurate forecasting
	OSIS	3. Absence of early warning detection systems
	OSOMS	3. Absence of, or ineffective Business Continuity Planning
		5. Insufficient Corporate Social Responsibility Programme.
FM5: Loss of process economic viability	**Fin.**	1. Market price fluctuation
		2. Currency exchange fluctuations
		3. Interest rate fluctuations
		4. Regional economic downturns
		5. Hostile takeover attempts
		6. Product liability
	Mar.	1. Market decline
		2. Competitive Innovation
		3. Competitor undercutting
	Gov.	1. Changes in Public Food Policy
		3. Political instability
		4. Import/export restrictions
	Soc.	1. Piracy/Terrorism
		2. War and conflict
		4. Household affordability
		5. Changing customer attitudes to consumption
		6. Criminal acts
		8. Poor relations with consumers and special interest groups
	Env.	4. Unsustainable Primary Production
	VCOMS	2. Poor financial robustness of value chain partners
		3. High concentration in supply chains
		4. High levels of power imbalance between actors
	OSOMS	1. Poor protection of intellectual property

FM6: Loss of Site	**Soc.**	6. Criminal acts
	Env.	1. Natural disasters
	OSOMS	3. Absence of, or ineffective Business Continuity Planning
FM7. Unable to Deliver	**Inf.**	1. Disruption to transport infrastructure
		3. Disruption to energy infrastructure
		4. Disruption to communications
	Soc.	6. Criminal acts
		7. Industrial actions
	VCIS	1. Poor reliability of external logistics providers
	OSLC	2. Lack of flexibility in internal distribution capacity
	OSIS	1. Breech in information/data security
		2. Breakdowns in internal information handling
FM8: Legally enforced cessation of activities	**OSRMP**	1. Challenges related to storing raw materials/finished inventory
		2. Product failure to comply with environmental legislation
		3. Product failure to comply with Health and Safety Legislation
FM9. Sub-Standard Product Quality	**Mar.**	4. Variability in availability of raw materials
		5. Variability in demand
	Gov.	3. Political instability
	Inf.	2. Disruption to water infrastructure
	Soc.	1. Piracy/Terrorism
		2. War and conflict
		6. Criminal acts
	Env.	1. Natural disasters
		2. Biological factors
	VCRMP	1. Inconsistent Raw material quality and heterogeneity
		2. Raw material and product related hazards
	VCIS	2. Deliberate withholding of information
	OSRMP	1. Challenges related to storing raw materials/finished inventory
		4. Insufficient capacity to meet changing order requirements
		6. Inability to react to changing circumstances
	OSIS	2. Breakdowns in internal information handling
	OSOMS	2. Lack of strategic decision making
		4. Poor human resource utilisation
FM10: Product Reject/Recall	**Gov.**	2. Private Food Policy
	Inf.	1. Disruption to transport infrastructure
	Soc.	7. Criminal acts
		8. Poor relations with consumers and special interest groups
	Env.	3. Anthropogenic environmental hazards
	VCRMP	2. Raw material and product related hazards
	VCIS	2. Deliberate withholding of information
		3. Lack of ability to trace food across the value chain
	VCOMS	1. Low level of training & experience in other companies' employees.
	OSRMP	1. Challenges related to storing raw materials/finished inventory

A user can further shortlist suggested vulnerabilities by scoring them using a Likert scale in which those scored as 5 are top priority vulnerabilities, those as 4 are secondary vulnerabilities, 3 refers to non-important at present vulnerabilities but which are projected to grow in importance in future, 2 are those vulnerabilities of very limited exposure and 1 represents irrelevant vulnerabilities. Vulnerabilities shortlisted with a 4 or 5 can be entered into the workbook (see Figure 8.3) in preparation for identification of countering resilience elements in Stage 3 (Chapter Nine) of the FDM-RES Framework. Those with a 3 should be logged and reviewed regularly to see if their importance grows.

8.3 Chapter Summary

The purpose of this Chapter has been to describe the conceptual research involved in Stage 2 of the FDM-RES Framework and it application as a practical toolkit in Stage 2 of the FDM-RES Workbook. As such, this Chapter began by outlining the necessity for focussing on vulnerability as a gauge of exposure to negative events and the principle of using exposure metrics and linked Failure Modes to identify a FDM's bespoke vulnerabilities. Step 2A of the FDM-RES Framework described the conceptual formation of a taxonomy of exposure metrics and the method by which they could be applied in a mapping process. Step 2A of the FDM-RES Workbook described the way in which this process would be implemented practically. Step 2B of the FDM-RES Framework concerned the conceptual development of an evaluation system by which high priority exposure metrics could be identified. It also presented a FDM specific taxonomy of Failure Modes and their relations with each of the aforementioned high priority exposure metrics. Step 2B of the FDM-RES Workbook described the practical evaluation of exposure metrics and identification of bespoke Failure Modes. Finally, Step 2C presented a synthesised FDM specific vulnerability taxonomy and proposed linkages between each vulnerability and the Failure Modes which they would ultimately lead to. This was mirrored by Step 2C of the FDM-RES Workbook which described the practical steps involved in using identified Failure Modes to shortlist bespoke vulnerability sources. Chapter 9 moves onto Stage 3 of the FDM-RES Framework/Workbook which concerns matching the causal vulnerabilities identified in this Chapter to countering resilience elements.

Chapter 9: A Tool for Identifying Countering Resilience Elements and their Evaluation

9.1 Introduction

This Chapter details stages 3 and 4 of the FDM-RES Framework and associated Workbook, which describe the selection of resilience elements to counter bespoke vulnerabilities and the evaluation of these elements respectively. As this Chapter refers heavily to a number of codes presented previously in Chapters 7-8, it begins with a small glossary section summarising relevant codes and meanings before moving onto Stage 3 of the FDM-RES Framework/Workbook. Stage 3 consists of three main sections, the first of which presents a conceptually synthesised taxonomy of FDM specific resilience elements. The second section identifies and describes the linkages between bespoke vulnerabilities faced and mitigating resilience elements. The final section describes how these resilience elements can be aligned according to the phase of disruption against which they are most effective. Stage 4 of the FDM-RES Framework concerns the evaluation and implementation of the resilience elements identified in Stage 3. As with previous chapters, each step of the conceptual FDM-RES Framework is followed by a description of the mirroring FDM-RES Workbook step that enables practical implementation of conceptual research contained within the framework.

9.2 Glossary

This Chapter presents a number of relational matrixes concerning the linkages between vulnerabilities and resilience elements and between resilience elements and failure modes. For space related reasons, these matrices draw heavily on coding used for these concepts in previous chapters. Therefore, to aid reader accessibility, a number of relevant keys have been included at the beginning of this chapter for reference. None of these present any new information. Table 9.1 displays FDM Specific Causal Vulnerability Sources Identified in Chapter Eight (Table 8.5). Table 9.2 displays codes for KPIs against which resilience elements can be evaluated (based on taxonomy presented in Chapter Seven (Table 7.1). Finally, Table 9.3 presents the codes and meanings from the FDM specific resilience elements taxonomy presented in Chapter 3 (Table 3.3).

Table 9.1: FDM Specific Causal Vulnerability Sources Identified in Chapter Eight (Table 8.5)

Supply Network Vulnerabilities					
Financial (Fin)	*Market (Mar)*	*Governance (Gov)*	*Infrastructure (Inf)*	*Societal (Soc)*	*Environmental (Env)*
1. Market price fluctuation [39-133-249] 2. Currency exchange fluctuations [39-130-133] 3. Interest rate fluctuations [266] 4. Regional economic downturns [68-114-249-266-267] 5. Hostile takeover attempts [133] 6. Product liability [39]	1. Market decline 2. Competitive Innovation [39-245] 3. Competitor undercutting [95-154]. *4. Seasonal variability in availability of raw materials (growing seasons, profitability of crop)**[134] *5. Variability in demand (seasonal, promotional and bullwhip)**[39-68-133-134-170-267-268]	1. ***Changes in Public Food Policy (e.g. production efficiency targets, health and nutrition guidelines)****[133-138-154-267-268]. 2. ***Private Food Policy (e.g. strict customer requirements on appearance, colour, shape and delivery time)****[138] 3. Political instability (regime changes, corruption)[70-124-245-267] 4. Import/export restrictions [15,5]	1. Transport infrastructure disruptions (pipelines, ports, roads, railways, airports)[70-95-114-124-154-269] 2. Water infrastructure disruptions [70-154] 3. Energy infrastructure disruptions (oil supply/price, electricity grid, gas supply)[70-154-266] 4. Communications infrastructure disruptions (cables, radio masts, satellites)[70-154][133].	1. Piracy/Terrorism[39-51-57-70-134-245-269–271] 2. War and conflict [3,12,13] 3. Workforce health (e.g. flu pandemic)[39-267] 4. ***Proportion of Consumer income available for food purchase**** [266] 5. ***Changing customer attitudes to consumption (e.g. health, lifestyle and fashion foods)****[134-138-267] 6. Criminal acts (such as fraud data hacking and sabotage)[39-114-133-249] 7. Industrial actions (strikes) [39-70-124-134-266-267] 8. Poor relations with consumers and special interest groups (e.g. customer communication, brand image, consumer confidence)[39-267]	1. Natural disasters (both Geological and Meteorological such as earthquakes, drought etc.) [39-68-70-95-114-133-134-138-154-159-245-249-266-269-271] 2. ***Biological factors (e.g. livestock disease, pests)****[70-134-138-249-266] 3. ***Anthropogenic hazards (such as pollution, land contamination)****[39-133-138] 4. ***Unsustainable Primary Production (Land use, loss of biodiversity, climate change)****[266]

Internal and Value Chain Vulnerabilities				
	Raw Material and Production (RMP)	*Logistics Control (LC)*	*Information System (IS)*	*Organisational Management Structure (OMS)*
Value Chain Origin Vulnerabilities (VC)	1. ***Inconsistent Raw material quality and heterogeneity****[124-133-267] 2. ***Raw material and product related hazards (shelf life, cross contamination, handling requirements)****.[39-40]	1. Reliability of external logistics providers[39-70-95-124-130] 2. High levels of geographically distant, outsourcing for which there is no alternative [16,23,24] 3. Strict customer requirements (in terms of lead times and quality) [70]	1. Lack of established, secure and integrated information sharing infrastructure [4,12,13,17,8] 2. Deliberate withholding of information (trust and cooperation)[70-159] 3. ***Lack of ability to trace food across the value chain****[40].	1. Low level of training & experience in other companies employees[70-95] 2. Poor financial robustness of value chain partners (exposure to bankruptcy or takeover) [95-124-154-159-245-267] 3. High concentration in supply chains (i.e. actors serving as both suppliers and competitors in different contexts)[70-124] 4. ***High levels of power imbalance between actors (contractual fairness and level of lock in)**** [70-124]
Organisation Specific Origin Vulnerabilities (OS)	1. ***Challenges related to storing raw materials/finished inventory (for example, storage requirements and ability to maintain ambient conditions)****[40]. 2. Product failure to comply with environmental legislation*[39-130-249] 3. Product failure to comply with Health and Safety Legislation. *[39-130-249] 4. Insufficient capacity to meet changing order requirements [39-70-130-166-170-245-267] 5. ***Inability to react to changing circumstances (ability to quickly substitute raw materials or ramp up production/ decrease lead time)****[70-249]	1. Inaccurate forecasting (e.g. subjective decision making) [3,5,7,18] 2. Lack of flexibility in internal distribution capacity (form, volume, transit time, traceability)[39-130-249]	1. Breech in information/data security (espionage, cyberattack, hardware failure)[124-267-271]. 2. Breakdowns in internal information sharing (reports reach correct staff, prompt response to customer complaints) [39-249] 3. Poorly developed early warning detection systems[130-249].	1. Poor protection of intellectual property[271] 2. Flawed strategic decision making (e.g. high level of bias, poor interpersonal skills, lack of cohesion between departments and limited risk awareness)[133-249-271]. 3. Absence of, or ineffective Contingency Planning (backup power, contingency plans)[40-70]. 4. Poor human resource utilisation (suitable staff training, effectiveness of knowledge transfer between staff levels, knowledge retention)[39-40-70-133-249-269-271] 5. Restricted Corporate Social Responsibility Programme [39]

Largely Uncontrollable
Partially Controllable
Mostly Controllable

Table 9.2 Codes for KPIs against which resilience elements are evaluated (based on taxonomy presented in Chapter Seven (Table 7.1).

KPI	KPI Sub-Pillar: Economic (E)	KPI Sub-Pillar: Social (S)	KPI Sub-Pillar: Environmental (ENV)
Cost (C)	**(CE1)** Raw Material Cost	**(CS1)** Human Rights Standards of Suppliers	**(CENV 1)** Environmental Standards of Suppliers
	(CE2) Utilities cost (water, electricity, gas, waste disposal)	**(CS2)** Social impact of utility generation and disposal	**(CENV 2)** Environmental legislation compliance
	(CE3) Inventory Carrying Cost	**CS3)** Job Satisfaction	
	(CE4) Spare Capacity Cost		
	(CE5) Staff Cost	**(CS4)** Fair Salary	**(CENV3)** Natural Capital Valuation
	(CE6) Gross Value added	**(CS5)** Labour Relations	
	(CE7) Market Concentration	**(CS6)** Regional employment	**(CENV4)** Environmental risk management procedure
	(CE8) Profit margins		
	(CE9) Net Profit	**(CS7)** Philanthropy and Local Community Investment	
Service Level (SL)	**(SLE1)** Order Fulfilment Time	**(SLS1)** Regular Review of Worker Rights	**(SLENV1)** End of Life Planning and Circular Economy
	(SLE2) Contract Fulfilment		
	(SLE3) Customer Responsiveness	**(SLS 2)** Occupational Health and Safety	
		(SLS 3) Employee Diversity: and Equal Opportunities	
	(SLE4) Customer Satisfaction	**(SLS 4)** Corporate Attitude to risk management	
	(SLE5) Traceability of incoming raw materials and outgoing produce		
Efficiency (E)	**(EE1)** Raw Material to Finished Product Conversion Rate	**(ES1)** Employee Appraisal and Development Systems	**(EENV1)** Energy, Water and Raw Material Efficiency During Manufacturing
			(EENV2) Emissions Related to Manufacturing
	(EE2) Employee productivity	**(ES2)** Average Employment Retention Rate	
		(ES3) Corruption	
Quality (Q)	**(QE1)** Safety of Goods	**(QS1)** Health and Nutrition of Goods	**(QENV1)** Animal Welfare
	(QE2) Shelf Life		
	(QE3) Product Reliability and Convenience	**(QS2)** Private labelling standards that go beyond legislative requirements	**(QENV2)** Production Certification Schemes that go beyond legislative requirements
		(QS3) Societal benefit of product	
		(QS4) Smell and Noise Reduction	**(QENV3)** Presence of emissions reduction and resource efficiency enhancement targets

Table 9.3: Codes and meanings from the FDM specific resilience elements taxonomy presented in Chapter 3 (Table 3.3)

Supply Network Resilience (SNR)	SNR 1. Collaboration
	SNR 2. Flexibility
	SNR 3. Visibility
	SNR 4. Adaptability
	SNR 5. Velocity
	SNR 6. Redundancy
	SNR 7. Node Criticality
	SNR 8. Established Communication Lines
	SNR 9. Robustness
	SNR 10. Trust
	SNR 11. Cohesion
	SNR 12. Contingency Plans
	SNR 13. Diversity
	SNR 14. Network Complexity
	SNR 15. Bargaining Power
	SNR 16. Community resources

Organisational Resilience (OR)	OR1. Agility
	OR 2. Flexibility
	OR 3. Risk Aware Culture
	OR 4. Redundancy
	OR 5. Early Warning Detection Systems
	OR 6. Security
	OR 7. Efficiency
	OR 8. Inventory Management
	OR 9. Financial Strength
	OR 10. Leadership Commitment
	OR 11. Relationships
	OR 12. Risk Management
	IO 13. Business Continuity
	OR 14. Human Resource Management
	OR 15. Innovation
	OR 16. Knowledge Management
	OR 17. Market Position
	OR 18. Adaptive Management

9.3 Overview of FDM-RES Framework/Workbook Stages 3 and 4

Stage 3 of the FDM-RES Framework concerns the conceptual research required to ensure that the optimal resilience elements are matched to the vulnerabilities identified in Stage 2 and Stage 4 proceeds to analyse selected resilience elements to ensure that they are synergistic with wider company goals and sustainability requirements established via the KPIs in Stage 1. This is summarised in Figure 9.1.

Stages 3 and 4 of the FDM-RES Framework therefore detail a substantial volume of novel conceptual research, beginning with the development of a unified and FDM specific taxonomy of resilience elements, complete with practical actions for each (Step 3A). As identified in the research gap analysis at the end of the review section in Chapter Five, the linkages between vulnerabilities and resilience elements are also poorly established in the literature, therefore Step 3B of the FDM-RES Framework adds substantially to the research field in a conceptual manor by pulling together linked vulnerabilities-resilience elements in the literature and augmenting them with industrial viewpoints.

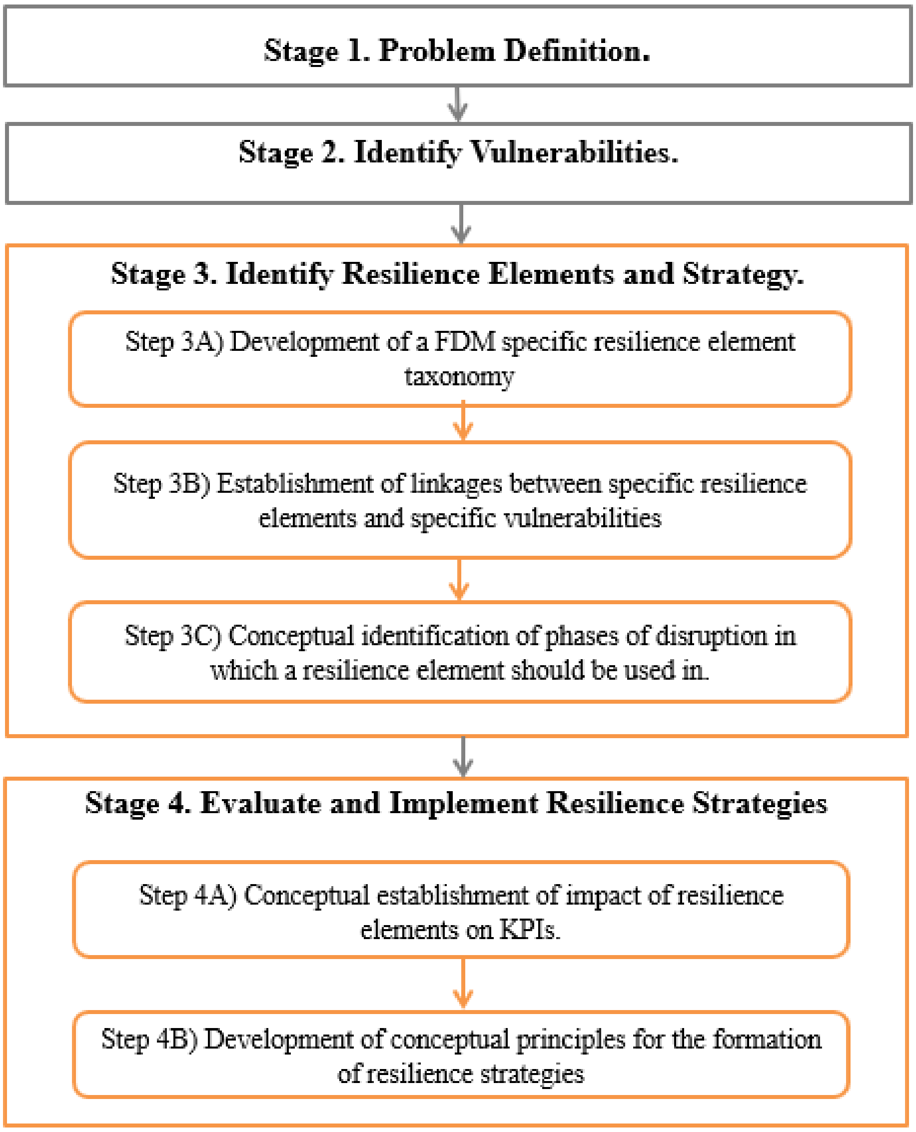
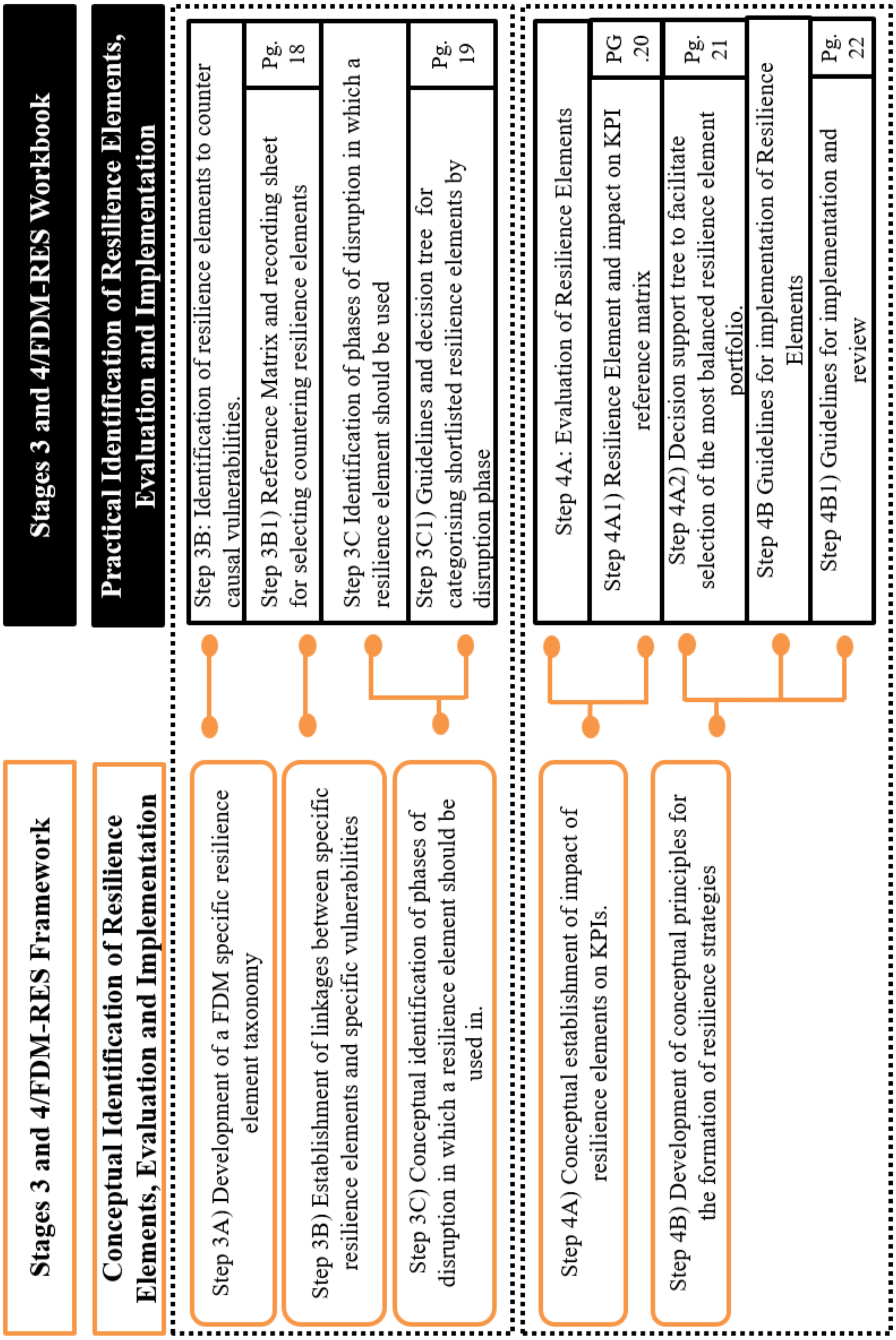


Figure 9.1 Overview of Stages 3-4 of the FDM-RES Framework.

Stage 4 of the FDM-RES Framework involves the novel linkages of individual resilience elements to FDM specific KPIs (as presented in Chapter 7, Table 7.1), based on food specific industrial interviews in order to provide a measurement by which to evaluate resilience elements. Following the format established in previous chapters, each of the aforementioned conceptual research steps within stages 3 and 4 of the FDM-RES Framework are mirrored by guidelines for practical application in the FDM-RES Workbook as shown in Figure 9.2.

Figure 9.2: Overview of the practical workbook stages involved in operational use of FDM-RES Framework Stages Three and Four



9.4 FDM-RES Framework Stage 3

Stage 3 of the FDM-RES Framework explores the linkages between the vulnerabilities identified in Stage 2, and specific resilience elements that can mitigate them.

9.4.1 FDM-RES Framework Step 3A

This step concerns the conceptual synthesis of a FDM specific taxonomy of resilience elements. The systematic review in Chapter 3 identified 61 articles from multiple academic disciplines which proposed one or more key elements for resilience. Many of these sources were inconsistent with the nomenclature they used for these resilience elements, but by analysing resilience elements based on their functional aspects (i.e. descriptions of the purpose and functional characteristics of a resilience element), rather than name, 34 unique resilience elements were identified overall. As in Chapter 3, these resilience elements were categorised according to whether they should be applied in response to 'organisational disruptions' (for example, machinery faults) or 'supply network disruptions' (for example, loss of a specific supplier), in which case, elements addressed ways in which the supply chain could collectively adapt. This breadth of resilience elements has, to the author's knowledge, not been attempted previously in the literature.

Further exploration of the functional aspects of these 34 resilience elements highlighted that some were much narrower in focus than others, and effectively slotted into the scope of broader elements. For example, flexibility is a broad element concerning the ability to call upon alternative options when responding to a disruption. The resilience elements of 'Community Resources' (alternative non-industry options an FDM can utilise in light of a disruption) and 'Node Criticality' (the design of value chains to avoid bottleneck entities) both refer to the provision of such alternative options in a narrower way. This is not to proclaim that they are the same element, simply that the narrower scope elements help enable the broader scope elements. These are now referred to as "Supporting" and "Core" resilience elements respectively and are displayed with respect to their 'organisational' and 'supply network' focus in Figure 9.3.

The relationship between each "core" element and its "supporting" elements is now described in more detail, beginning with an organisational focus.

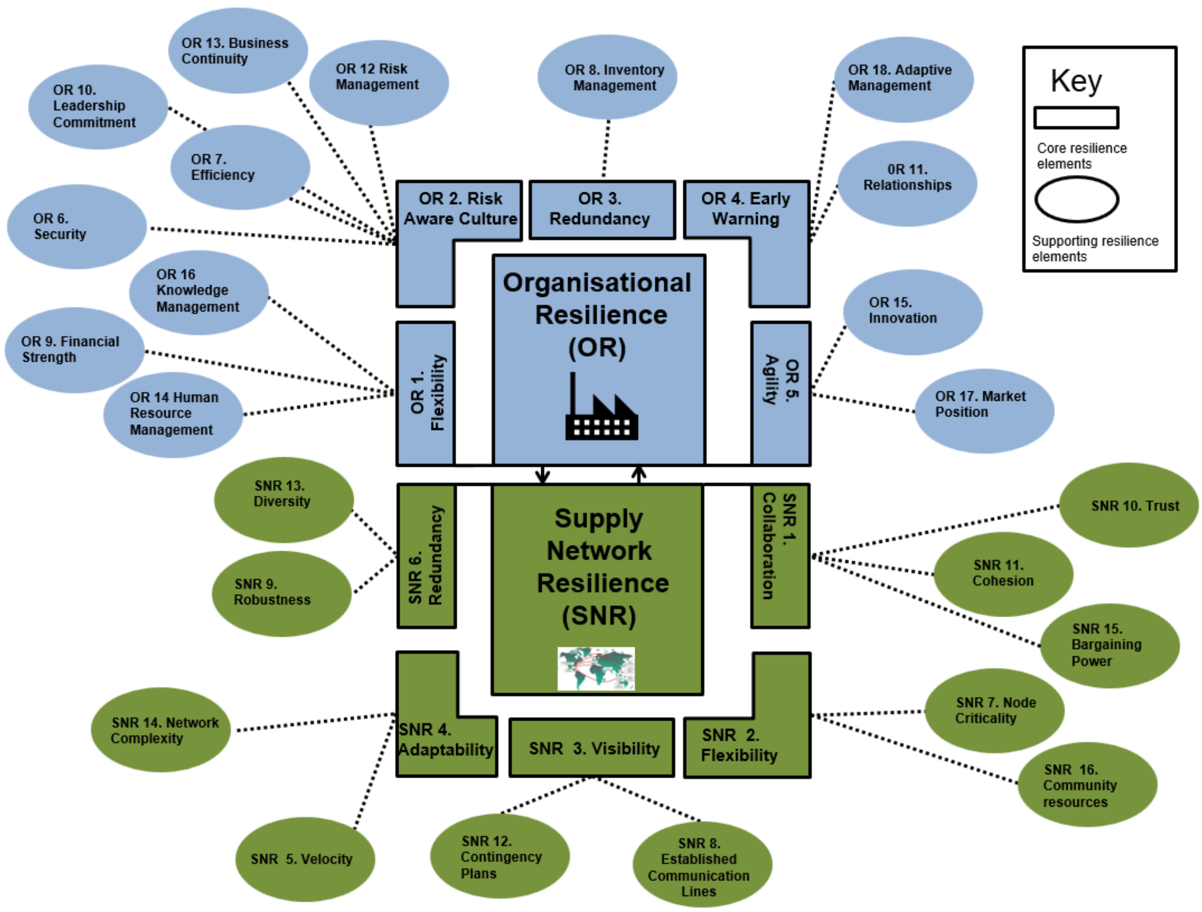


Figure 9.3: Proposed categorisation of the 34 resilience elements identified by review into broad "Core" and specific "Supporting" Elements from an organisational (blue) and supply network (green) perspective.

9.4.1.1 Proposed 'Core' and 'Supporting' Organisational (OR) Resilience elements

OR 1: Flexibility. For most organisations, there will be two broad areas in which flexibility can be implemented; at sourcing and at production/distribution [46]. At sourcing, flexibility concerns ability to quickly change inputs (or mode of receiving inputs) through utilization of common product platforms, product modularity, multiple pathways, supply contract flexibility and alternate suppliers [138]. At production and distribution, flexibility entails the ability to quickly change outputs or the mode of delivery, for example, via multi-sourcing, delayed commitment/production, alternate distribution channels and fast re-routing of requirements [166]. 'Financial Strength' (OR9) concerns easily accessible liquid assets and so is a pre-requisite for many of the aforementioned flexibility options [46]. 'Human Resource Management' (OR 14), and 'Knowledge Management' (OR 16) concern aspects of how skills are developed, utilised and retained in an organisation so as to be able to rapidly adapt to changing job roles in a disruption [21, 58]. Both are important enablers of an organisation being able to switch sourcing inputs, production processes and distribution approaches.

OR 2: Risk Aware Culture. Risk aware culture broadly describes the infrastructure a firm has in place to manage risk. It goes beyond risk management in the sense of an assigned individual(s) simply identifying and mitigating risks on a case by case basis [49, 107]. Instead, it concerns the presence of a culture that encourages and enables organisation wide learning and adaptation from past disruptions and also leadership that espouses this [46, 70]. It has been suggested that this may manifest in the form of high organisation wide efficiency, the presence of a business continuity team and/or active risk management and a high degree of joint decision making [22, 48, 169]. These principals are clearly reflected in the resilience elements 'Business Continuity' (OR 13), 'Risk Management' (OR 12) and 'Efficiency' (OR 7). However, 'Security' (OR 6), which is an important physical risk reducer and 'Leadership Commitment' (OR 10) which is vital to the aforementioned joint decision making, can both also be seen as supporting elements.

OR 3: Redundancy. Firm level redundancy concerns excess capacity to what is normally required. In this way it buffers normal activities rather than providing options to do things differently as is the case with the element of 'flexibility'. Common examples could include surplus raw materials, holding surplus finished inventory, or surplus to normal production capacity [102]. However, such approaches typically come at the cost of reduced efficiency, and must be matched on an individual basis to specific identified risks [130, 270]. It has been suggested that redundancy is best targeted at risk sources from beyond supply chain boundaries (such as natural disasters) and that elements such as 'flexibility' are more effective for dealing with intra- supply chain disruptions [118]. In either case, 'Inventory Management' (OR 8) which concerns accurate and fast rerouting of internal stock is a major component of managing such buffers efficiently [51, 160].

OR4: Early Warning Detection Systems

Early warning detection systems concern a broad suite of attributes aimed at providing enhanced foresight of disruption so that an organisation can spend more time preparing for and less time reacting to disruption. It includes monitoring abilities in the form of physical IT infrastructure as well as the staff training and internal information flows that allow effective utilisation of information obtained and is of particular significance with the rise of 'Big Data' and The Internet of Things (IOT). As such, actions such as 'Adaptive Management' (OR 18) which concerns how an FDM learns from past disruptions and adapts operations based on these experiences, and 'Relationships' (OR 11) which concerns how information in relayed between internal teams are both important supporting elements [55, 271].

OR5: Agility. Agility is closely related to flexibility, but whereas flexibility concerns alternative ‘options’, agility relates to how these options are used and particularly the speed at which they can be implemented to recover lost functionality [116]. Interestingly, whilst agility focuses on quick recovery, it does not always have to involve the most efficient response [143, 272]. At an Organisational level, it concerns considerations such as ability to reduce production times, setup times and to change production capacity at speed. Therefore ‘Innovation’ (OR 15) which concerns the presence of shared beliefs, openness to learning and joint decision making is a key passive enabler of quickly adapting as an organisation [22, 107]. ‘Market Position’ (OR 17) is also a key enabler of agility as it concerns how factors such as the management of brand equity, customer loyalty, market share and product differentiation can allow an FDM to make the most of an unexpected disruption [46]. For example, in a disruption, a strong brand image combined with good customer communication can enable a supplier to promote substitute product lines, perhaps even securing future market share.

9.4.1.2 Proposed ‘Core’ and ‘Supporting’ Supply Network (SNR) Resilience Elements

SNR 1: Collaboration. Collaboration refers to two or more actors working together to generate advantages that could not be achieved individually [110-113, 165]. This can range from sharing of limited information to joint decision making, synchronisation of operations, and more equal sharing of risk and assets, depending upon end consumer need and the level of trust between partners [99, 109]. A number of supporting elements are important in enabling Collaboration to occur effectively and these include ‘Trust’ (SNR 10), ‘Cohesion’ (SNR 11), and ‘Bargaining Power’ (SNR 15).

SNR 2: Flexibility. In a supply chain context, flexibility concerns the degree by which a supply chain can maintain function and respond effectively to changing environment and customer requests through partnerships [272]. It concerns alternate options that partners or the wider operating environment can provide, for example, postponement options, alternate infrastructure, logistics or staff [47, 94]. ‘Node Criticality’ (SNR 7) which concerns relative numbers of single key supplier or buyers in a supply chain is a key aspect [120]. ‘Community Resources’ (SNR 16) which considers the range of ecological, economic, social, physical, institutional and cultural resources a community can draw upon when faced with disruption is highly important from a FDM flexibility perspective [269].

SNR 3: Visibility. Visibility is a key supply chain scale resilience element. It concerns the ability to see structures, products and processes from one end of the supply network to the other. Clearly, there is major overlap with ‘Established Communication Lines’ (SNR 8) which concerns effective and efficient flow of information from one end of the supply chain to the other [44, 119]. However, it is not just about information flowing in from the supply chain, but about directing the right knowledge to the right people at the right time [108, 121]. Therefore, ‘Established Communication Lines’ (SNR 8) and the presence of Cross-Value Chain ‘Contingency Plans’ (SNR 12) are of high importance. Together, these ensure that information about company processes and assets or about the wider operating environment such as consumer trends, and competitor technology arrives at the appropriate person and that that person has a pre-established set of guidelines for what to do if something goes wrong.

SNR 4: Adaptability. Adaptability is a measure of a system’s ability to adapt incrementally or to completely transform in response to a changing operating environment [82]. To be able to do so, it is important for supply chains to possess Self-Organisation which refers to the autonomy and power of a system to realign itself as opposed to being completely at the whim of external forces [20, 41]. For example, this might refer to a cross-value chain disruption response team that collectively agrees upon and implements a course of action, as opposed to a value chain of spot market buyer-sellers who are completely at the whim of outside forces, such as fluctuations in raw material availability. Of key importance to this is the speed at which value chain partners can collectively react. As such, ‘Velocity’ (SNR 5) which concerns the speed and efficiency with which products traverse a supply chain is crucial [45-46, 112]. Equally, the ‘Network Complexity’ (SNR 14) of a value chain’s wider supply network will affect the speed at which the value chain adapts [98, 103].

SNR 5: Redundancy. Redundancy at a supply chain scale concerns system wide design of emergency back up and storage facilities, surplus pathways between nodes and the extent to which different supply chain nodes and components are replaceable [81, 125, 274]. An important supporting element is ‘Robustness’ (SNR 9) which is a marker of system ability to absorb sudden change without losing core functionality [160]. ‘Diversity’ (SNR 13) has been linked to redundancy in the context of different skill sets that can be employed to reach the same outcome at a supply chain level [96, 102].

Using the ‘core’/’supporting’ categorisation system, each resilience element was categorised alongside their practical actions into a unified taxonomy. This was achieved based on actions provided for each element in the literature (see Chapter 3) but also made FDM specific through a number of preliminary industry interviews. The proposed taxonomy alongside respective actions for each, based on the categorisation system proposed in Figure 9.2 can be found in Table 9.4.

Table 9.4 Taxonomy of 'Core' Resilience Elements and practical actions for each

<table>
<tr><th colspan="2">Organisational Resilience</th><th colspan="2">Supply Network Resilience</th></tr>
<tr><td>Core Resilience Element</td><td>Practical Actions</td><td>Core Resilience Element</td><td>Practical Actions</td></tr>
<tr><td rowspan="6">OR 1. Flexibility</td><td>OR1: Ensure that alternative raw material supplies that match customer product specifications and internal manufacturing specifications are available. For example, this may be achieved by maintaining at least one secondary supplier on a rolling low order volume just in case.</td><td rowspan="5">SNR 1. Collaboration</td><td>SNR 11: Integration of systems with suppliers/clients. This may entail:
i) Integrated order and delivery scheduling across two or more partners in a value chain.
ii) Linked complaints evaluation software between two or more value chain partners.</td></tr>
<tr><td>OR1: Ensure that production lines can accept substitute ingredients. For example, by ensuring:
i) Production line ability to deal with slightly different shapes, sizes and cooking times.
ii) Careful design of labelling to accommodate potential changes to 'free-range' or 'GM Free' status of supply.</td><td>SNR 1: Coordination of activities, including product design, with suppliers/clients. For example, by involving suppliers in discussion with retailers over new product design.</td></tr>
<tr><td>OR1: For larger FDMs, the ability to switch production between sister sites. Achieved via cross training of staff and tactical design of equipment/processes for interoperability between sites.</td><td>SNR 10: Sharing of risk with supply chain suppliers/clients via moves away from spot market, buyer seller relations to contractual long-term partnerships with established cross-value chain disaster response teams.</td></tr>
<tr><td>OR1: Where sister sites are not available, of it is impractical to use them, to ensure the availability of suppliers to whom processing can be outsourced at short notice.</td><td>SNR 15: Avoidance of asymmetric supply chain relationships via:
i) Avoidance where possible of unfair contracts with large retailers where penalties are high, and collaboration is low.
ii) Avoidance where possible of using small suppliers who would not have the financial robustness to cover liability costs in the event of a disruption that was found to be their fault.</td></tr>
<tr><td rowspan="2">OR 9: Ensuring that finance is readily available in the event of a disruption.
i) Depending on FDM size, this may entail including a good number of liquid assets in the company portfolio.</td><td>SNR 11: Development of cohesive supply chain standards concerning types of production processes and raw materials that are not allowed and the integration of this into the auditing processes of all value chain partners.</td></tr>
<tr><td>SNR 2. Flexibility</td><td>SNR 2: Ensure that additional carriers are available at short notice which can fulfil the specific product requirements for that stage of the value chain.</td></tr>
</table>

	OR 14/16: Ensuring that staff skillsets are broad and that there is a high level of company knowledge retention so that staff can respond to novel situations and cover different roles more easily in the event of a disruption. This may entail: i) Internal secondments and graduate schemes ii) Strong staff support, from competitive salaries to continued professional development training and career support.		**SNR 7:** Ensure that alternative suppliers who match customer specifications are available for use a short notice. This may entail: i) A streamlined supplier audit process for emergency situations ii) Established communication protocols with customers to ensure the smoothest possible transition iii) Careful design of labelling with regard to origin and production technique claims**.**
			SNR 2: Selection of suppliers/clients based on flexibility of capacity. This may entail: i) Supplier ability to produce higher or lower volumes at short notice. ii) Supplier ability to increase/decrease frequency of deliveries.
OR 2. Risk Aware Culture	**OR 6**: Presence of Information and Physical Security. This may entail: i) Internet security packages. ii) Storage of critical information such as production schedules in multiple, secure locations. iii) Site physical security. iv) Production line security such as metal detectors to identify contamination.		**SNR 16:** Ensuring that FDM activities align well with local communities, for example: i) Ensuring that reliable local transport and housing is available for the FDM workforce. ii) Ensuring that peak FDM power water draws do not clash with high local peak demand. ii) Ensuring that the FDM is actively involved in all local infrastructure developments (i.e. roads, flood defences, green sites).
	OR 7: Efficiency standards such as six sigma.	SNR 3. Visibility	**SNR 8**: Timely sharing and updating of demand forecasts with suppliers and buyers.
	OR 12/13: Infrastructure in place to manage risk such as Business Continuity and Enterprise Risk Management.		**SNR 12:** Presence of risk management strategies throughout operations of all supply chain partners.
	OR 10: Ensure that resilience strategies are cohesive across the entire organisation, rather than ad hoc individual team strategies, via consistent senior director which factors resilience into all new strategic ventures (i.e. new product launches, acquisition of new companies).		**SNR 3:** Creation of integrated value chain material traceability systems. For example, via physical or electronic (RFID) tags which allow the traceability of individual food products from production to retail.
			SNR 8: Creation of integrated and efficient communication protocols with value chain partners.

OR 3. Redundancy	**OR 3**: Spare capacity which may take the form of: i) Designing in capacity to hold surplus raw materials. ii) Designing in extra production line capacity. iii) Designing in capacity to hold surplus finished inventory.	SNR 4. Adaptability	**SNR 15/5**: Reducing geographic distance to suppliers and customers where possible. When not, efforts should be made to ensure long distance suppliers are involved with low complexity, small volume and high market use products to ensure they are unlikely to be delisted overnight and that any disruption will have a minimal impact on FDM performance.
	OR 8: Ensuring that adequate Inventory Management systems are in place to maintain order scheduling and shelf life of all spare capacity generated by **OR 3.**		**SNR 4**: The ability of a value chain to self-organise by collectively agreeing standards and protocols and to communicate this effectively.
OR 4. Early Warning Systems	**OR 18**: Ensuring that past disruptions are learnt from to provide foresight and to extend preparation time for future possible disruptions. For example, via regular formal evaluation meetings with designated individuals from all teams.	SNR 6. Redundancy	**SNR 13**: Existence of alternative physical routes, such as roads, rail and shipping lanes, between a FDM and suppliers/customers.
	OR 11: Ensure that cohesive relationships exist between all teams. In particular, this should involve established communication protocols between teams concerning what to share, with whom and when.		**SNR 9**: Design of the value chain so that there is some slack to absorb disruption for a defined time period whilst still maintaining function. This could entail: i) The buffering effect of Supplier/FDM/Customer Depots ii) Availability of 3PL chillers storage facilities within the value chain. iii)The ability of certain supply chain entities (particularly wholesalers and suppliers) to hold surplus inventory.
OR 5. Agility	**OR 5**: Implement strategies which allow the rapid reduction of production times at short notice. This may involve: i) Contingency plans to facilitate staff availability. ii) Ability to reduce shift change over times. iii) Guidelines on acceptable trade-offs on quality for gains in time and volume.		
	OR 5: Ability to reduce set up times. For FDMs major factors will likely include: i) Contingency plans to facilitate staff availability. ii) Guidelines on acceptable trade-offs on quality for gains in time and volume.		
	OR 15/17: The ability to take advantage of disruption thus going beyond recovery and enabling growth. This may entail: i) Presence of established communications channels with end consumers, perhaps via retailers to promote product differentiation or even substitute products and thus secure market share.		

Having completed Step 3A of the FDM-RES Framework, this Chapter now moves on to Step 3B. The FDM-RES Workbook does not cover Step 3 A as at this point, the resilience element taxonomy displayed in Table 9.1 cannot be implemented without knowing which vulnerability source each resilience element targets. Therefore Stage 3 of the FDM-RES Workbook also begins at Step 3B.

9.4.2 FDM-RES Framework Step 3B

Step 3B uses findings from the systematic review in Chapter 3 (Table 3.7) in addition to Industry interviews to propose conceptual linkages between the FDM specific causal vulnerabilities proposed in Stage 2 of the FDM-RES Framework and the FDM specific resilience elements proposed in Table 9.1. These can be seen from an organisational perspective in Table 9.5 and from a supply network perspective in Table 9.6.

Table 9.5: Proposed linkages between organisational resilience elements and target vulnerabilities.

Proposed Organisational Resilience Elements-Vulnerability Linkages		
Core resilience element	**Supporting resilience element**	**Linked causal vulnerability that use of this resilience element can mitigate**
OR 1: Flexibility		***Fin:*** 1; ***Mar:*** 2-5; ***Gov:*** 1-4; ***Inf:*** 1-4; ***Soc:*** 1,2, 6, 7; ***Env:*** 1-3; ***VCRMP***:1; ***VCLC***: 1,2; ***VCOMS***: 2-4; ***OSRMP***: 4-5; ***OSLC***:1,2
	OR 9: Financial Strength	***Fin***: 1-6; ***Mar***: 4, 5; ***Gov***: 4; ***Inf***: 1-4; ***Soc***: 1,2,3,6,7; ***Env***: 1-3; ***VCRMP***: 1; ***OSRMP***:2,3, 5
	OR 14: Human Resource Management	***Mar***: 2; ***OSRMP***: 1,2,3,5; ***OSLC***: 1; ***OSIS***: 1,2; ***OSOMS***: 1,2 and 4
	OR 16: Knowledge Management	***Mar***: 4,5; ***Gov***: 1,2; ***Soc***: 8; ***VCRMP***: 2; ***VCLC***:3; ***OSLC***: 1; ***OSRMP***: 1,2,3; ***OSOMS***:2
OR 2: Risk Aware Culture		***Fin:*** 5, 6; ***Mar***: 4; ***Gov***: 1,2; ***Inf***: 1-4; ***Soc***: 4, 5, 8; ***Env***: 4; ***VCRMP***: 2; ***OSRMP***: 1,2,3; ***OSIS***: 3; ***OSOMS***:1-5
	OR 6: Security	***Fin***: 6; ***Soc***: 6, 8; ***OSRMP***: 1; ***OSIS***: 1; ***OSOMS***: 1
	OR 7: Efficiency	***Mar***: 2, 3; ***Gov***: 2; ***Env***: 4; ***VCRMP***: 1; ***VCLC***: 2,3;
	OR 10: Leadership Commitment	***Fin:*** 5; ***Mar:*** 2; ***Soc:*** 4,5, 8; ***Env: 4***; ***VCIS***: 1, 3; ***OSIS***: 3; ***OSOMS: 1-5***
	OR 12: Risk Management	***Fin***: 1-6; ***Mar:*** 4,5; ***Gov***: 3-4; ***Inf***: 1-4; ***Soc*** 1-3,6-8; ***Env***: 1-4; ***VCRMP***: 2; ***OSRMP***: 1,2,3: ***VCLC***: 1; ***OSIS***: 1,2; ***VCOMS***: 2; ***OSOMS***: 3;
	OR 13 BCM	***Inf***: 1-4; ***Soc***: 3, 6, 7; ***Env***: 1; ***OSRMP: 1; OSIS:*** 1,2 ***VCOMS***: 3
OR 3: Redundancy		***Fin***: 1; ***Mar*** 4, 5; ***Gov***: 4; ***Inf***:1-4 ***Soc***: 1,2; ***Env***: 1-3; ***VCRMP***: 1; ***OSRMP***: 4; ***VCLC***: 2; ***OSLC***:1;
	OR 8: Inv. Man.	***OSRMP***: 4,5; ***VCLC***: 3; ***OSLC***: 1-2; ***VCIS***: 3
OR 4: Early Warning		***Fin***: 1,4; ***Mar***: 1, 4, 5; ***Gov***: 1,4; ***Inf***: 1-4; ***Soc***: 1-8; ***Env***: 1-4; ***OSIS***:1; ***VCOMS***: 2
	OR 11: Relationships	***VCRMP***:2; ***VCLC***: 3; ***VCIS***: 1,2; ***VCOMS***: 1,2; ***OSRMP***:1,2,3; ***OSLC***:1; ***OSIS***: 2; ***OSOMS:*** 2,4
	OR 18: Adaptive Management	***Mar***: 3,4, 5; ***Inf***: 1-4; ***Env***: 4; ***VCRMP***: 2; ***OSRMP***: 1-5; ***VCIS:*** 1,3; ***OSIS***:1-3; VCOMS: 3,4; ***OSOMS***: 1-5
OR 5: Agility		***Gov***:3,4; ***Inf***: 1-4; ***Soc***:1,2,6-8; ***Env***: 1-3; ***VCRMP***: 1; ***OSRMP***: 4,5 ***OSLC***: 1; ***VCIS***: 2,3
	OR 15: Innovation	***Mar***: 1-5; ***Soc***: 4, 5; ***VCOMS:*** 3,4
	OR 17: Market Position	***Fin***: 1, 4, 6; ***Mar***: 1-5; ***Soc***: 4, 5, 8; ***Env***: 4; ***VCRMP***: 1

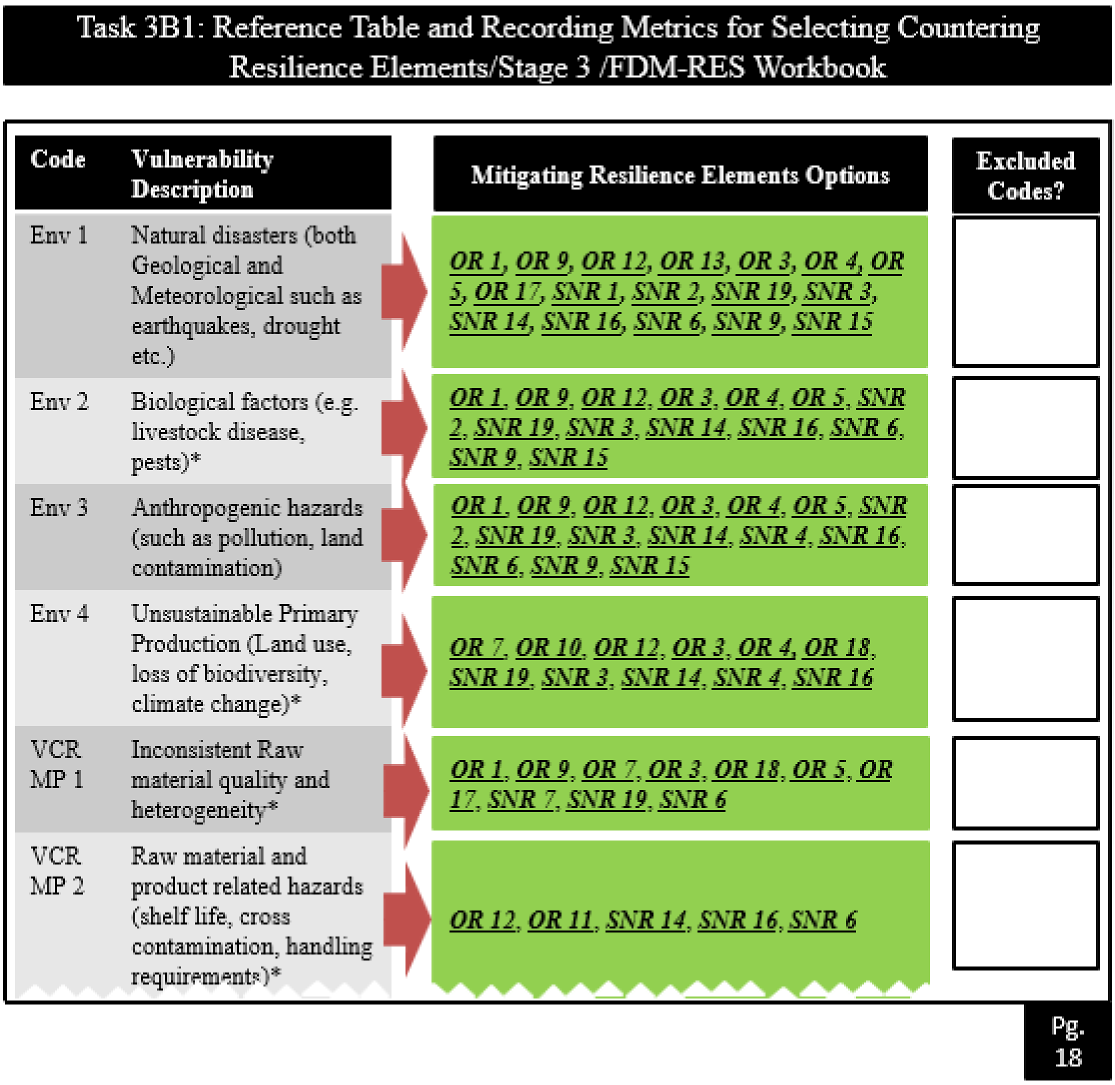
Table 9.6: Proposed linkages between supply network FDM resilience elements and the causal vulnerability sources which they mitigate.

Proposed Supply Network Resilience Elements-Vulnerability Linkages		
Core resilience element	**Supporting resilience element**	**Linked causal vulnerability that use of this resilience element can mitigate**
SNR 1: Collaboration		***Mar***: 1,4; ***Gov***: 1,2; ***Env***: 4: ***OSLC***:1; ***VCIS***:1,3; ***VCOMS***:1, 2,4
	SNR 10: Trust	***Gov***:2; ***VCIS***:2,3, ***VCOMS***: 4
	SNR 11: Cohesion	***Mar***: 3-5; ***Gov***: 1,2, 4; ***Soc***:4,5,8; ***VCLC***: 1; ***VCIS***:1-3; ***VCOMS***: 1,3,4
	SNR 15: Bargaining Power	***Gov***: 2; ***VCLC***:3; ***VCOMS***:3,4
SNR 2: Flexibility		***Gov:*** 3,4; ***Inf***:1-4; ***Soc***:1, 2, 7; ***Env***: 1-3
	SNR 7: Node Criticality	***Mar***: 4-5; ***Gov***: 3,4; ***VCRMP***: 1; ***VCLC***:1-3; ***VCOMS***: 1-4
	SNR 16: Community Resources	***Mar:4; Inf***:1-4; ***Soc***: 6-8 ***Env***:1-4; ***VCRMP***: 1
SNR 3: Visibility		***Fin***: 1-3; ***Mar***: 2,4,5; ***Inf***: 1,4; ***Soc***: 1-8 ***Env***:1-4
	SNR 8: Established Communications Lines	***VCLC:*** 2,3***;*** ***VCIS***:1-3; ***VCOMS***:1,2
	SNR 12: Contingency Plans	***Fin***: 1-6; ***Mar:*** 4,5; ***Gov***: 3-4; ***Inf***: 1-4; ***Soc*** 1-3,6-8; ***Env***: 1-4; ***VCRMP***: 2; ***OSRMP***: 1,2,3: ***VCLC***: 1; ***OSIS***: 1,2; ***VCOMS***: 2; ***OSOMS***: 3;
SNR 4: Adaptability		***Fin: 4; Gov***: 1-4; ***Soc*****:** 4,5***;*** ***Env***: 3,4; ***VCIS***: 1,3; VCOMS: 3,4
	SNR 5: Velocity	***Mar***: 2,3,4,5; ***VCLC***: 3; ***VCIS***: 3;
	SNR 14: Network Complexity	***Mar***: 5; ***Gov***: 3,4; ***Inf***:1,4; ***Env***: 1-4; ***VCRMP***: 2; ***VCLC***: 2; ***VCIS***:3; ***VCOMS***: 1,2
SNR 6: Redundancy		***Mar***: 4,5; ***Inf***:1; ***Env***: 1-3; ***VCRMP***: 1,2; ***VCOMS***: 2
	SNR 9: Robustness	***Fin***: 1-3; ***Mar***: 2-5; ***Gov***: 3,4; ***Soc***: 1, 2,3,6,7; ***Env***; 1-3; ***VCIS***: 1; ***VCOMS***:2
	SNR 13: Diversity	***Fin: 4; Mar***: 1,4,5; ***Inf***:1-4; ***Env***: 1-3 ***VCLC***:1; ***VCOMS***:2

Having outlined the conceptual relational links between internal and value chain specific resilience elements and the vulnerability sources they respectively address, this Chapter now moves to describe their practical application in Step 3B of the FDM-RES Workbook

9.4.3 FDM-RES Workbook Step 3B.

The shortlist of causal vulnerability factors an FDM-RES Workbook user would have identified in Step 2, may well have been a mix of internal, value chain and external vulnerabilities. Therefore, the workbook reference table utilises both internal and supply network specific resilience elements to address this as exemplified in the workbook snapshot provided in Figure 9.4. The workbook reference table spans from beginning to end of the vulnerability taxonomy (Table 8.5) i.e. from Fin 1 to OSOMS 5 inclusively, and for each a comprehensive list of mitigating internal and supply network resilience elements are provided. For reasons of space, this example provided in Figure 9.4 is a cut-away shot, placed between Env 1-4 and VCRMP1-2. In this way, resilience elements with the highest number of linked vulnerabilities can be prioritised in preparation for full evaluation in Stage 4 of the FDM-RES Workbook, although it is possible that an FDM might have reasons for discarding certain elements, for example based on their size and network position and so the option to exclude certain elements has been included in the workbook.



Task 3B1: Reference Table and Recording Metrics for Selecting Countering Resilience Elements/Stage 3 /FDM-RES Workbook

Code	Vulnerability Description	Mitigating Resilience Elements Options	Excluded Codes?
Env 1	Natural disasters (both Geological and Meteorological such as earthquakes, drought etc.)	OR 1, OR 9, OR 12, OR 13, OR 3, OR 4, OR 5, OR 17, SNR 1, SNR 2, SNR 19, SNR 3, SNR 14, SNR 16, SNR 6, SNR 9, SNR 15	
Env 2	Biological factors (e.g. livestock disease, pests)*	OR 1, OR 9, OR 12, OR 3, OR 4, OR 5, SNR 2, SNR 19, SNR 3, SNR 14, SNR 16, SNR 6, SNR 9, SNR 15	
Env 3	Anthropogenic hazards (such as pollution, land contamination)	OR 1, OR 9, OR 12, OR 3, OR 4, OR 5, SNR 2, SNR 19, SNR 3, SNR 14, SNR 4, SNR 16, SNR 6, SNR 9, SNR 15	
Env 4	Unsustainable Primary Production (Land use, loss of biodiversity, climate change)*	OR 7, OR 10, OR 12, OR 3, OR 4, OR 18, SNR 19, SNR 3, SNR 14, SNR 4, SNR 16	
VCR MP 1	Inconsistent Raw material quality and heterogeneity*	OR 1, OR 9, OR 7, OR 3, OR 18, OR 5, OR 17, SNR 7, SNR 19, SNR 6	
VCR MP 2	Raw material and product related hazards (shelf life, cross contamination, handling requirements)*	OR 12, OR 11, SNR 14, SNR 16, SNR 6	

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Figure 9.4: Example FDM-RES Workbook process for the identification of resilience elements.

9.4.4 FDM-RES Framework Step 3C

In Step 1 of the FDM-RES Framework, it was identified that there are four phases of disruption against which resilience elements should be used (see Figure 9.5). Elements categorised in the Readiness Phase concern elements that assist in monitoring changes to the operating environment and those which, whilst being useful in later phases, must be built in in advance. Elements in the Response Phase focus on mitigating the impact of disruption and helping to maintain functionality. Elements in the Recovery Phase are orientated towards minimising the time needed to restore any lost functionality and enabling adaptation at an operational level (such as accepting new ingredients or distribution routes). Adaptive Phase elements concern the ability for long term, system wide, adaptation, perhaps significantly affecting core function, in response to changing operating environments.

Based on the aforementioned principles, Figure 9.6 displays resilience elements suitable for each phase as proposed by the author of this thesis. The categorisation of resilience elements by phase is heavily based on existing categorisations in the literature [21-22, 45, 52, 55, 98, 274-275]. However, none of the cited literature works were FDM specific and none considered the full range of resilience elements presented in Table 9.4. Thus, many of the linkages presented in Figure 9.6 are original work conducted by this author, achieved through analysis of the descriptions of resilience elements provided by their respective authors for indications of the phase in which they should be employed.

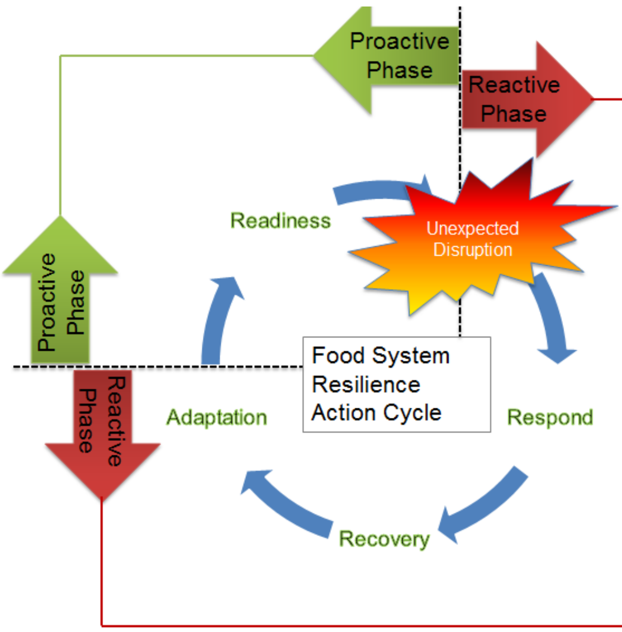


Figure 9.5: The different phases of resilience

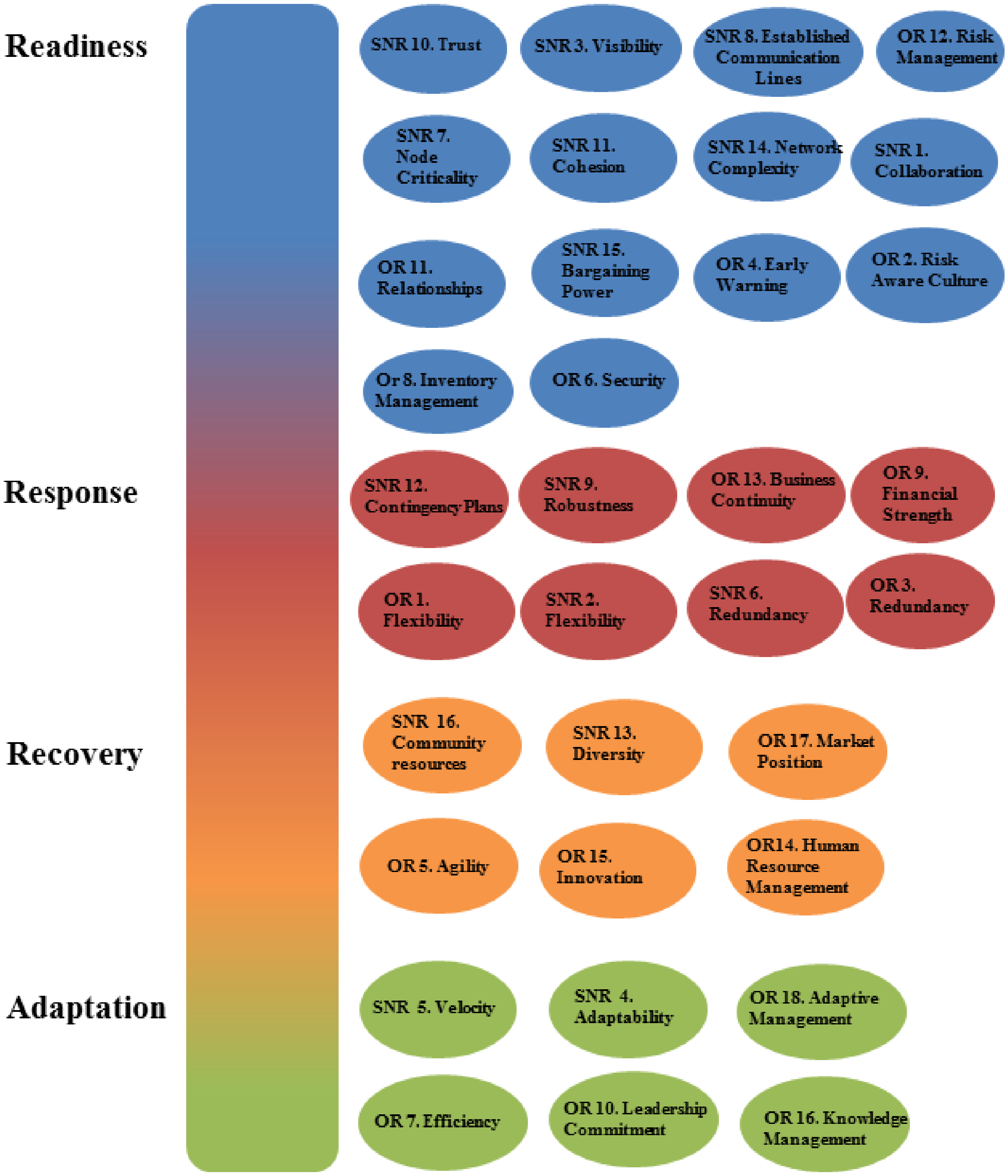


Figure 9.6: Proposed Categorisation of resilience elements by phase of disruption to which they are best suited

9.4.5 FDM-RES Workbook Step 3C

Practically, categorising elements by phase fulfils two key purposes. The first is that it provides a mechanism for FDM-RES Workbook users to achieve the ‘type’ of resilience they identified as being priority in the scope and boundaries exercise as part of Workbook Stage 1. For users who selected either ‘engineering’ or ‘ecological’ resilience, the priority will be resilience elements which help to respond and recover with maximum positive impact on cost and service level KPIs. This can therefore help to shortlist resilience elements longlisted in Step 3B. The adaptive ‘type’ of resilience requires selection of elements form all four phases. However, the selection of type of resilience also has implications for Evaluation and Implementation in Stage 4 of the FDM-RES Workbook. With the Engineering and Ecological ‘type’ of resilience, the priority, once implemented, is regular review of ‘response’ and ‘recovery’ elements for fit to KPIs. However, with the Adaptive ‘type’ of resilience, the regular review of the state of ‘readiness’ and ‘adaptive’ elements will guide which ‘response’ and ‘recovery’ elements are maintained and replaced.

To assist with decision making, the FDM-RES Workbook Task 3C1 takes the form of a decision tree to assist users in selecting the appropriate resilience elements based on their previously selected type of resilience (refer to FDM-RES Workbook Task 1A1). A workbook example of this decision tree is displayed in Figure 9.7. This therefore completes Stage 3 of the FDM-RES Framework and Workbook. This Chapter now proceeds to explore Stage 4 of the FDM-RES Framework and Workbook respectively.

9.5 FDM-RES Framework Stage 4: Evaluate and Implement Resilience Strategies

Stage 4 of the FDM-RES Framework consists of the conceptual steps involved in evaluating the resilience elements shortlisted in the previous stage in order to identify those that best fit the KPIs identified in Stage 1. It then established the conceptual best practice for implementing resilience elements. An overview of Stage 4 can be found in Figure 9.1.

9.5.1 FDM-RES Framework Step 4A

The first step in the evaluation of shortlisted resilience elements is to identify the impacts of each resilience element on the resilience KPIs identified in Stage 1.

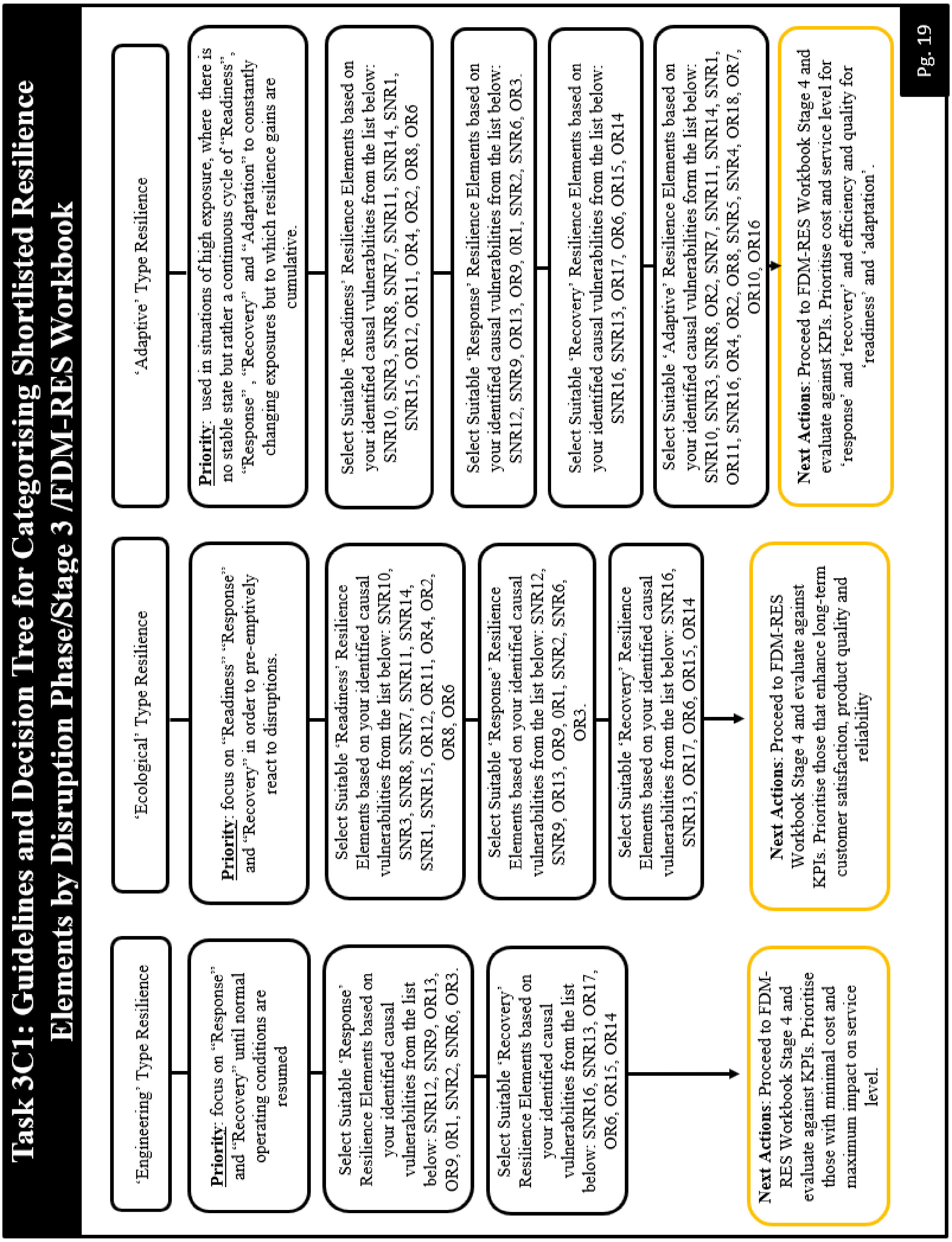


Figure 9.7: Workbook guidance on categorising resilience elements by phase of disruption

This is important, because, if for example, an organisation prioritised mostly Service Level KPIs in Stage 1 and found that of the resilience elements shortlisted in Stage 3, several were associated with negative impacts on Service Level, there would understandably be a conflict. However, there are no existing relational links in the literature between resilience elements (and impact on KPIs. Therefore, at a conceptual level there is a need for the construction of relational matrices which indicate which KPIs each resilience element has either a positive or negative impact on. These were achieved through in-depth interviews with four major FDMs. The resulting proposed linkages between organisation specific resilience elements and KPI impacts are displayed in Table 9.5 and those between supply network resilience elements and KPIs in Table 9.6. Invariably, such an approach can be a guideline only, and the precise impact of a resilience element on KPIs will always be influenced to a degree by factors such as company size and supply network location. However, because the FDM-RES Workbook is designed to be repeated regularly, it is anticipated that over time, a user's in-house data will gradually supplement/replace the proposed linkages in Tables 9.7/9.8.

Having conceptually linked resilience elements to likely costs and benefits in terms of KPIs, it is now possible to explore how these linkages could be used by an FDM-RES Workbook user to evaluate their shortlist of resilience elements from FDM-RES Workbook Stage 3.

9.5.2 FDM-RES Workbook Step 4A (Describing Task 4A1 and Task 4A2)

Task 4A1 picks up from Task 3C which shortlisted potential resilience elements according to whether they suited the phases of disruption that must be targeted in order to achieve the 'type' of resilience selected by the user in Stage 1. Such shortlisted resilience elements can then undergo a second stage of analysis against the KPIs selected by the user in Stage 1. In doing so, available resilience elements which have only positive impacts on the identified KPIs can be categorised as 'Primary' choice resilience elements and those which have some benefit but also some negative impact on user KPIs can be categorised as 'Secondary' choice resilience elements, which are to be utilised if primary choice elements are insufficient. This process is described in the FDM-RES Workbook example provided in Figure 9.8. As described in Chapter 7, this example uses the disruption phases of response and recovery for engineering 'types', readiness, response and recovery for ecological 'types' and readiness, response, recovery and adaptation for adaptive 'types' of resilience. It also uses the recommended KPI's for each 'type' of resilience provided in Chapter 7.

Table 9.7: Proposed impacts of organisational resilience elements on KPIs

Impact of organisation specific resilience elements on KPIs			
Resilience Element	Practical Actions (as outlined in Table 9.1)	KPIs on which impact is Positive	KPIs on which impact is Negative
OR 1: Flexibility	**OR 1(i)**: Existence of raw material substitutes.	SLE1, 2, 3, 4	SLENV1 CE1,2,6,8 CENV 1, 3 and 4 EE1,2 EENV1,2 QE4 QS2 QUENV1,2
	OR 1(ii): Ability of production line to accept substitute ingredients.	SLE1, 2, 3, 4 and 5	SLENV1 CE1,2,6,8 CENV 1, 3 and 4 EE1,2 EENV1,2 QE4 QS2 QUENV1,2
	OR 1(iii): Ability to switch production sites.	SLE2,	CE1, 2, 5, 6 and 8 CS6 SLE1,3, 4 SLENV 1 EE1 and 2 EENV 1 and 2
	OR 1(iv): Possibility of outsourcing process (in the event of a disruption).	SLE2	CE1, CE7 CS6,7 CENV1-4 SLE3, 4,5 SLS1-4 SLENV1 EENV1,2 QE3 QS2 QENV1-3
	OR 9: Availability of easily accessible financial assets.	SLE2	CE8
	OR 14/16: Broad staff skillsets, high company knowledge retention and the ability of staff to fulfil multiple roles.	SLE1-5 SLS 1-4 SLENV1 CS3,4,6 EE1 and 2 ES1-3 EENV1-2 QE1-3	CE5
OR 2: Risk Aware Culture	**OR 6**: Presence of Information and Physical Security.	QE1 SLE2 SLS2 and 4	CE5
	OR 7: Efficiency standards such as	SLE1	CE5

	six sigma.	EE1 and 2 QE1-3	
	OR 12/13: Infrastructure in place to manage risk such as Business Continuity and Enterprise Risk Management.	CE8 CS5 CENV2 and 4 SLE1-5 SLS2 and 4 SLENV1 QE1-3 QS4	CE5
	OR 10: Presence of cohesive central leadership support.	CS1,3 4, 5, 6 and 7 CENV 1-4 SLE1-5 SLS1-4 SLENV 1 EE1-2 ES1-3 EENV1-2 QS1-3 QENV1-3	N/A
OR 3: Redundancy	**OR 3**: Spare capacity.	CE8 SLE1-3	CE2-4 EENV1-2, EE1
	OR 8: Inventory Management.	CE3, 7 CENV2 SLE1-5 SLENV1	N/A
OR 4: Early Warning	**OR 18**: Adaptive Management.	CE8 CS3 and 4 CENV 1-4 SLE 1-5 SLS1-4 SLENV1 EE1-2 ES1-3 EENV 1-2 QE2- 3 QS1-4 QENV 1-3	CE5
	OR 11: Relations between teams and impact on communication and the flow of information.	CE1-4 CS4 CENV1,2, 3 and 4 SLE1-5 SLS1-4 SLENV1 EE1-2 ES1-3 EENV1-2 QE1-3 QENV1-3	CE5
OR 5: Agility	**OR 5 (i)**: Ability to reduce production times.	SLE1-4	CE5
	OR 5 (ii): Reduce set up times.	SLE1-4	CE5
	OR 15/17: Innovation and Market Position.	CE7-9, SLE3 and 4, CS6, ES1, QE3, QS2,3, QENV1-3	CE5 SLENV1 EENV1,2

Table 9.8: Proposed impacts of supply network specific resilience elements on KPIs

Impact of supply network specific resilience elements on KPIs			
Resilience Element	Practical Actions (as outlined in Table 9.1)	KPIs on which impact is Positive	KPIs on which impact is Negative
SNR 1: Collaboration	**SNR 11(i)**: Integration of systems with suppliers/clients.	CE2,3,4,7 CENV1-4 SLE1-5 SLS4 SLENV1 EE1,2 EENV1,2 QE3 QS2 QENV1-3	CE5
	SNR 1: Coordination of activities, including product design, with suppliers/clients.	CE2,3,4,7 CENV1-4 SLE1-5 SLS4 SLENV1 EE1,2 EENV1,2 QE1-3 QS1-4 QENV1-3	CE5
	SNR 10: Sharing of risk with supply chain suppliers/clients.	CE7 CS1,2,4 CENV1,2,4 SLS4	CE5
	SNR 15: Avoidance of asymmetric supply chain relationships.	SLE1-5 QE1-3	CE1-2 CENV1-4 SLENV1
	SNR 11(ii): Development of cohesive supply chain standards.	SLE1-5 EE1 SLENV1 QE1,3 QS1-4 QENV1-3	CE1-6
SNR 2: Flexibility	**SNR 2 (i)**: Existence of alternative supply chain carriers	SLE2	CE8 CENV1 QE2
	SNR 7: Presence of alternative suppliers/clients	SLE1-2	CE1-4,8 CS1,2 CENV1-4 SLE4,5 SLENV1 EE1,2 EENV1,2 QE3 QS2,3 QENV1-3
	SNR 2 (ii): Selection of suppliers/clients based on flexibility	CE3,4 SLE1-4	CE1-2 CS1,2

	of capacity	QE3 QS2,3	CENV1-4
	SNR 16: Ensuring that FDM activities align well with local communities.	CS5-6 CENV2 and 5 SLE1 ES2 EENV1 QS3,4	CE2
SNR 3: Visibility	**SNR 8 (i)**: Timely sharing and updating of demand forecasts with suppliers and buyers	CE1-6,8 SLE1-4 EE1,2 SLENV1 EENV1 QE2	CE5
	SNR 12: Presence of risk management strategies throughout operations of all supply chain partners.	CE1,9 CS1,2 CENV1-4 SLE1-5 QE1-3 QS1,2 QENV1,2	CE5
	SNR 8(ii): Creation of integrated and efficient communication protocols with value chain partners	CE1-4 SLE1-5 QE2	CE5
	SNR 3: Creation of integrated value chain material traceability systems	SLE4-5 QE1-3 SLENV1 QS2 QENV1,2	CE5
SNR 4: Adaptability	**SNR 14:** Reducing Network Complexity	SLE1-5	CE1-2,5 CS6
	SNR 4/5: Increasing the ability of a value chain to collectively adapt to external conditions in a timely manner.	CE1,2 CENV2,4 SLE3,4,5 QE1,3 QS1,2 QENV1-3	CE7,8 CENV 1,3,4 SLE1 SLENV1 EE1 EENV1-2
SNR 6: Redundancy	**SNR 13**: Existence of alternative physical routes, such as roads, rail and shipping lanes, between a FDM and suppliers/customers	SLE1-2	CE1,2,5 EENV2 QE2
	SNR 9: Design of the value chain so that there is some slack to absorb disruption for a defined time period whilst still maintaining function.	SLE1-4 QE1-3	CE1-5,8 EENV1-2

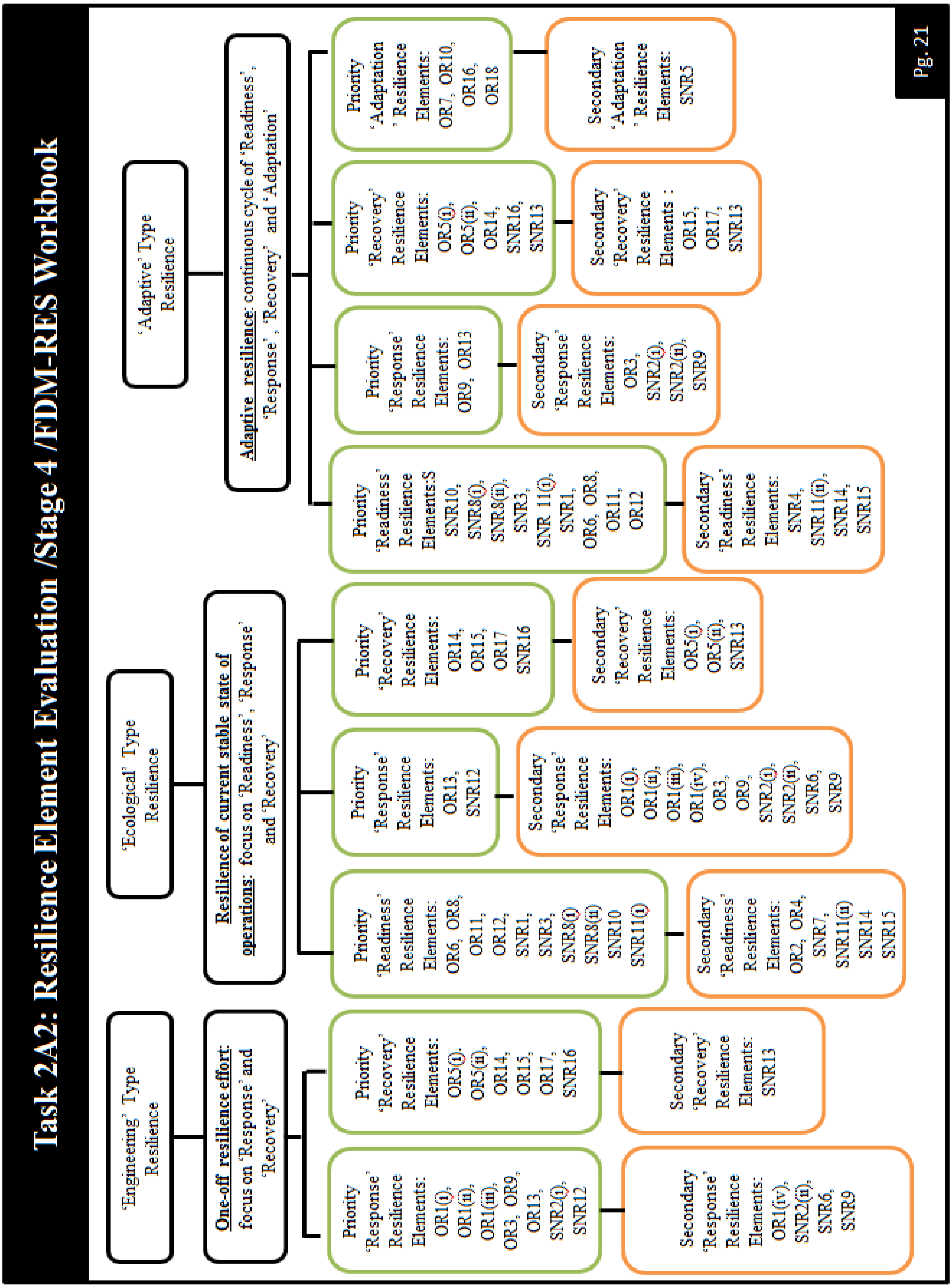


Figure 9.8: Workbook example of resilience evaluation process.

For engineering resilience these are KPIs that affect core company viability, and these were identified as SLE2, QE1 and CENV1. Ecological resilience prioritises identifying and avoiding failure states, and so KPIs would include factors that in the short to medium term may affect company viability. These were identified as CE1, 8 and 9, CS5, CENV2, SLE 1-5, SLS1-2, EE1 and QE1, 3. In the adaptive 'type' of resilience, there is no stable state of operations to preserve and so KPIs should reflect constant long-term scanning of potential viability threats in the medium to long term. As this is up to the company to decide, this 'type' of resilience effectively includes all KPIs.

9.5.3 FDM-RES Framework and Workbook Step 4B

Step 4B concerns the principles governing implementation and review of these resilience elements within an FDM. Depending on the balance of supply network specific resilience elements chosen in relation to organisation specific elements, this will require collective implementation either between internal business teams or between organisations. To do so, requires formation of steering committee, which has strong leadership support and the ability to centrally allocate resources and coordinate communications. Members of this committee should originate from all relevant departments or organisations. Just like with the ERM procedure, it is important to ensure that the right people are aware of their responsibilities based on the resilience strategy selected. This should be achieved through an evolving (as opposed to static) resilience register that includes details of the current mapping results, identified priority vulnerabilities and current resilience elements that are being used to counter them. This register should also provide step by step instructions of what is expected of the named individuals who are responsible across different organisational teams/different value chain organisation's and contact details and guidelines for them to provide regular reports. This should be regularly monitored by the steering team as it effectively provides a key aspect of value chain visibility and thus should be seen as part of the early warning mechanisms in place.

It is likely that over time, a significant volume of real-world data regarding the impact of resilience strategies, both in terms of effectiveness and cost, will be generated, and this must be recorded by the steering committee for use in future applications of the FDM-RES Workbook. This is important because, unlike ERM process which sometimes can prioritise internal risks, it has to be remembered that in a resilience context, the biggest source of risks by far is likely to be the external supply network environment, which due to its volatility, will be constantly evolving. Therefore, to ensure that resilience elements remain proportional to real world supply network state and exposure to vulnerability, regular re-application of the FDM-RES Workbook will be necessary. As such, a key role of the steering committee will be to coordinate dates for the re-application of the framework with all relevant participants. Finally, this FDM-RES Workbook and underpinning conceptual framework should also be consulted whenever new products are at the design stage, or when changes to business strategy are considered, such as outsourcing, thus bringing to bear the full suite of supply network mapping metrics to evaluate the impacts of the change on organisational resilience. In terms of implementation in the FDM-RES Workbook, Step 4B1 consists of the aforementioned principles as a simple checklist for users to follow.

9.6 FDM-RES Framework and Workbook Conclusions, Advantages and Limitations

The FDM-RES Framework has fulfilled a number of objectives conceptually and practically. At a conceptual level it addresses a number of identified research gaps including the creation of a synthesised FDM specific definition of resilience and the generation of FDM specific taxonomies of Supply Network Mapping Metrics, Failure Modes, Causal Vulnerabilities and Resilience Elements. Another key area of novelty is the generation of linkages between individual units of each taxonomy, based on SLR findings and in-depth industry interviews. Due to the use of synthesis from a systematic cross disciplinary review, it also considers a much larger pool of potential resilience elements and vulnerability sources than previous approaches. The novel categorisation according to whether an element is a ‘core’ or ‘supporting’ element, along with practical steps for each allows for much greater operationalisation of resilience elements than has been previously attempted. This represents a significant contribution to the field of SCRES.

The framework also forms the basis for a practical tool, in the form of the FDM-RES Workbook which mirrors each step of the FDM-RES Framework and provides guidelines, reference tables and working space to aid a FDM in enhancing their resilience. A major advantage of this practical approach is that it allows the user to develop resilience to the real-world state of their entire supply network, not just the immediate value chain partners combined with reliance on historical risk scenarios that traditional risk management approaches have considered. Another advantage of the FDM-RES Workbook is its design for integration with existing industry ERM processes so as to aid functionality. This is reflected not only in the stages of the FDM-RES Workbook itself, but also the components within, such as the FDM KPI taxonomy which have been designed to complement rather than replace existing company measures whilst guiding their use so as to consider previously overlooked factors, such as the link between resilience and wider sustainability.

By the same hand, however, there are limitations in the sense that because supply networks cannot be measured in the lab, they are by nature dependent on the subjective inputs of supply chain professionals to perform the workbook stages accurately and without bias. Furthermore, as has been mentioned previously, whilst care has been taken to develop the relational linkages between the various components of the FDM-RES Framework using SLR findings supplemented by in-depth industry interviews, it has to be remembered that such linkages can only ever be guidelines- different companies will face different circumstances, which will influence their own bespoke results from the FDM-RES Workbook. With this in mind, the next Chapter takes the FDM-RES Workbook to a real-world industry setting and practically applies it in the context of case studies with two major UK FDMs

9.7 Chapter Summary

Chapter 9 has detailed the final two stages of the FDM-RES Framework and mirroring Workbook, which focus on the selection of resilience elements to identify vulnerabilities identified in Stage 2, and their evaluation and implementation. Stage 3 of the FDM-RES Framework categorised a number of the resilience elements that an FDM would use, and the specific vulnerability sources that each would mitigate as well as the practical actions for each. It has also detailed how these elements focus on different phases of disruption and the way in which the choice of ‘type’ of resilience from Stage 1 can help refine selection of resilience elements. The corresponding Stage 3 of the FDM-RES Workbook detailed the practical steps by which an FDM would utilise these conceptual developments. Stage 4 of the FDM-RES Framework described the conceptual principles for evaluating resilience elements based on their impacts on the KPIs suggested in Stage 1. It also described the principles behind implementation of the final selected resilience elements in such a way as to ensure accurate dissemination of knowledge to key stakeholders and regular review. Stage 4 of the FDM-RES Workbook provided the decision tree to support evaluation as well as the checklist to guide practical implementation. As the final research tool chapter, a brief concluding summary describing the strengths and weaknesses of the FDM-RES Framework/Workbook approaches was also provided. The next Chapter concerns the application of the entire FDM-RES Workbook in a practical case study context.

Chapter 10: Case Studies

10.1 Introduction

This Chapter documents two case studies with comparable UK FDMs which are designed to demonstrate the practical application of the FDM-RES Workbook and the conceptual rigour of the underlying FDM-RES Framework. In doing so, it fulfils Research Objective 4 of this Thesis. As the chapter uses a number of the codes presented in Chapters 7-9 in order to represent the significant number of linkages between exposure metrics, failure modes, vulnerabilities and resilience elements, it begins with a brief glossary of the meanings of relevant codes. The Chapter then proceeds to describe the pilot study and its contribution to the implementation of the main case studies. It continues with a brief overview of the case study process, providing overviews of the selected companies, justification for their selection and details of the practical steps in the application of the case studies. It then proceeds to focus on each case study individually, presenting and introduction to the nature, size and scope of each focal company, before describing the application of the FDM-RES Workbook, the results and analysis and finally the conclusions for each. The final section consists of a brief comparative discussion, highlighting key similarities and differences as well as implications for the wider UK FDM sector.

10.2 Glossary

The practical application of the FDM-RES Workbook to two case studies relies on the use of a number of codes representing high priority exposure metrics, failure modes, vulnerabilities, resilience elements and KPIs. To aid reader accessibility of these codes, their meanings are summarised below. Table 10.1 displays codes and meanings from the FDM specific KPIs presented in Chapter 7 (Table 7.1). Table 10.2 displays codes and meanings for the situations in which case an exposure metric is a high priority as presented in Chapter 8 (Table 8.2). Table 10.3 summarises Failure Mode codes and meanings as displayed in Chapter 8, Table 8.3. Table 10.4 displays FDM Specific Causal Vulnerability Sources Identified in Chapter 8 (Table 8.5). Finally, Table 10.5 displays Resilience Element Codes and meanings as presented in Chapter 9 (Table 9.1).

Table 10.1: Codes and meanings for the FDM specific KPIs presented in Chapter 7 (Table 7.1).

KPI	KPI Sub-Pillar: Economic (E)	KPI Sub-Pillar: Social (S)	KPI Sub-Pillar: Environmental (ENV)
Cost (C)	**(CE1)** Raw Material Cost	**(CS1)** Human Rights Standards of Suppliers	**(CENV 1)** Environmental Standards of Suppliers
	(CE2) Utilities cost (water, electricity, gas, waste disposal)	**(CS2)** Social impact of utility generation and disposal	**(CENV 2)** Environmental legislation compliance
	(CE3) Inventory Carrying Cost	**CS3)** Job Satisfaction	
	(CE4) Spare Capacity Cost		
	(CE5) Staff Cost	**(CS4)** Fair Salary	**(CENV3)** Natural Capital Valuation
	(CE6) Gross Value added	**(CS5)** Labour Relations	
	(CE7) Market Concentration	**(CS6)** Regional employment	**(CENV4)** Environmental risk management procedure
	(CE8) Profit margins		
	(CE9) Net Profit	**(CS7)** Philanthropy and Local Community Investment	
Service Level (SL)	**(SLE1)** Order Fulfilment Time	**(SLS1)** Regular Review of Worker Rights	**(SLENV1)** End of Life Planning and Circular Economy
	(SLE2) Contract Fulfilment		
	(SLE3) Customer Responsiveness	**(SLS 2)** Occupational Health and Safety	
		(SLS 3) Employee Diversity: and Equal Opportunities	
	(SLE4) Customer Satisfaction	**(SLS 4)** Corporate Attitude to risk management	
	(SLE5) Traceability of incoming raw materials and outgoing produce		
Efficiency (E)	**(EE1)** Raw Material to Finished Product Conversion Rate	**(ES1)** Employee Appraisal and Development Systems	**(EENV1)** Energy, Water and Raw Material Efficiency During Manufacturing
			(EENV2) Emissions Related to Manufacturing
	(EE2) Employee productivity	**(ES2)** Average Employment Retention Rate	
		(ES3) Corruption	
Quality (Q)	**(QE1)** Safety of Goods	**(QS1)** Health and Nutrition of Goods	**(QENV1)** Animal Welfare
	(QE2) Shelf Life		
	(QE3) Product Reliability and Convenience	**(QS2)** Private labelling standards that go beyond legislative requirements	**(QENV2)** Production Certification Schemes that go beyond legislative requirements
		(QS3) Societal benefit of product	
		(QS4) Smell and Noise Reduction	**(QENV3)** Presence of emissions reduction and resource efficiency enhancement targets

Table 10.2: Codes and meanings for the situations in which case an exposure metric is a high priority as presented in Chapter 8 (Table 8.2).

High Priority Exposure Codes and Meanings
PES1: Geographically clustered **PES2**: High number of long distance (particularly international) suppliers. Amplified when volumes are low and /or complexity of product is high and the FDM has limited ability to hold raw materials in reserve. **PES3**: Limited alternative suppliers which could fit product specification
PEI1: Absence of sister sites which could take over production/supply staff/equipment in a disruption situation. **PEI2:** Inflexible production characteristics that limit ability to change production capacity at short notice and finished inventory stores are low.
PEC1: Significant geographic distance to customer
SES1: Tightly geographically Secondary Suppliers **SES2:** Limited financial robustness of secondary suppliers **SES3:** Limited auditing of secondary suppliers **SES4:** Highly specific product with few alternative suppliers
SEU1: Limited supplier peak capacity
SEW1: Absence of suitable alternate service providers **SEW2:** Limited ability of service provider to change collection capacity at short notice
SET1: Absence of suitable alternate service providers **SET2:** Limited ability of service provider to change collection capacity at short notice
SEG1: High potential impact on operations combined with poorly established communication protocols between Gov. and FDM. **SEG2**: Political instability/inconsistency **SEG3:** High levels of corruption
SEN1: Limited reliability (particularly concerning public image) **SEN2:** Critical to process (i.e. certification) but without alternative providers available.
ICRM1: Long production timescale **ICRM2:** Few growers **ICRM3:** Tight geographic restrictions on supply **ICRM4:** Short lead time, combined with low supplier reserves and/or ability to change supply volume.
ICE1: Absence of suitable alternate service providers **ICE2:** Limited ability of service provider to change supply at short notice **ICE3**: Communication routes susceptible to disruption (i.e. single phone line in region prone to strong weather)
ICW1: Absence of suitable alternate service providers **ICW2:** Limited ability of service provider to change collection capacity at short notice **ICW3:** Communication routes susceptible to disruption (i.e. single phone line in region prone to strong weather)
MFRM1: High frequency inbound deliveries using singular transport mode and route with limited ability to switch.
MFE/W1: Heavy reliance on grid with little in the way of redundant lines or spare capacity (such as generators)
MFI1: High frequency deliveries using singular transport mode and route with limited ability to switch.
MFO1: High frequency outbound deliveries using singular transport mode and route with limited ability to switch.
IFRM1: Lack of communications integration, increasing time taken to act on incoming information.
IFI1: Lack of communications integration/protocols between teams
IFO1: Lack of communications integration, increasing time taken to act on incoming information.

IFO2: Communication routes susceptible to disruption (i.e. single phone line in region prone to strong weather)
RLH1: Buying-selling relationship where interdependence is high (i.e. both parties are, for various potential reasons, very important to each other's viability) and adversity is particularly high or collaboration is particularly low. **RLH2:** Long term partnership where there is a strong power imbalance in favour of one party who uses this to impose heavy contractual penalties without efforts to integrate, with, invest in the development of and collaborate with partners.
RLV1: Vertical partners are closely integrated on product specifications yet supply each other under circumstances of high competition leading to the risk of monopolisation.
RLO1: For Buyer-Seller relations see horizontal relations criteria **RLO2:** Situations where the relationship is advisory or regulatory and where the other party has a large influence on consumer opinion but where collaboration/integration is low

Table 10.3: Failure Mode codes and meanings as displayed in Chapter 8, Table 8.3.

Failure Mode	***Description/Characteristics***
FM1. Raw Material Shortage	All manner of upstream disruptions which limit raw material availability from the focal FDMs perspective.
FM2. Raw Material Sub-Standard Quality	All manner of upstream disruptions, which, whilst not necessarily halting raw material supply to the FDM, significantly affect the quality of raw materials received (e.g. size and credence factors)
FM3. Unable to produce/ Scrap/Rework	Occurs when a product is unable to move beyond the FDM production line, whether because production could not be attempted in the first place, because the final product needed to be reworked, or because the finished product was unfit for any other use thus requiring scrappage.
FM4.Labour Shortage	Refers to any factor(s) which limit labour availability at FDM sites
FM5: Loss of process economic viability	Factors leading to a particular process becoming commercially untenable for the FDM. Examples include raw materials simply not being profitable, wider market saturation or evolving consumer trends.
FM6: Loss of Site	Refers to any number of disruptions which either prevent or severely hinder operations at a particular plant.
FM7: Unable to Deliver	Goods are finished to specification but are prevented from being sold by various internal or downstream disruptions that prevent packing, loading or delivery.
FM8: Legally enforced cessation of specific operations	Situations which could result in a regulatory body forcing the FDM to cease operations in response to major legislative violations, for example, environmental breaches, significant health and safety concerns, or major incidents of food contamination.
FM9. Sub-Standard Product Quality and Possible Reject	Any disruptions which, whilst not forcing a scrap/rework, do impact on the final quality and may result in concessionary rates or penalties being applied by the customer.
FM10: Product Recall	This failure mode refers to any disruption(s) which result in food either being rejected at the retailer depot, or food which has made it onto retailer shelves or consumers' homes, being recalled.

Table 10.4: FDM Specific Causal Vulnerability Sources Identified in Chapter 8 (Table 8.5)

Largely Uncontrollable

Supply Network Vulnerabilities

Financial (Fin)	*Market (Mar)*	*Governance (Gov)*	*Infrastructure (Inf)*	*Societal (Soc)*	*Environmental (Env)*
1. Market price fluctuation [39-133-249] 2. Currency exchange fluctuations [39-130-133] 3. Interest rate fluctuations [266] 4. Regional economic downturns [68-114-249-266-267] 5. Hostile takeover attempts [133] 6. Product liability [39]	1. Market decline 2. Competitive Innovation [39-245] 3. Competitor undercutting [95-154]. *4. **Seasonal variability in availability of raw materials (growing seasons, profitability of crop)****[134] *5. **Variability in demand (seasonal, promotional and bullwhip)****[39-68-133-134-170-267-268]	1. ***Changes in Public Food Policy (e.g. production efficiency targets, health and nutrition guidelines)****[133-138-154-267-268]. 2. ***Private Food Policy (e.g. strict customer requirements on appearance, colour, shape and delivery time)****[138] 3. Political instability (regime changes, corruption)[70-124-245-267] 4. Import/export restrictions [15,5]	1. Transport infrastructure disruptions (pipelines, ports, roads, railways, airports)[70-95-114-124-154-269] 2. Water infrastructure disruptions [70-154] 3. Energy infrastructure disruptions (oil supply/price, electricity grid, gas supply)[70-154-266] 4. Communications infrastructure disruptions (cables, radio masts, satellites)[70-154][133].	1. Piracy/Terrorism[39-51-57-70-134-245-269–271] 2. War and conflict [3,12,13] 3. Workforce health (e.g. flu pandemic)[39-267] 4. ***Proportion of Consumer income available for food purchase**** [266] 5. ***Changing customer attitudes to consumption (e.g. health, lifestyle and fashion foods)****[134-138-267] 6. Criminal acts (such as fraud data hacking and sabotage)[39-114-133-249] 7. Industrial actions (strikes) [39-70-124-134-266-267] 8. Poor relations with consumers and special interest groups (e.g. customer communication, brand image, consumer confidence)[39-267]	1. Natural disasters (both Geological and Meteorological such as earthquakes, drought etc.) [39-68-70-95-114-133-134-138-154-159-245-249-266-269-271] *2. **Biological factors (e.g. livestock disease, pests)****[70-134-138-249-266] *3. **Anthropogenic hazards (such as pollution, land contamination)****[39-133-138] *4. **Unsustainable Primary Production (Land use, loss of biodiversity, climate change)****[266]

Partially Controllable

Mostly Controllable

Internal and Value Chain Vulnerabilities

	Raw Material and Production (RMP)	*Logistics Control (LC)*	*Information System (IS)*	*Organisational Management Structure (OMS)*
Value Chain Origin Vulnerabilities (VC)	*1. **Inconsistent Raw material quality and heterogeneity****[124-133-267] *2. **Raw material and product related hazards (shelf life, cross contamination, handling requirements)****.[39-40]	1. Reliability of external logistics providers[39-70-95-124-130] 2. High levels of geographically distant, outsourcing for which there is no alternative [16,23,24] 3. Strict customer requirements (in terms of lead times and quality) [70]	1. Lack of established, secure and integrated information sharing infrastructure [4,12,13,17,8] 2. Deliberate withholding of information (trust and cooperation)[70-159] *3. **Lack of ability to trace food across the value chain****[40].	1. Low level of training & experience in other companies employees[70-95] 2. Poor financial robustness of value chain partners (exposure to bankruptcy or takeover) [95-124-154-159-245-267] 3. High concentration in supply chains (i.e. actors serving as both suppliers and competitors in different contexts)[70-124] **4. *High levels of power imbalance between actors (contractual fairness and level of lock in)**** [70-124]
Organisation Specific Origin Vulnerabilities (OS)	*1. **Challenges related to storing raw materials/finished inventory (for example, storage requirements and ability to maintain ambient conditions)****[40]. 2. Product failure to comply with environmental legislation*[39-130-249] 3. Product failure to comply with Health and Safety Legislation. *[39-130-249] 4. Insufficient capacity to meet changing order requirements [39-70-130-166-170-245-267] **5. *Inability to react to changing circumstances (ability to quickly substitute raw materials or ramp up production/ decrease lead time)****[70-249]	1. Inaccurate forecasting (e.g. subjective decision making) [3,5,7,18] 2. Lack of flexibility in internal distribution capacity (form, volume, transit time, traceability)[39-130-249]	1. Breech in information/data security (espionage, cyberattack, hardware failure)[124-267-271]. 2. Breakdowns in internal information sharing (reports reach correct staff, prompt response to customer complaints) [39-249] 3. Poorly developed early warning detection systems[130-249].	1. Poor protection of intellectual property[271] 2. Flawed strategic decision making (e.g. high level of bias, poor interpersonal skills, lack of cohesion between departments and limited risk awareness)[133-249-271]. 3. Absence of, or ineffective Contingency Planning (backup power, contingency plans)[40-70]. 4. Poor human resource utilisation (suitable staff training, effectiveness of knowledge transfer between staff levels, knowledge retention)[39-40-70-133-249-269-271] 5. Restricted Corporate Social Responsibility Programme [39]

Table 10.5: Resilience Element Codes and meanings as presented in Chapter 9 (Table 9.1)

Supply Network Resilience (SNR)	SNR 1. Collaboration
	SNR 2. Flexibility
	SNR 3. Visibility
	SNR 4. Adaptability
	SNR 5. Velocity
	SNR 6. Redundancy
	SNR 7. Node Criticality
	SNR 8. Established Communication Lines
	SNR 9. Robustness
	SNR 10. Trust
	SNR 11. Cohesion
	SNR 12. Contingency Plans
	SNR 13. Diversity
	SNR 14. Network Complexity
	SNR 15. Bargaining Power
	SNR 16. Community resources

Organisational Resilience (OR)	OR1. Agility
	OR 2. Flexibility
	OR 3. Risk Aware Culture
	OR 4. Redundancy
	OR 5. Early Warning Detection Systems
	OR 6. Security
	OR 7. Efficiency
	OR 8. Inventory Management
	OR 9. Financial Strength
	OR 10. Leadership Commitment
	OR 11. Relationships
	OR 12. Risk Management
	IO 13. Business Continuity
	OR 14. Human Resource Management
	OR 15. Innovation
	OR 16. Knowledge Management
	OR 17. Market Position
	OR 18. Adaptive Management

10.3. Pilot Study

The purpose of this case study is to validate the FDM-RES Workbook (i.e. the practical arm of the FDM-RES Conceptual Framework). Given the complex and lengthy nature of the FDM-RES Workbook and the importance of ensuring user understanding, a pilot study was seen as being essential in order to refine the questionnaire used to guide the case study process. A number of authors have identified the importance of pilot studies in testing and refining questionnaires (and the researchers questioning technique) as well as being of significance in identifying the types of companies that are most suitable for the investigation [225, 250].

Based on this requirement, pilot studies were initiated with two relevant FDMs with whom research connections already existed and who are now referred to as PS1 and PS2. Both are medium to large FDMs who were internationally based, but who both also possess substantial UK manufacturing activities, thus making them highly relevant to the context of this research. The pilot studies were performed as a series of telephone interviews with the Milk Buyer and Responsible Sourcing Manager and the Sustainability Manager at PS1 and with the Manufacturing Development Director and the Business Process Manager at PS2.

The pilot study questionnaire used was designed to follow the practical stages of the FDM-RES Workbook which is displayed in Figure 10.1. An example of how the pilot study mirrors this can be seen in the introductory overview sent out to participants in advance as shown in Figure 10.2. Stage 1 focused on identifying resilience of what to what, the type of resilience sought, the scope of resilience sought and the KPIs that were to be used to benchmark this. Stage 2 involved the identification of the participants bespoke supply network vulnerabilities. It began with a mapping process to identify unique priority exposure points, associated failure modes and linked causal vulnerabilities. The participants were also given the opportunity to feedback at each stage, their own failure modes, and causal vulnerabilities and to modify the proposed linkages between the two.

Stage 3 consisted of the identification of suitable resilience elements based on the causal vulnerabilities identified in Stage 2. Participants were given the opportunity to suggest their own resilience elements, modify the existing ones and to modify/suggest new linkages between resilience elements and specific causal vulnerabilities. Finally, Stage 4, concerned the evaluation of resilience elements selected in section three based on their impact on KPIs and ability to deliver the 'type' of resilience defined in Stage 1. Structuring the questions in this way provided not only a method to test the workbook practical tools but also to validate and enhance the conceptual basis beneath the FDM-RES Framework too.

10.3.1 Analysis of Pilot Study Results

The findings from the pilot studies were beneficial in developing the strategy used in the two main case studies in a number of ways. Firstly, they identified a number of KPIs and causal vulnerabilities that were not as relevant to FDM resilience as the initial literature review would have suggested. For example, a number of causal vulnerabilities and KPIs relating to household affordability of food in the UK were modified because they were not directly within manufacturer's ability to directly control, due to the fact that they have little influence over market prices. Furthermore, a number of teething problems relating to academic terminology which was confusing to Industrialists were identified and adapted accordingly and the time lengths for the questionnaires were adapted.

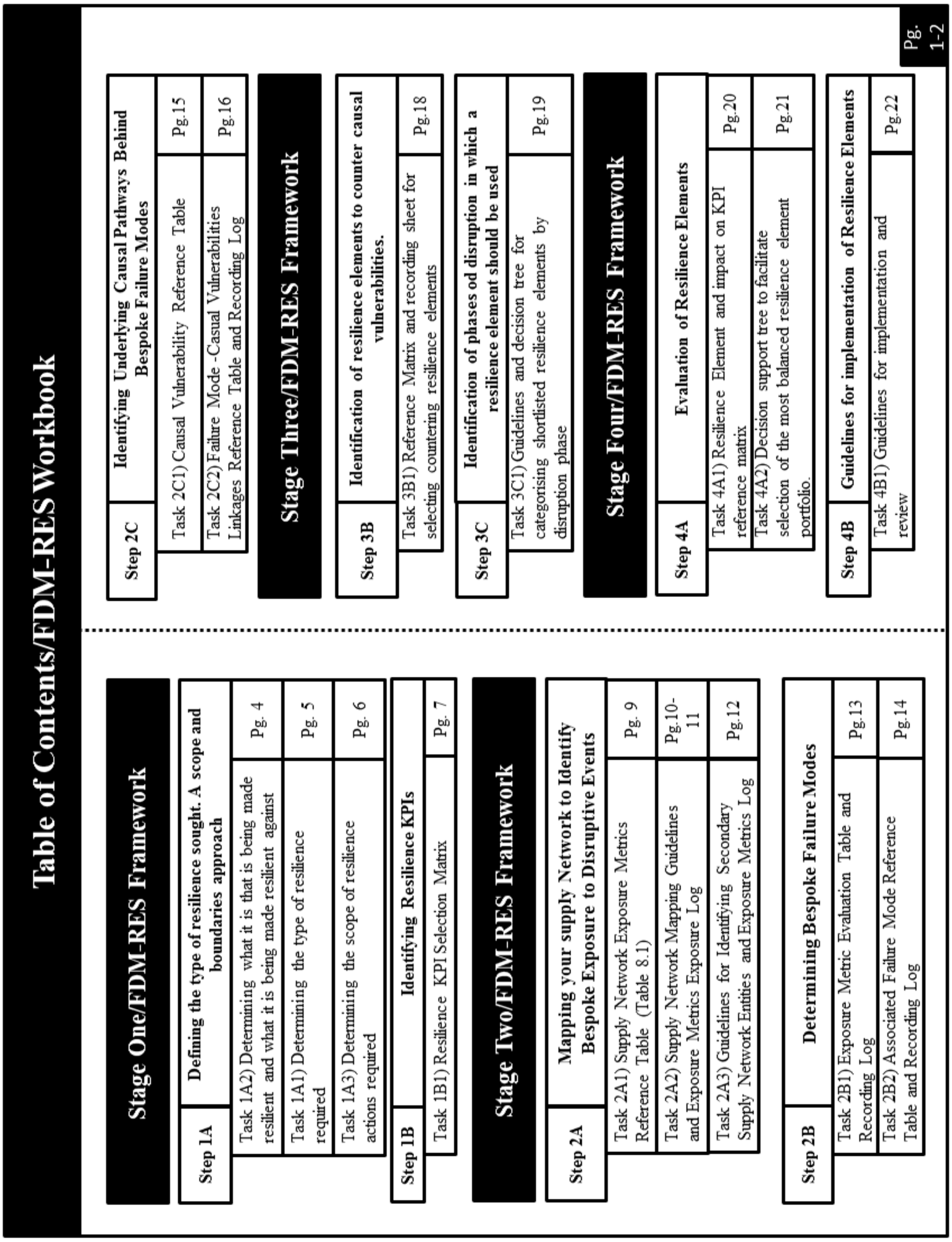


Figure 10.1: Overview of the FDM-RES Workbook stages, mirrored in the pilot study and subsequent main case studies questionnaires.

PS1 Resilience Questionnaire Overview

Thank you for agreeing to take part in this doctoral research investigating resilience in the food manufacturing sector. The aim of this document is to provide an overview of what will be involved in the investigation.

Project Purpose: This project explores the key performance indicators, types of disruption faced and the mitigation options available to food and drink manufacturers to help us validate out model of what it means to be resilient in this sector.

Requested input: The researcher will require access to 1-4 staff with a broad knowledge of company supply chain management activities, particularly knowledge of risk management, key performance indicators and responding to disruptions.

Total Time: Approximately 2 hours

Stage 1: What does resilience mean to your organisation? Scope, Boundaries and KPIs

This section will comprise of basic questions concerning what aspects of your organisation would benefit from being made more resilient, what it is they are being made resilient to and the types of KPIs that you would use as an organisation to measure this resilience.

Stage 2: Mapping your supply network and identifying vulnerabilities

This section will comprise of questions exploring your organisations supply network, focussing on network complexity, the was in which material, energy and information flow through your network and the relations you hold with other supply network organisations.

Stage 3: Identifying resilience actions with which to mitigate the vulnerabilities faced by your organisation

Questions in this section focus on the types of strategies available to your organisation to counter the vulnerabilities identified in Section Three

Stage 4: Evaluating resilience options

This final section assess the impact of resilience options chosen in Section Four based on their impact on organisational KPIs

Figure 10.2: Pilot study participant introduction, highlighting the chosen question format closely mirrors the FDM-RES Workbook.

10.4 Overview of the Main Case Studies

Whilst a number of industrial contacts had been made as part of this research only two companies were taken forward to the case study phase. These were both large organisations within the chilled prepared food sector of the UK Food and Drink Manufacturing Industry and were partly chosen from the established contacts because they were directly comparable in terms of the types of products they produced their relatively large size and their production process thus enabling cross referencing of findings to enhance consistency. However, the two case studies also share unique differences in terms of absolute size, product range and customers, allowing for the components of the FDM-RES Workbook to be tested in different ways. These similarities and differences are outlined in Table 10.6 and are described in detail in the appropriate case study sections.

The bakery/chilled convenience sector is highly competitive, with a high level of competition between each FDM/retailer partner and other retailers and their partner FDMs. For this reason, Non-Disclosure Agreements with each of the FDMs in this case study were requested. Whilst this did not limit the application of the FDM-RES Workbook itself, it did restrict the form in which findings could be published. As such, the case study organisations will from now onwards be referred to as FDM1 and FDM 2 respectively.

Three main approaches to data collection were used as part of the case study: site visits, interviews and questionnaires. Before the site visits both telephone and email contact were used to identify interests of the companies participating in the study, present the methodology of the FDM-RES Workbook and explain the main objectives of the case studies. Following initial contact, site visits to the respective companies' headquarters took place where in-person interviews were held with company employees. These were the Raw Materials Manager and the Sustainability Manager for FDM1 and the Head of Innovation, Senior Product Manager and Supply Chain Manager for FDM2.

During the interviews, a questionnaire was used for structure and the final versions of these questionnaires for FDM1 and FDM2 can be found in Appendices 1 and 2 respectively. Following the site visits and in-person interviews, further email contact was needed to collect additional information, often originating from other company employees who were not available during the main interview but who were needed for some of the more specific supply network mapping metrics.

Table 10.6: Comparison of case study companies.

Comparison Criteria	FDM1	FDM2	Level of Comparability
Product Type	Chilled Sandwiches, Prepared Meals and Snacks	Chilled Sandwiches, Prepared Meals and Snacks	High
Company Size	Large with approximately 33000 staff	Relatively Large with approximately 1,500 staff.	High
Collaboration with Retailer Customer(s)	High	High	High
Number of Retailer Customer(s)	Multiple Retailers and Caterers	One Retailer	Low
Supplier Base	Large and International	Large and International	High
Range of Products	High range of sandwiches, snacks, meals, sauces, salads and desserts	Focus on Sandwiches and meals with a much smaller range of snacks and desserts all for one private label	Low
Production Process	High reliance on manual labour for sandwich assembly	High reliance on manual labour for sandwich assembly	High
Range of Production Sites	Multiple (over ten nationwide)	Two (geographically clustered)	Low

10.5 FDM 1 Scope and Context

FDM1 is a leading manufacturer of bakery related chilled retail/catering produce in the UK. This predominantly takes the form of sandwiches which generate 35% of company income and for which FDM1 possesses a ~50% market share and which will be the main focus of this case study. However, the organisation also produces other chilled products including chilled prepared meals, soups, snacks and sauces for retails and cooking sauces, pickles, Yorkshire puddings, ambient cakes and chilled desserts for the catering and manufacturing market. The scope of FDM1 is truly international, with manufacturing in both the UK and US generating total revenue of over £2 billion in 2016 and global supply networks supporting both. This Case study focuses on UK operations only, of which manufacturing is spread over a number of sites nationwide and which together employ approximately 33000 staff. Customers include a number of large multiple retailers in addition to a number of high street catering names and well-known manufacturing brands. However, the vast scope of FM1s operations means that they also pull in a number of international suppliers in Europe and South East Asia, as well as secondary supply network actors such as Government bodies, research associations and logistics providers.

10.5.1 Case Suitability

FDM 1 is representative of the massive growth seen in the chilled prepared food sector in the UK in recent years. The market has ballooned from a value of £550m in 1989 to £11.5bn in 2016 and £11.8 bn in 2017 [276]. The reasons for this rapid growth are in part linked to the rise of the large retailers who offer vast market penetration for such foods and who have been able to use their huge purchasing power to drive down production costs and lead times as well as to increase quality. However, the reasons are also societal, driven by the same ‘time poverty’ which facilitated the rise of the large retailers themselves, i.e. a demand for food that is both high in quality and ease of preparation at minimal cost.

FDM1’s supply network considerations are also representative of other trends within the wider UK Food and Drink Manufacturing sector, such as increasing reliance on the presence of an unbroken chilled chain, the need for high frequency deliveries of short shelf life products, and the necessity of getting such products to the place of consumption which are often retail outlets located in highly urban areas. To do so requires heavy use of road infrastructure in the UK, something that represents a major potential exposure to disruption due the high frequency of use and lack of alternatives. In response to this, FDM 1 has invested heavily in recent years in their own logistics arm to reduce reliance on third party logistics providers. In addition to reliance on roads, disruption to the UK ports is a major resilience consideration, given that alternatives such as air freight are prohibitively expensive, again, a risk factor that is shared by many UK international FDMs.

FDM1 also enjoys a collaborative long-term partnership with their retailer customers, something that is increasingly common within the wider UK FDM sector as retailers, facing fierce competition for market share amongst one another, increasingly seek to streamline their own supply chains against competition. The result is that whilst there is still immense pressure to fulfil contract deadlines, competition it is increasingly more in the form of supply chains vs supply chain rather than inter-value chain friction. This move away from buyer-seller/spot market relations means that food value chains are increasingly willing to focus on issues of sustainability and particularly resilience that would not necessarily have been consider previously.

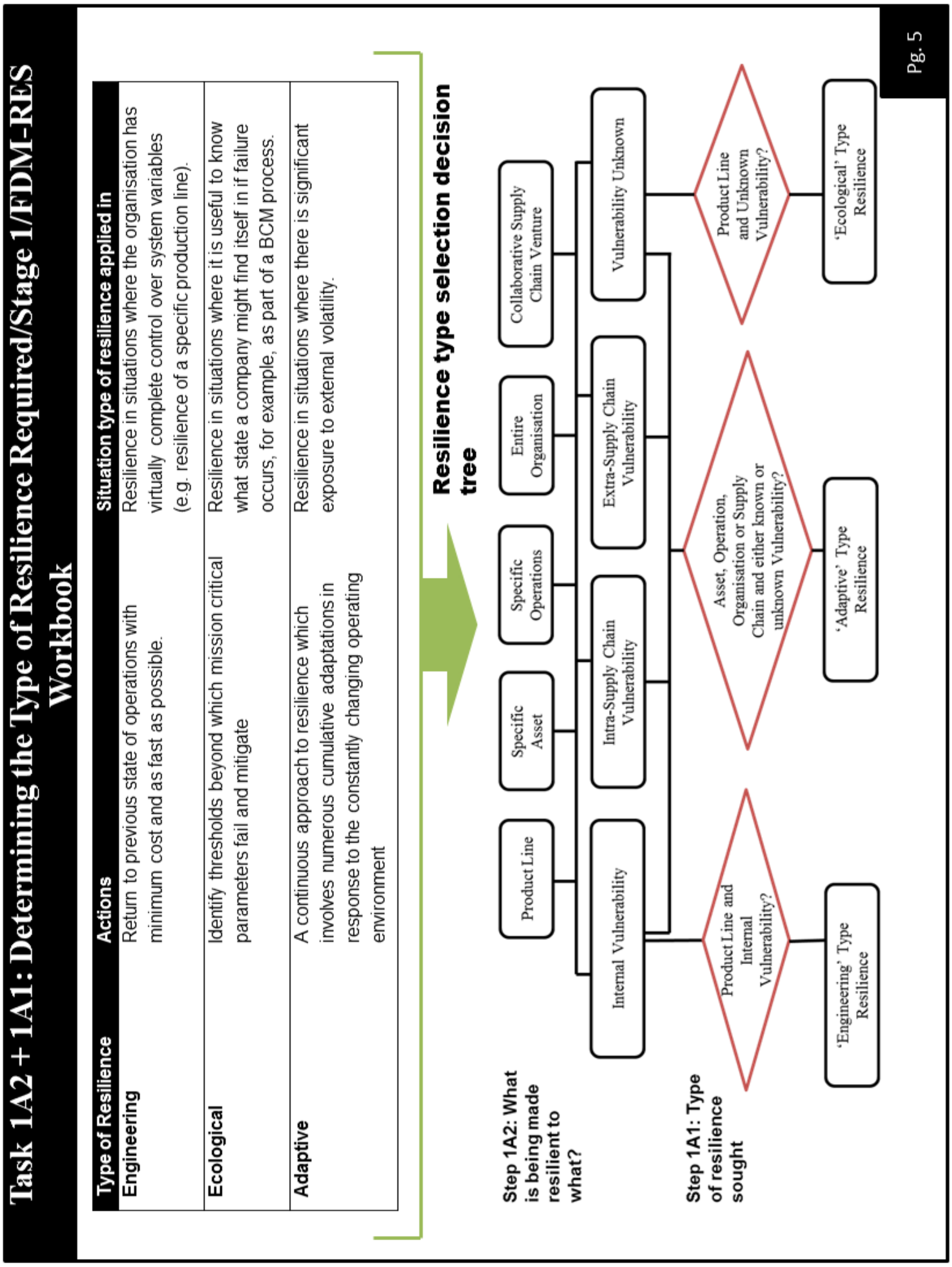
As a result, FDM1 and the chilled convenience food sector which it represents possess a number of similarities with the broader UK FDM sector in terms of infrastructure dependencies, exposure to wider supply network volatility and pressures from societal trends and retailers. These traits also enable the FDM-RES Workbook to be tested in the broadest sense possible through the application and validation of the full range of resilience KPIs (FDM-RES Workbook Stage 1, Chapter 7), internal, value chain and external vulnerability sources (FDM-RES Workbook Stage 2, Chapter 8) and the internal and supply network resilience capabilities (FDM-RES Workbook Stage 3, Chapter 9).

10.5.2 Application of FDM-RES Workbook and Results

The case study involved the implementation of all four stages of the FDM-RES Workbook (see Figure 10.1) in order to enable verification in principle and adaptation where necessary based on analysis of results. Application of the four workbook stages are now discussed in detail.

10.5.2.1 FDM-RES Workbook Stage 1: Problem Definition

In line with the FDM-RES Workbook, application of the case study began with the identification of what is to be made resilient to what (Task 1A2), specification of the 'type' of resilience sought (Task 1A1), the associated phases targeted (Task 1A3) and the KPIs against which the case study organisation wishes to benchmark resilience (Task 1B1). The first stage of the problem definition addresses Task 1A2 of the FDM-RES Workbook and identifies what was being made resilient to what. FDM1 identified that the 'object' being made resilient was the supply of a specific sandwich line to five major retailers. In line with Workbook guidelines, this placed the object being made resilient within the category of 'specific operations', as it is too broad to describe the simple sandwich processing line itself, but instead concerns all of the wider value chain and supply network supporting entities involved in delivering the product to the customer. This therefore opens up the sandwich line to a range of external volatility, to a degree that it cannot be addressed by the Engineering or Ecological 'types' of resilience and so the adaptive 'type' of resilience was selected (See example FDM-RES Workbook page in Figure 10.3).



Task 1A2 + 1A1: Determining the Type of Resilience Required/Stage 1/FDM-RES Workbook

Type of Resilience	Actions	Situation type of resilience applied in
Engineering	Return to previous state of operations with minimum cost and as fast as possible.	Resilience in situations where the organisation has virtually complete control over system variables (e.g. resilience of a specific production line).
Ecological	Identify thresholds beyond which mission critical parameters fail and mitigate	Resilience in situations where it is useful to know what state a company might find itself in if failure occurs, for example, as part of a BCM process.
Adaptive	A continuous approach to resilience which involves numerous cumulative adaptations in response to the constantly changing operating environment	Resilience in situations where there is significant exposure to external volatility.

Figure 10.3: FDM-RES Workbook process for identifying what is being made resilient to what and the type of resilience sought.

In line with guidance offered in the FDM-RES Workbook, FDM1 selected a wide range of KPIs which reflect the importance of being able to adapt as an organisation. Given the range of KPIs available for consideration when the adaptive type of resilience was selected, it was realised that not all would be relevant to an organisation and of those that were, not all would have the same level of importance to the organisation. Therefore, the questionnaire allowed participants to rank KPIs using a Likert scale of 1-5 with 5 being priority KPIs, 4 being secondary KPIs, 3 being non-important at present but projected to grow in importance in future, 2 being a nice to have and 1 being unimportant. The KPIs identified by FDM1 are displayed in Figure 10.4.

Task 1B: Determining Resilience KPIs/Stage 1 /FDM-RES Workbook

Using the KPI reference table provided overleaf, please prioritise the KPIs which must benefit from any resilience efforts.

These should be ranked as follows:
1: Unimportant,
2: Nice to have but otherwise relatively unimportant,
3: Currently low priority but likely to become increasingly important in future,
4: Of significant but secondary current importance, and finally
5: Priority importance

1: Unimportant	2: Nice to have	3. Low but growing importance	4. Secondary priority	5.Top priority
CE4; CENV3; EE1; ES3	CS2,4,6; QS3,4; QENV2,3	CE3,8,9; CENV1;CS3,5; SLS3;	CENV4; CS1; CE5,7; SLE2,3; SLS1,2,4; SLENV1; EENV1,2; EE2;ES1,2; QE3; QS1,2	CE1,2,6; CENV2; CS7; SLE1,4,5; SLS2; QE1,2; QENV1

Pg. 7

Figure 10.4: Priority KPIs for measuring resilience, identified by FDM1.

The results are interesting because they show that whilst many of the priority elements for resilience are those which you would expect, such as Contract Fulfilment and compliance with Environmental/Health and Safety legislation, there are a number of unexpected KPIs such as Animal Welfare and Community Investment and Philanthropy. The case study process identified that many of these choices were a result of increasingly collaborative relationships with long term retail customers who are increasingly driving the implementation of their own private food standards schemes. Such schemes represent a growing awareness of the importance of value chain sustainability and to a degree, resilience, but also credence factors, such as animal welfare and local sourcing, to distinguish their products. The KPIs taken forward for use in evaluating resilience elements in Stage 4 of the Case study were the Priority and Secondary KPIs. This therefore concludes the case study application of Stage 1 of the FDM-RES Workbook.

10.5.2.2 FDM-RES Workbook Stage 2: Identification of Vulnerabilities

Application of the case study technique to Stage 2 of the FDM-RES Workbook involved the utilisation of the supply network mapping technique developed in Chapter 8 to identify priority exposure metrics (FDM-RES Workbook Tasks 2A1-3), associated failure modes (FDM-RES Workbook Tasks 2B1-2) and underlying causal vulnerabilities (FDM-RES Workbook Tasks 2C1-2).

The first step, Task 2A1, involved the use of the exposure metrics reference table (see Table 8.1, Chapter 8) to identify metrics for FDM1's primary supply network entities. The data, collected in tabular form, is presented in Table 10.7. All metrics represent the most accurate averages that the participants could provide.

Table 10.7 FDM1 Primary Supply Network Entity Exposure Metrics

Primary Supply Network Entities	**Input Criticality**	**Material Flow**	**Information Flow**	**Relational Links**
Chicken Supplier **Location**: Thailand **Potential Alternatives**: Multiple (both in SE Asia and UK) **Level of Auditing/ Financial Security**: High	**Production Constraints:** Rearing time from hatchling to slaughter ~6 weeks. **Lead Time:** Provide Forecast 1 week in advance and confirm 24 hours **Supplier Reserves:** Limited but early slaughter possible **Supplier Capacity to Alter Volume:** As above	**Inbound Transport Type:** Ship Freight, chilled and Road, chilled artic lorry **Inbound Transport Volumes:** ~30 pallets daily **Inbound Transport Frequency:** daily **Inbound Transport Route:** Mediterranean/Suez route (12 weeks shipping time). Road from Felixstowe to supplier depot and from there to FDM1 site (2-3 hours). **Presence of alternative types/routes:** Shipping can take the horn of Africa but this adds on approx. four weeks. Otherwise air freight. Alternative road routes may or may not be possible depending on disruption circumstances.	**Inbound information type:** Digital and phone exchange of forecasts, order summary and dispatch report. Phone confirmation where necessary. **Inbound information route:** fiber optics and phone lines. Information backed up on geographically separated servers **Inbound information frequency:** Weekly	**Presence of Buying–Selling Relationship?** Yes **Level of Adversity:** Low **Interdependence:** Low **Level of Collaboration**: Low
Bread Supplier **Location:** UK, Midlands **Potential Alternatives:** Very limited **Level of Auditing/Financial Security:** High	**Production Constraints: low-**less than 24 hours for bread although the wheat itself can take up to 130 days **Lead Time:** Provide Forecast 1 week in advance and confirm 24 hours **Supplier Reserves:** low **Supplier Capacity to Alter Volume:** high due to	**Inbound Transport Type:** Road, artic lorry. **Inbound Transport Volumes:** ~ 40 pallets daily **Inbound Transport Frequency:** daily **Inbound Transport Route:** Road direct to FDM1 Manufacturing plant (@2-3 hours) **Presence of alternative types/routes:** Alternative road routes may or may not be possible depending on disruption circumstances.	**Inbound information type:** Digital and phone exchange of forecasts, order summary and dispatch report. Phone confirmation where necessary. **Inbound information route:** fiber optics and phone lines. Information backed up on geographically separated servers **Inbound information**	**Presence of Buying–Selling Relationship?** Yes **Level of Adversity:** Low **Interdependence:** high **Level of Collaboration**: Low

	short production time		**frequency:** Daily	
Mayonnaise Supplier **Location:** UK, North East **Potential Alternatives:** Multiple **Level of Auditing/ Financial Security:** High	**Production Constraints:** none-less than 24 hours **Lead Time:** Provide Forecast 1 week in advance and confirm 24 hours **Supplier Reserves:** High **Supplier Capacity to Alter Volume:** High	**Inbound Transport Type:** Road, artic lorry. **Inbound Transport Volumes:** ~6 pallets daily **Inbound Transport Frequency:** daily **Inbound Transport Route:** Road from supplier depot to FDM1 manufacturing site (@2-3 hours) **Presence of alternative types/routes:** Alternative road routes may or may not be possible depending on disruption circumstances.	**Inbound information type:** Digital and phone exchange of forecasts, order summary and dispatch report. **Inbound information route:** fiber optics and phone lines. Information backed up on geographically separated servers **Inbound information frequency:** Daily	**Presence of Buying–Selling Relationship?** Yes **Level of Adversity:** Low **Interdependence:** Low **Level of Collaboration**: Low
Packaging Supplier **Location:** UK, South East **Potential Alternatives:** Limited **Level of Auditing/ Financial Security:** High	**Production Constraints: Lead Time:** Provide Forecast 1 week in advance and confirm 24 hours **Supplier Reserves:** High **Supplier Capacity to Alter Volume: H**igh	**Inbound Transport Type:** Road, artic lorry. **Inbound Transport Volumes**: ~15 pallets per week **Inbound Transport Frequency:** weekly **Inbound Transport Route:** road from supplier depot (@2-3 hours) **Presence of alternative types/routes:** Alternative road routes may or may not be possible depending on disruption circumstances.	**Inbound information type:** Digital and phone exchange of forecasts, order summary and dispatch report. **Inbound information route:** fiber optics and phone lines. **Inbound information frequency:** Weekly	**Presence of Buying–Selling Relationship?** Yes **Level of Adversity:** Low **Interdependence:** High **Level of Collaboration**: Low
Non-Resale Suppliers **Location:** UK, Midlands **Potential Alternatives:** Very Limited **Level of Auditing/ Financial Security:** High	**Production Constraints:** None **Lead Time:** Provide Forecast 1 week in advance and confirm 24 hours **Supplier Reserves:** N/A Typically prototype products **Supplier**	**Inbound Transport Type:** Road, artic lorry **Inbound Transport Volumes:** Small, typically 1-2 pallets **Inbound Transport Frequency:** Monthly **Inbound Transport Route:** Road direct from supplier to FDM1 Manufacturing site (@2-3 hours) **Presence of alternative types/routes:** Alternative road routes may or may	**Inbound information type:** Digital and phone exchange of forecasts, order summary and dispatch report. **Inbound information route:** fiber optics and phone lines. Information backed up on geographically separated servers	**Presence of Buying–Selling Relationship?** Yes **Level of Adversity:** Low **Interdependence:** High **Level of Collaboration**: Low

	Capacity to Alter Volume: N/A	not be possible depending on disruption circumstances.	**Inbound information frequency:** Daily	
<u>FDM1</u> Chicken/Mayonnaise sandwich production **Location:** UK, Midlands	**Production Constraints:** Cleaning cycles/ staff availability **Lead Time:** 24 hours **Reserves:** None **Supplier Capacity to Alter Volume:** High but dependent on labour	**Outbound Transport Type:** Chilled artic lorry **Outbound Transport Volumes**: ~60 pallets daily **Outbound Transport Frequency:** hourly **Outbound Transport Route:** Road direct from FDM1 production line to retailer depot (@2-3 hours) **Presence of alternative types/routes:** Alternative road routes may or may not be possible depending on disruption circumstances.	**Outbound information type:** Digital and phone exchange of forecasts, order summary and dispatch report. **Outbound information route:** fiber optics and phone lines. **Outbound information frequency:** Daily	**Intra-organisational Competition:** Low **Intra-organisational Collaboration:** High **Level of intra-organisational integration:** High
<u>Retailer Customer</u> **Location:** UK, Midlands **Potential Alternatives: Limited** (due to tight batch specifications) **Level of Auditing/ Financial Security:** High	**N/A**	**Outbound Transport Type:** Chilled artic lorry **Outbound Transport Volumes:** ~1 (mixed) pallet daily **Outbound Transport Frequency:** hourly **Outbound Transport Route:** road from retailer depot to individual stores (@2-5 hours) **Presence of alternative types/routes:** Alternative road routes may or may not be possible depending on disruption circumstances.	**Outbound information type:** Digital and phone exchange of forecasts, order summary and dispatch report. **Outbound information route:** fiber optics and phone lines. Information backed up on geographically separated servers **Outbound information frequency:** Daily	**Relationship:** Long term value chain collaboration **Power Imbalance:** Medium **Integration of operations:** High **Willingness to invest in supplier quality & sustainability:** High **Willingness to collaborate with value chain:** High **Restrictions on supplier sourcing:** High **Penalties for late/sub-standard delivery:** High

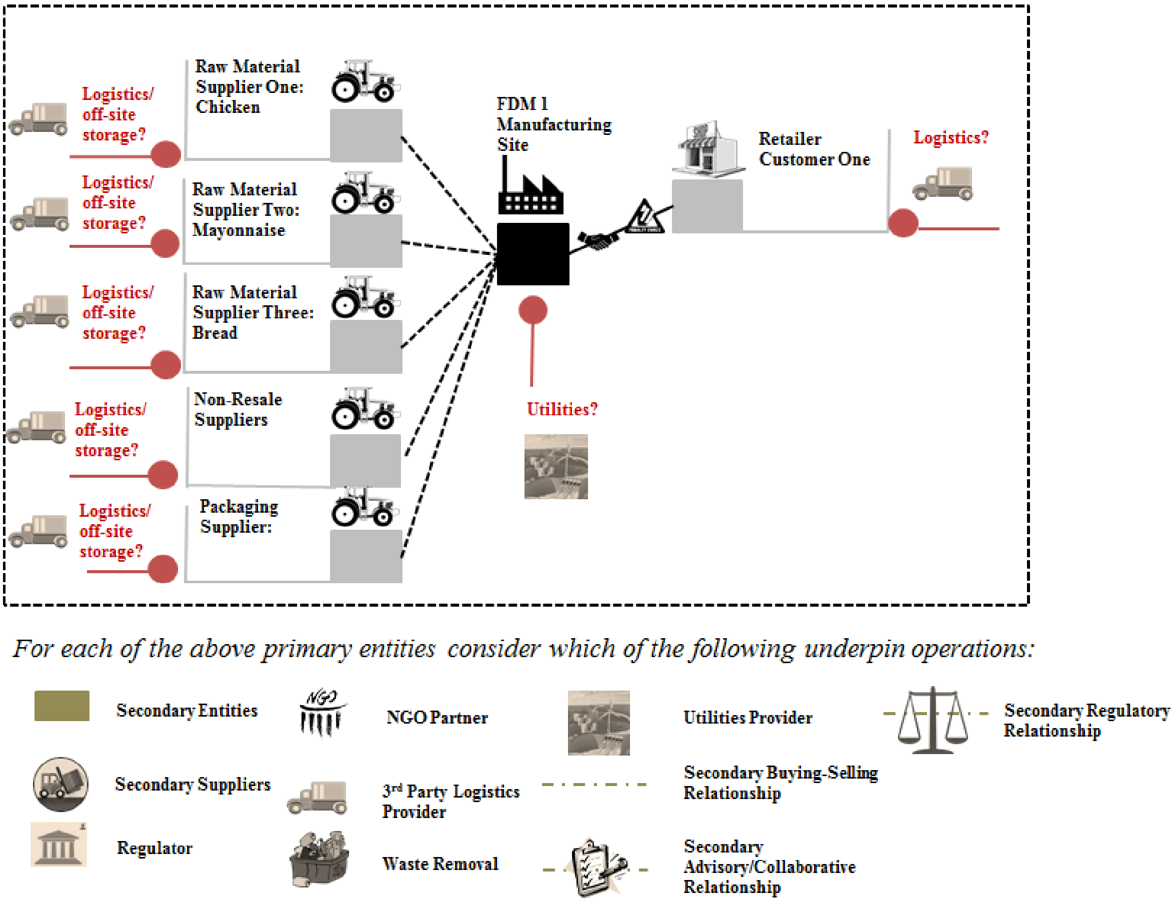


Figure 10.5: Mapping of FDM1 Primary Supply Network Entities and resulting questions regarding Secondary (supporting) Network Entities.

FDM-RES Workbook Task 2A2/A3 involved the development of these into a hand drawn map which enabled their comparison with a number of secondary entity suggestions to identify the types of secondary entity that FDM1 should collect exposure metrics for. (See Figure 8.4 in Chapter 8 for Guidance on this process). In the case of FDM1, this mapping process raised a number of questions concerning secondary entities such as logistics, supplier offsite storage and utility suppliers of FDM1 as shown in Figure 10.5. Details for these entities were then collected in a similar way as for the primary entities, considering input criticality, material flow, information flow and relational links. The results can be found in Table 10.8.

Table 10.8: Exposure metrics regarding FDM1's Secondary Supply Network Entities.

Secondary Supply Network Entities	**Input Criticality**	**Material Flow**	**Information Flow**	**Relational Links**
3rd Party Logistics Providers: **Numbers:** Each of the five suppliers contracts their own 3PL logistics. These are only used for inbound deliveries **Geographic Location(s):** National Coverage **Alternatives that match product transport requirements:** High **Ability to change collection capacity at short notice:** High	**N/A**	**Inbound Transport Type:** Road, chilled and ambient lorry **Inbound Transport Volumes:** between 10 pallets for 7.5 tonne lorries and 26 for articulated lorries. **Inbound Transport Frequency:** Hourly **Inbound Transport Route:** Various, road **Presence of alternative types/routes:** Alternative road routes may or may not be possible depending on disruption circumstances.	**Inbound information type:** Digital and phone exchange of forecasts, order summary and dispatch report. **Inbound information route:** fiber optics and phone lines. Information backed up on geographically separated servers **Inbound information frequency:** Hourly	**Relationship:** Long term collaboration **Power Imbalance:** low **Integration of operations:** High **Willingness to invest in supplier quality & sustainability:** low **Willingness to collaborate with value chain:** High
Raw Materials Suppliers Off-Site Storage **Numbers:** Numerous **Geographic Location(s):** National **Alternatives that match product transport requirements:** High **Ability to change collection capacity at short notice:** High	N/A	N/A	**Inbound information type:** Digital and phone exchange of forecasts, order summary and dispatch report. **Inbound information route:** fiber optics and phone lines. Storage on geographically separated servers **Inbound information frequency:** Daily	**Presence of Buying–Selling Relationship?** Yes **Level of Adversity:** Low **Interdependence:** Low **Level of Collaboration:** Low
FDM1 Utilities Providers **Location of supplier/infrastructure:** Utilities suppliers are all UK based. **Presence of alternatives:** Yes, but they would likely share similar infrastructure.	**Peak capacity of supplier:** Extremely unlikely that FDM1 would exceed capacity	**Physical route:** Water via underground pipes & electricity via overland lines. Both have redundant infrastructure **Locations of reserves:** FDM1 has generators for 24 hours of operations and could hire more (<24 hours' notice). Spare water tanks within 24 hours' notice.	**Inbound information type:** Digital and phone **Inbound information route:** fiber optics and phone lines. **Inbound information frequency:** Weekly	**Buying–Selling Relationship?** Yes **Level of Adversity:** Low **Interdependence:** Low **Level of Collaboration:** Low

Having mapped out FDM1's primary and secondary supply network entities and collected the associated exposure metrics, the case study proceeded to FDM-RES Workbook Task 2B1 and the evaluation of the metrics to determine which were priority exposures. As a preliminary step to offer validation for the framework, FDM1 was asked to suggest what they preliminarily thought were their priority exposures and the answers were as follows (in no order of importance):

a) Road Closures,

b) Bakery Fire and Temporary Closure and;

c) Extreme weather Events in Growing Areas

These responses were then temporarily put to one side so that the FDM-RES Workbook guidelines for identifying priority exposure metrics could be tested. This was achieved via cross referencing of the exposure metrics collected in Tables 10.7 and 10.8 with the exposure metric evaluation table displayed in Table 10.2. The priority exposure metrics as suggested by the framework are displayed in Table 10.9. In total, five high priority exposure metrics were identified for FDM1.

The first concerned the primary supplier of chicken for FDM1 and the exposure metrics surrounding material flow. It was identified that the long distances involved, singular transport routes with limited alternatives, combined with the short lead time FDM1 faced in manufacturing the sandwich made this a priority exposure point (MFRM1 in the priority exposure references provided in Table 10.2). This was compounded by the fact that, whilst alternate chicken suppliers that met retailer specifications did exist, often the cooked chicken required specific flavouring which in practice, made switching supplier quickly challenging. The next three out of five high priority exposure metrics all clustered around FDM1s primary bread supplier. The first concerned fact that their bread supplier was one of the few geared up to make bread to their very exact specifications and very high quantities in the country, thus aligning with priority exposure PES3 in reference Table 10.2.

The second concerned the related exposure that these large volumes required incredibly frequent (hourly) deliveries which were entirely dependent on limited road routes for transport with no non-road-based alternatives. Given the impracticality of FDM1 storing bread in any meaningful quantities (due to shelf life, capacity and quality restrictions) this aligned with high priority exposure MFRM1 in reference Table 10.2.

Table 10.9 Evaluation of identified exposure metrics identified by FDM1.

	Supply Network Entity	Supply Network Complexity	Input Criticality	Material Flow	Information Flow	Relational Links
Primary Supply Network Entities	Chicken Supplier	Low Priority Exposure	Low Priority Exposure	MFRM1 High Priority Exposure	Low Priority Exposure	Low Priority Exposure
	Bread Supplier	PES3 High Priority Exposure	Low Priority Exposure	MFRM1 High Priority Exposure	Low Priority Exposure	RLH1High Priority Exposure
	Mayonnaise Supplier	Low Priority Exposure	Low Priority Exposure	Low Priority Exposure	Low Priority Exposure	Low Priority Exposure
	Packaging Supplier	Low Priority Exposure	Low Priority Exposure	Low Priority Exposure	Low Priority Exposure	Low Priority Exposure
	Non-Resale Suppliers	Low Priority Exposure	Low Priority Exposure	Low Priority Exposure	Low Priority Exposure	Low Priority Exposure
	FDM1	Low Priority Exposure	Low Priority Exposure	MFO1 High Priority Exposure	Low Priority Exposure	Low Priority Exposure
	Retailer Customer	Low Priority Exposure	Low Priority Exposure	Low Priority Exposure	Low Priority Exposure	Low Priority Exposure
Secondary Supply Network Entities	3rd Party Logistics	Low Priority Exposure	Low Priority Exposure	Low Priority Exposure	Low Priority Exposure	Low Priority Exposure
	Supplier Off-Site Storage	Low Priority Exposure	Low Priority Exposure	Low Priority Exposure	Low Priority Exposure	Low Priority Exposure
	FDM Utility Providers	Low Priority Exposure	Low Priority Exposure	Low Priority Exposure	Low Priority Exposure	Low Priority Exposure

FDM1 was able to provide numerous anecdotes of times when heavy snowfall, particularly in 2010, prevented road deliveries of bread for two days, which led to a build-up of hundreds of tonnes of raw material which the manufacturer could not then convert into sandwiches. The final priority exposure relating the primary bread supplier concerned the relational links enjoyed with that supplier. The fact that interdependence (due to high volumes and very specific product specifications) was high but that collaboration was relatively low meant that in the case of a major disruption, FDM1 would struggle to find alternatives.

The final high priority exposure metric concerned FDM1 themselves and focussed on their own outbound deliveries. These were heavily dependent on road transport and with no non-road alternatives being available, a high number of daily deliveries and tight retailer penalties for non/late delivery, FDM1s outbound deliveries were identified as a high priority exposure (MFO1 in the priority exposure references provided in Table 10.2). In summary, these workbook results would appear to closely mirror the three top priority exposure points that FDM1 identified independently, lending weight to practical efficacy of the FDM-RES Workbook.

The next step, Task 2B2, proceeded to use the identified priority exposures to highlight potential resulting failure modes. This was achieved through cross referencing of the identified priority exposures with linked failure modes using the relational matrix in the FDM-RES Workbook (See Table 8.4, Chapter 8). The associated failure mode for each priority exposure is displayed in Table 10.10. Having identified bespoke failure modes, causal vulnerabilities could then be identified as part of FDM-RES Workbook Tasks 2C1 and 2C2. This was facilitated by the cross referencing of the failure modes identified in Table 10.10 with the causal vulnerability reference matrix in the workbook (See Table 8.6, Chapter 8). The results are shown in Table 10.11.

Table 10.10: FDM1 Failure modes based on their identified priority exposure metrics.

Priority Exposure Point	**Associated Failure Mode**
PES3	FM1, 2 and 5
MFRM1	FM1, 2 and 3
MFO1	FM7 and FM10
RLH1	FM 1, 2, 3, 5 and 10

Table 10.11: FDM1 Vulnerability sources, validation of exposure and failure mode likelihood.

Failure Mode	**Associated Causal Vulnerability (s)**		**Vulnerability**	**Failure Mode Likelihood**
FM1	**Mar.**	4. Variability in availability of raw materials	5	5
		5. Variability in demand	5	5
	Gov.	3. Political instability	4	5
		4. Import/export restrictions	3	5
	Inf.	1. Disruption to transport infrastructure	5	4
		3. Disruption to energy infrastructure	4	2
		4. Disruption to communications	4	1
	Soc.	1. Piracy/Terrorism	5	5
		2. War and conflict	5	5
		6. Criminal acts	5	4
		7. Industrial actions	2	1
	Env.	1. Natural disasters	5	5
		2. Biological factors	5	5
		3. Anthropogenic environmental hazards	2	4
		4. Unsustainable Primary Production	2	2
	VCRMP	4. Outsourcing of Processing Procedures	4	5
	VCLC	1. Poor reliability of external logistics providers	2	5
	VCIS	1. Lack of established, integrated information sharing infrastructure	5	5
	VCOMS	1. Low level of training & experience in other company's employees.	4	5
		3. High concentration in supply chains	4	2
	OSRMP	1. Challenges related to storing raw materials/finished inventory	2	5
		6. Inability to react to changing circumstances	5	2
	OSLC	1. Inaccurate forecasting	5	2
		2. Lack of flexibility in internal distribution capacity	1	1
	OSIS	1. Breech in information/data security	5	5
		2. Breakdowns in internal information handling	1	2
		3. Absence of early warning detection systems	2	5
	OSOMS	2. Lack of strategic decision making	4	5
		5. Insufficient Corporate Social Responsibility Programme.	2	3
FM2	**Mar.**	4. Variability in availability of raw materials (growing seasons, profitability of crop)	5	5
		5. Variability in demand	5	5
	Gov.	3. Political instability	4	5
		4. Import/export restrictions	3	5
	Soc.	1. Piracy/Terrorism	5	5
		2. War and conflict	5	5
	Env.	1. Natural disasters	5	5
		2. Biological factors	5	5
		4. Unsustainable Primary Production	2	2
		1. Inconsistent Raw material quality and	4	5

	VCRMP	heterogeneity		
	VCIS	2. Deliberate withholding of information	3	5
	OSIS	3. Absence of early warning detection systems	2	3
	OSRMP	1. Challenges related to storing raw materials/finished inventory	2	5
		6. Inability to react to changing circumstances	5	2
	VCOMS	1. Low level of training & experience in other companies' employees.	4	2
		2. Poor financial robustness of value chain partners	5	4
	OSOMS	2. Lack of strategic decision making	4	3
FM3	**Gov.**	1. Changes in Public Food Policy	3	2
		2. Private Food Policy	3	3
	Inf.	1. Disruption to transport infrastructure	5	3
		2. Disruption to water infrastructure	2	4
		4. Disruption to communications	4	5
	Soc.	3. Workforce health	5	3
		6. Criminal acts	5	4
	VCIS	1. Lack of established, integrated information sharing infrastructure	5	5
		2. Deliberate withholding of information	3	5
	OSRMP	1. Challenges related to storing raw materials/finished inventory	2	5
		4. Insufficient capacity to meet changing order requirements	5	5
	OSLC	1. Inaccurate forecasting	5	2
	OSIS	1. Breech in information/data security	5	5
		2. Breakdowns in information handling	1	2
	OSOMS	2. Lack of strategic decision making	4	3
		3. Absence of, or ineffective Business Continuity Planning	2	5
FDM5	**Fin.**	1. Market price fluctuation	5	3
		2. Currency exchange fluctuations	5	3
		3. Interest rate fluctuations	5	2
		4. Regional economic downturns	5	2
		5. Hostile takeover attempts	1	2
		6. Product liability	3	5
	Mar.	1. Market decline	2	2
		2. Competitive Innovation	2	2
		3. Competitor undercutting	2	2
	Gov.	1. Changes in Public Food Policy	3	2
		3. Political instability	4	5
		4. Import/export restrictions	3	5
	Soc.	1. Piracy/Terrorism	5	3
		2. War and conflict	5	3
		4. Proportion of Consumer income available for food purchase	1	2
		5. Changing customer attitudes to consumption	1	2
		6. Criminal acts	5	3
		8. Poor relations with consumers and special interest groups	5	3

	Env.	4. Unsustainable Primary Production	2	2
	VCOMS	2. Poor financial robustness of value chain partners	5	4
		3. High concentration in supply chains	4	4
		4. High levels of power imbalance between actors	4	4
	OSOMS	1. Poor protection of intellectual property	2	4
FDM7	**Inf.**	1. Disruption to transport infrastructure	5	5
		3. Disruption to energy infrastructure	4	2
		4. Disruption to communications	4	5
	Soc.	6. Criminal acts	5	4
		7. Industrial actions	2	5
	VCIS	1. Poor reliability of external logistics providers	2	5
	OSLC	2. Lack of flexibility in internal distribution capacity	2	2
	OSIS	1. Breech in information/data security	5	5
		2. Breakdowns in internal information handling	2	2
FDM10	**Gov.**	2. Private Food Policy	3	2
	Inf.	1. Disruption to transport infrastructure	5	4
	Soc.	7. Criminal acts	5	4
		8. Poor relations with consumers and special interest groups	5	3
	Env.	3. Anthropogenic environmental hazards	2	2
	VCRMP	2. Raw material and product related hazards	5	3
	VCIS	2. Deliberate withholding of information	3	5
		3. Lack of ability to trace food across the value chain	3	5
	VCOMS	1. Low level of training & experience in other company's employees.	4	2
	OSRMP	1. Challenges related to storing raw materials/finished inventory	2	5

To validate this stage of the FDM-RES Workbook, FDM1 was also asked, prior to seeing the results, to rank the framework causal vulnerabilities (see Table 10.4) according to how significant a threat they were perceived to be. This was achieved via a Likert scale, with 5 being priority vulnerabilities, 4 being secondary vulnerabilities, 3 being non-important at present but projected to grow in importance in future, 2 being very limited exposure and 1 representing irrelevant vulnerabilities. Participants were also asked to identify the failure modes that they believed each vulnerability would lead to, thus helping to validate the FDM-RES Framework Vulnerability-Failure Mode linkages (See Table 8.4, Chapter 8). This also used a Likert scale of 1-5 with 5 representing certain cause-effect, 4-2 representing decreasing likelihood and 1 representing no linkage.

Excluding duplicate vulnerabilities associated with more than one failure mode, the FDM-RES Workbook identified 52 unique vulnerabilities facing FDM1. Of these 30 (57%) were identified as being of either priority or secondary importance to FDM1. Furthermore, 59 (56%) of the proposed linkages between a given failure mode and its causal vulnerability were identified as being either certain (score of 5) of very likely (score of 4). However, it is important to note that the relevance of vulnerability and its likelihood to result in the projected failure mode is highly organisational specific. For example, FDM1 identified that whilst exposed to financial turbulence (e.g. regional economic downturns), in practice these vulnerabilities had never resulted in loss of economic viability because the duration of a disruption had never been long enough.

It also became clear that the size of FDM1 meant that their exposure to a number of vulnerabilities was considerably lower than might have been expected. For example, FDM1 was so large that vulnerabilities such as hostile takeover attempts were not the threat they might be to smaller FDM's. Equally because they supplied so many retailers, market decline in one area often led to opportunities in another. This was a factor in environmental disasters too, where even though FDM1 acknowledged a direct link between natural disasters and shortages of raw material/quality limitations (i.e. Likert score of 5 for FM1+2), they could easily afford to air freight in produce from elsewhere. In summary, whilst the case study validated the vulnerabilities-failure mode relationships described in the FDM-RES Framework, the practical context of the organisation will always influence the actual outcome. Having identified FDM1's bespoke vulnerability sources, the case study moved on to Stage 3 of the FDM-RES Workbook and the identification of mitigating Resilience Elements.

10.5.2.3 FDM-RES Workbook Stage 3: Identification of Mitigating Resilience Elements

The case study application of workbook Stage 3 began with the cross referencing of the primary and secondary priority vulnerabilities identified in Stage 2 (i.e. those that scored 4 or 5) with the workbook resilience element-vulnerability relational matrix (See Tables 9.3 and 9.4, Chapter 9). Results are shown in Table 10.12 below.

Table 10.12: FDM1 Priority Resilience Elements.

Order of Importance	**Suggested Resilience Element**	**Number of associated underlying vulnerabilities**	**Feasibility validation**
1	**OR 12:** Risk Management	23	4
2	**SNR 12**: Contingency Plans	22	5
3	**OR 4**: Early Warning	21	3
4	**OR1:** Flexibility	19	5
5	**OR 9**: Financial Strength	18	5
6	**SNR 3**: Visibility	15	3
7	**SNR 9**: Robustness	14	2
7	**OR 5:** Agility	14	5
8	**OR 3**: Redundancy	13	2
9	**OR 18**: Adaptive Management	12	3
10	**SNR 14**: Network Complexity	10	4
10	**SNR 16**: Community Resources	10	3
11	**SNR 13**: Diversity	9	4
11	**OR 13** Business Continuity Management	9	5
11	**SNR 2**: Flexibility	9	5
12	**SNR 6**: Redundancy	8	3
12	**OR 2**: Risk Aware Culture	8	4
12	**SNR 1**: Collaboration	8	5
12	**SNR 7**: Node Criticality	8	5
13	**OR 10:** Leadership Commitment	7	4
14	**OR 16**: Knowledge Management	6	3
14	**OR 17**: Market Position	6	4
14	**OR 11**: Relationships	6	4
15	**SNR 4**: Adaptability	4	4
15	**SNR 11**: Cohesion	4	5
15	**OR 15**: Innovation	4	5
16	**OR 14**: Human Resources	3	3
16	**OR 6**: Security	3	4
16	**SNR 8**: Est Communications	3	5
17	**SNR 5**: Velocity	2	5
17	**OR 8**: Inventory Management	2	5
17	**SNR 15**: Bargaining Power	2	5
18	**SNR 10**: Trust	1	4
18	**OR 7**: Efficiency	1	3

As resilience elements can counter multiple vulnerabilities, it is possible to rank these elements by how many of an organisation's given vulnerabilities they are able to mitigate. This is highlighted in Table 10.12 which shows how the top priority resilience element for FDM1 is OR12 Risk Management because it mitigates 23 individual vulnerabilities.

As a validation check of the practicability of the resilience elements detailed in the FDM-RES Framework, FDM1 was asked to identify whether they currently implemented each resilience element in their organisation and whether there was scope to implement it more effectively. This was facilitated using a Likert scale of 1-5, with 5 being fully implemented and no room for improvement, 4 being implemented but with room for small improvements, 3 being poorly implemented but with signs of potential benefit to be gained from implementation, 2 being not implemented and of limited conceivable benefit and 1 being completely impractical. The results are revealing in that they suggest a number of resilience elements are already practically implemented, particularly elements concerning speed and reactivity as well as collaboration and contingency planning/business continuity. Some improvements were identified as being possible regarding early warning detection and visibility and the only elements that were identified as being of limited use were those that related to redundancy of some kind.

10.5.2.4 FDM-RES Workbook Stage Four: Evaluation and Implementation of Resilience Elements

The final stage of the case study involved the evaluation of shortlisted resilience elements based on the impact on KPIs and the alignment with the type of resilience identified as a priority in Stage 1. It was not possible to actually implement a resilience strategy in the organisations as for the companies involved, participation was seen as exploratory only. However, this section involved collection of information on how the company in question would practically go about implementing the final resilience elements selection if they were in apposition to do so (i.e. Task 4B1).

The first stage of evaluation was to compare the longlist of resilience elements against the type of resilience identified in Stage 1 of the FDM-RES Workbook. The reason for this is that if FDM1 had prioritised an engineering type of resilience, they would have prioritised just response and recovery phase (adding readiness to the list, if ecological resilience had been chosen), thus filtering the resilience elements longlist generated in Stage 3. However, as FDM1 had identified that the type of resilience sought was ‘adaptive’, no resilience elements were excluded.

The next step in the evaluation was to cross reference resilience elements longlisted in Table 10.12 with the KPI Impact Matrix (described in Table 9.6, Chapter 9). In this way, those resilience elements with only positive impacts on Priority and Secondary Priority KPIs identified by FDM1 in Stage 1 can be categorised as first choice elements and those with some negative impacts on secondary choice KPIs as second choices. By nature, resilience elements which have a negative impact on priority KPIs are discarded. The results are displayed in Table 10.13.

At this stage, FDM1 was not asked to validate the projected impacts of resilience elements on KPIs because the sustainability manager who held the relevant expertise had been interviewed as part of the development of the conceptual linkages in Chapter 9 and the raw materials manager participating in this case study did not have the relevant expertise. The results highlight how OR9 (Availability of easily accessible financial assets), OR10 (Presence of cohesive central leadership support) and OR 8 (Inventory Management) are the first-choice resilience elements for FDM1 due to the fact that they have only positive impacts on both primary and secondary KPIs identified by that organisation. This illustrates the fundamental fact that very few resilience elements come without some form of indirect cost. The elements without cost, whilst not being without merit, do not tackle the largest range of bespoke vulnerabilities facing FDM1 (see Table 10.12). Therefore, the final stage of evaluation involved cross referencing the secondary choice resilience elements in Table 10.13 with the resilience elements ranked in Table 10.12 according to how many vulnerabilities they targeted.

Table 10.13: Evaluation of FM1 Resilience Elements Shortlist based on impacts on KPIs.

<table>
<tr><td rowspan="2">FDM1 Priority KPIs</td><td rowspan="2">CE1,2,6; CENV2; CS7; SLE1,4,5; SLS2; QE1,2; QENV1</td><td>First Choice Resilience Elements</td><td>Second Choice Resilience Elements</td></tr>
<tr><td rowspan="2">OR9, OR10, OR8</td><td rowspan="2">SNR 11(i), SNR1, SNR10, SNR 8(i), SNR12, SNR 8(ii), SNR3, OR14, OR16, OR6, OR7, OR12, O13, OR18, OR11, OR5(i), OR5(ii), OR15, OR17</td></tr>
<tr><td>FDM1 Secondary KPIs</td><td>CENV4; CS1; CE5,7; SLE2,3; SLS1,2,4; SLENV1; EENV1,2; EE2;ES1,2; QE3; QS1,2</td></tr>
</table>

Resilience elements that appear as either first or second choice elements in Table 10.13 and which mitigate the highest number of vulnerabilities are selected first. As FDM1 is attempting to create an adaptive type of resilience, the phase of each selected resilience element was noted and the shortlisting was stopped when a top three elements associated with each phase of resilience had been identified as illustrated in Figure 10.6.

Normally, this final step of the FDM-RES Workbook involves outlining the practical steps for implementation of the shortlisted resilience elements and their regular review. This could not be trialled in the case study because FDM1 was validating the workbook for research rather than organisational reform purposes. However, care was taken to discuss the practical implications of implementing the resilience elements shortlisted in Figure 10.6. In terms of the readiness elements, OR12 Risk Management, SNR3 Visibility and SNR 1 Collaboration, FDM1 identified that at an organisational level, if senior management agreed with the findings of the FDM-RES Workbook, then the most practical way forward would be to assign relevant individuals to prepare action plans based on the identified resilience elements and to present them to senior management for approval. If this was obtained, these team members would be given time and resources to implement, monitor and review resilience initiatives.

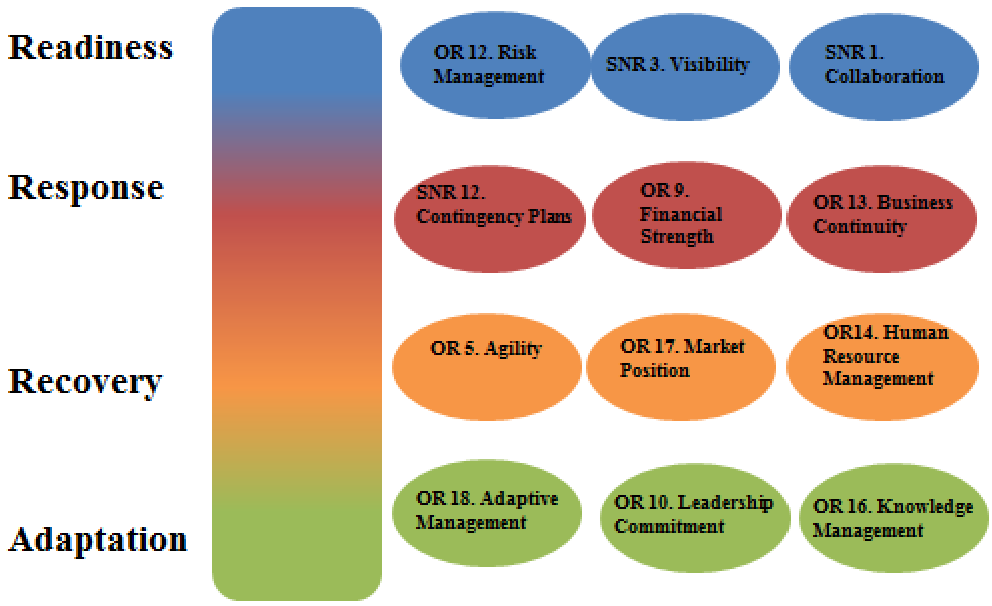


Figure 10.6: Final Resilience Elements recommended for FDM1.

10.5.3 Case Study One Conclusions

The purpose of Case Study 1 has been to illustrate the usability of the FDM-RES Workbook in a real-world context and to test the ability of the underlying FDM-RES Framework to be able to respond to different contextual settings. In this respect, FMD1 provided a number of unique considerations, in terms of its very large size, volumes of produce, purchasing power (and therefore to a degree bargaining power) and the number of large retailers it supplied. One of the first observations, was the knowledgeability of case study participants on aspects related to disruptive events, impacts on company performance and on mitigation strategies used in the past. This was associated with a high existing level of ERM and BCM Practice.

Another interesting manifestation of FDM1s size was the selection of KPIs, where it became apparent that there was a fairly broad spread of KPIs around the social and environmental pillars of cost, service level, quality and efficiency as well as the economic pillar. It was indicated through questioning that this is a result of FDM1s value chain being well established, with long-term partnerships existing not just between FDMs and retailers, but between FDMs and their suppliers too. This move away from the spot market had enabled investment in KPIs linked to sustainability, in addition to the more commonly seen economic KPIs. The large nature of FDM1 and large product inventory also means that their supplier pool is large, some of whom were primary producers, making some of the elements such as community investment and biodiversity preservation much more relevant.

This came across in some of the priority exposure metrics where bad weather in growing regions was listed as a major exposure by FDM1, alongside relations with their bakery supplier and road closures. These were mirrored by the priority exposures suggested by the FDM-RES Framework, thus offering validation. The case study also validated the suitability of the linkages proposed between the failure modes identified by the exposure metrics and the underlying causal vulnerabilities, with 56% of the proposed linkages being identified as either certain (score of 5) or very likely (score of 4) to follow one another. More so, all of the linkages proposed by the FDM-RES Framework were picked up as a possible outcome, regardless of how likely FDM1 thought them to be, further supporting the conceptual robustness of the framework relational linkages. Furthermore 57% of the vulnerabilities suggested by the FDM-RES Framework were identified as being of either priority or secondary importance to FDM1. Whilst this might not sound like a significant number, it has to be accepted that given the very specific nature of many FDMs and the broad spectrum of the vulnerability taxonomy proposed in the FDM-RES Framework, it is highly unlikely that there would ever be a 100% match. Furthermore, just because a company does not identify vulnerability as being a priority, it does not necessarily mean that this will always be the case and so the FDM-RES Workbook serves a purpose by drawing attention to potential future vulnerabilities.

All of the final resilience elements shortlisted in Figure 10.6 were identified by FDM1 as being relevant to their operations, although for some, such as collaboration and contingency planes, the respondent struggled to see how they could enhance implementation above what was already being done. Yet for others, such as adaptive management (i.e. learning and adapting as an organisation from past disturbances) it was identified that improvements could be made, for example, regarding staff retention or legacy plans so as to better retain knowledge. As a final consideration, FDM1 explained that there were too few exercises where individuals got together and linked events such as vulnerabilities faced, with failure modes and with countering strategies which considered their impact on KPIs. Therefore, feedback from FDM1 was that a hand tool such as the workbook was more intuitive for this initial collection of data and establishment of linkages than, for example, a computer database

10.6 FDM 2 Scope and Context

FDM2 is also a UK leading manufacturer of chilled convenience foods. Whilst still a major UK manufacturer, FDM2's operations are somewhat smaller than FDM1, with a smaller range of products, prioritising a range of sandwiches as well as pastries, ready meals and desserts. As with FDM1, the product of interest in this case study was a specific sandwich line. FDM2 also manufactures for just one major retailer, with no production for catering, and employs a much smaller figure of approximately 1,500 staff. Sites are restricted to two in the midlands, operating 7 days a week and 24 hours a day, yet their supporting supply network is still highly international and involve a comparably large range of secondary supply network entities to FDM1, including international suppliers in Europe and South East Asia, third party storage and logistics providers, government agencies and a variety of infrastructure providers.

10.6.1 Case Suitability

Similar to FDM1, FDM2 shares a number of characteristics which help make it representative of the wider UK FDM sector. These include heavy dependence on port infrastructure necessary to receive international supplies from Europe and South East Asia, and on chilled articulated lorries and the UK's road infrastructure to collect these/deliver to customers. It also operates exclusively in the chilled prepared foods sector, helping to make findings easily comparable with those of FDM1 and thus adding reliability to findings. However, in addition to these similarities, there are also a number of differences which help to test the applicability of the FDM-RES Framework in different contexts.

One such major difference is the significantly lower number of sites available to FDM2 (only two) which could limit resilience given that a number of the resilience elements identified in this thesis focus on the ability to flex production and share staff between sites. Another is the unique criticality of staff for FDM2, which is heavily dependent on manual labour to fill, cut and package sandwiches. Much of this labour is provided by agency staff, sourced from EU workers which have been jeopardised by recent political developments regarding the UK's membership of the EU. Furthermore, the work itself is often quite demanding, requiring staff to stand in cold conditions doing repetitive tasks for extended periods of time. For this reason, FDM2 heavily prioritises staff welfare and this is reflected in a very different KPI portfolio as opposed to FDM1.

Other considerations in selecting FDM2 were the smaller range of products and single customer, both of which impact on potential resilience elements available. In summary FDM2 shares enough operating similarities to be representative of the wider UK FDM sector and comparable with findings from FDM1 whilst providing the opportunity to validate the FDM-RES Workbook's suitability in addressing a number of company contextual differences.

10.6.2 Application of FDM-RES Workbook and Results

As with the first case study, the case study process took the form of the application of each of the four stages of the FDM-RES Workbook and these are now discussed in detail.

10.6.2.1 FDM-RES Workbook Stage One: Problem Definition

In line with the FDM-RES Framework Workbook, the case study began with stage one ‘problem identification’. The first task was 1A2 which concerned the identification of what was being made resilient to what. FDM2 identified that the ‘object’ being made resilient was the supply of a specific sandwich line to a single retailer. In this case, the specific sandwich line was a Chicken Bacon and Lettuce Sandwich, chosen to be as similar as possible to the product line selected in case study one by FDM1, thus enabling fairer comparison of other variables such as the differences in size and customer numbers faced by FDM2. As with the first case study, this placed the object being made resilient within the category of ‘specific operations’, as it’s resilience could not be analysed without consideration for a raft of wider value chain and supply network supporting entities involved in delivering the product to the customer. Therefore, the adaptive type of resilience was selected.

In line with guidance offered in the FDM-RES Framework Workbook, FDM2 also selected a wide range of KPIs which went beyond immediate company viability (i.e. the engineering resilience type) and protection of a current business model (i.e. the ecological resilience type) and reflect the importance of being able to adapt as an organisation. As before, these KPIs were collected using a Likert scale of 1-5 with 5 being priority KPIs, 4 being secondary KPIs, 3 being non-important at present but projected to grow in importance in future, 2 being a nice to have and 1 being unimportant. The KPIs identified by FDM2 are displayed in Figure 10.7.

The results are interesting because they show that FDM2 places a much higher emphasis on the need for resilience strategies to preserve economic cost indicators and aspects relating to job satisfaction/salary/labour relations relative to FDM1. Questioning revealed that the reason economic indicators were ranked so highly was that the limited number of sites meant that economic efficiency at each must be high as there was nowhere else to pick up the slack at an organisational level. Staff received such a high priority due to their essential role in a production line that is largely un-automated. Therefore, ensuring the morale of staff working long hours, doing physical work and in cold conditions was paramount and this is also reflected in scores for worker rights and staff retention. Perhaps as is to be expected for a retailer with one main customer, service level and quality in terms of economics were even more prioritised than FDM1.

Task 1B: Determining Resilience KPIs/Stage 1 /FDM-RES Workbook

Using the KPI reference table provided overleaf, please prioritise the KPIs which must benefit from any resilience efforts.

These should be ranked as follows:
1: Unimportant,
2: Nice to have but otherwise relatively unimportant,
3: Currently low priority but likely to become increasingly important in future,
4: Of significant but secondary current importance, and finally
5: Priority importance

1: Unimportant	2: Nice to have	3. Low but growing importance	4. Secondary priority	5.Top priority
CS7; ES3	CE4; CS6; QS4	CE6, CS1 and 2; CENV 1,3,4 and 5; SLS3; SLENV1; QS1,2 and 3; EENV1 and 2; QENV 1,2 and 3	CE2 and 7; EE1 and 2; QE3	CE1,3,5,8 and 9; CS3,4 and 5; CENV2; SLE1-5; SLS 1,2 and 4; ES1 and 2; QE 1 and 2

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Figure 10.7: FDM2 KPIs.

Questioning suggested that this was partly related to the comparatively lower bargaining power FDM2 had in comparison to FDM1 with their customer and partly due to the relatively lower number of options that were available to FDM1 as a smaller organisation, to address threats to these KPIs. At the same time, other social and environmental aspects that were beyond the immediate 'factory walls' such as environmental standards and human rights were ranked much lower. Interestingly however, the case study questioning process identified that this was not because FDM2 was not aware of these considerations or their importance, but that they were currently beyond their immediate control. Furthermore, their small size meant that compared to FDM1, they had less resources to invest in these areas. It was suggested that closer bonds with their retailer partner who do have substantial private environmental and social standards would see these KPIs becoming increasingly important in future, hence their score of 3.

10.6.2.2 FDM-RES Workbook Stage Two: Identification of Vulnerabilities

Application of Stage 2 of the FDM-RES Workbook consisted of the implementation of Tasks 2A1, 2A2 and 2A3.

Task 2A1 involved the collection of data in tabular form concerning the primary entities involved in the Chicken, Bacon and Mayonnaise sandwich supply network based on the workbook guideline table (See Table 8.1, Chapter 8). Expanding on the primary suppliers and in line with workbook task 2A2, metrics of network complexity, input criticality, material flow, information flow and relational links, were mapped (see Table 10.14 for results).

Table 10.14: FDM2 Primary Supply Network Entity Exposure Metrics.

Primary Supply Network Entities	**Input Criticality**	**Material Flow**	**Information Flow**	**Relational Links**
<u>Chicken Supplier</u> **Location**: Thailand **Potential Alternatives**: Multiple (both in SE Asia and UK) **Level of Auditing/ Financial Security**: High	**Production Constraints:** Rearing time from hatchling to slaughter ~6 weeks. **Lead Time:** Provide Forecast 1 week in advance and takes 10 weeks to ship **Supplier Reserves:** Limited but early slaughter possible **Supplier Capacity to Alter Volume:** As above	**Inbound Transport Type:** Ship Freight, chilled and Road, chilled artic lorry **Inbound Transport Volumes: ~**10 pallets @ 1500KG daily **Inbound Transport Frequency:** twice weekly **Inbound Transport Route:** Mediterranean/Suez route (10 weeks shipping time). Road from Southampton to supplier depot and from there to FDM2 site (@2-3 hours). **Presence of alternative types/routes:** Air freight at higher cost. Possible alternate road routes depending on disruption.	**Inbound information type:** Digital and Phone exchange of forecasts, order summary and dispatch report. **Inbound information route:** fiber optics and phone lines. Information backed up on geographically separated servers **Inbound information frequency:** Daily	**Presence of Buying–Selling Relationship?** Yes **Level of Adversity:** Low **Interdependence:** Low **Level of Collaboration**: Low
<u>Bread Supplier</u> **Location:** UK, Midlands **Potential Alternatives:** Very limited	**Production Constraints: low-** less than 24 hours for bread although the wheat itself can take up to 130 days	**Inbound Transport Type:** Road, artic lorry. **Inbound Transport Volumes:** ~ 20 pallets daily **Inbound Transport Frequency:** daily	**Inbound information type:** Digital and Phone exchange of forecasts, order summary and dispatch report.	**Presence of Buying–Selling Relationship?** Yes **Level of Adversity:** Low **Interdependence**

Level of Auditing/ Financial Security: High	**Lead Time:** 1 week forecast & 24-hour confirmation **Supplier Reserves:** low **Supplier Capacity to Alter Volume:** High	**Inbound Transport Route:** Road direct to FDM2 Manufacturing plant (@2-3 hours) **Presence of alternative types/routes:** Possible alternate road routes depending on disruption	**Inbound information route:** fiber optics and phone lines. **Inbound information frequency:** Daily	**:** high **Level of Collaboration**: Low
Lettuce Supplier **Location:** UK, South East **Potential Alternatives:** Multiple but limited by season **Level of Auditing/ Financial Security:** High	**Production Constraints:** Growing time of 2-3 weeks **Lead Time:** Provide Forecast 1 week in advance and confirm 24 hours **Supplier Reserves:** limited **Supplier Capacity to Alter Volume:** Limited	**Inbound Transport Type:** Road, 7.5 tonne lorry **Inbound Transport Volumes:** ~10 pallets daily **Inbound Transport Frequency:** daily **Inbound Transport Route:** Road from supplier depot to FDM2 manufacturing site (@2-3 hours) **Presence of alternative types/routes:** Possible alternate road routes depending on disruption	**Inbound information type:** Digital and Phone exchange of forecasts, order summary and dispatch report. **Inbound information route:** Fiber optics and phone lines. **Inbound information frequency:** Daily	**Presence of Buying–Selling Relationship?** Yes **Level of Adversity:** Low **Interdependence :** Low **Level of Collaboration**: Low
Packaging Supplier **Location:** UK, South East **Potential Alternatives:** Limited **Level of Auditing/ Financial Security:** High	**Production Constraints: Lead Time:** 1 week forecast & 24-hour confirmation **Supplier Reserves:** High **Supplier Capacity to Alter Volume: H**igh	**Inbound Transport Type:** Road, artic lorry. **Inbound Transport Volumes**: ~10 pallets per week **Inbound Transport Frequency:** weekly **Inbound Transport Route:** road from supplier depot (@2-3 hours) **Presence of alternative types/routes:** Possible alternate road routes depending on disruption	**Inbound information type:** Digital & Phone exchange of forecasts, order summary and dispatch report. **Inbound information route:** Fiber optics & phone. **Inbound information frequency:** Weekly	**Presence of Buying–Selling Relationship?** Yes **Level of Adversity:** Low **Interdependence :** High **Level of Collaboration**: Low
Bacon Supplier **Location:** Ireland **Potential Alternatives:** Very Limited **Level of Auditing/ Financial Security:** High	**Production Constraints:** rearing for bacon takes longer than pork at about 24 weeks **Lead Time:** Provide Forecast 1 week in advance and confirm 24 hours **Supplier**	**Inbound Transport Type:** Ship freight from supplier in Ireland (2-3 days). Chilled articulated lorry from supplier depot in Manchester (2-3 hours) **Inbound Transport Volumes:** Approx. 6 pallets daily **Inbound Transport Frequency:** Daily	**Inbound information type:** Digital and Phone exchange of forecasts, order summary and dispatch report. **Inbound information route:** Fiber optics & phone lines. Information	**Presence of Buying–Selling Relationship?** Yes **Level of Adversity:** Low **Interdependence :** High **Level of Collaboration**: Low

	Reserves: Supplier holds some limited reserve **Supplier Capacity to Alter Volume:** limited due to minimum slaughter age	**Inbound Transport Route:** Road direct from supplier to FDM1 Manufacturing site (@2-3 hours) **Presence of alternative types/routes:** Air freight replacement for Ferry in the case of extensive delays but at cost. Possible alternate road routes depending on disruption	backed up on geographically separated servers **Inbound information frequency:** Daily	
FDM2 Chicken/Lettuce/Bacon sandwich production **Location:** UK, Midlands	**Production Constraints:** Cleaning cycles/ staff availability **Lead Time:** 24 hours **Reserves:** None **Supplier Capacity to Alter Volume:** High but dependent on labour	**Outbound Transport Type:** Chilled artic lorry **Outbound Transport Volumes**: ~30 pallets daily **Outbound Transport Frequency:** hourly **Outbound Transport Route:** Road direct from FDM1 production line to retailer depot (@2-3 hours) **Presence of alternative types/routes:** Possible alternate road routes depending on disruption	**Outbound information type:** Digital and Phone exchange of forecasts, order summary and dispatch report. **Outbound information route:** Fiber optics & phone lines. Back-up data via geographically separated servers & hard copies in fire proof safe. **Outbound information frequency:** Daily	**Intra-organisational Competition:** Low **Intra-organisational Collaboration:** High **Level of intra-organisational integration:** High
Retailer Customer **Location:** UK, Midlands **Potential Alternatives: Limited** (due to tight batch specifications) **Level of Auditing/ Financial Security:** High	**N/A**	**Outbound Transport Type:** Chilled artic lorry **Outbound Transport Volumes:** ~1 (mixed) pallet daily **Outbound Transport Frequency:** hourly **Outbound Transport Route:** road from retailer depot to individual stores (@2-5 hours) **Presence of alternative types/routes:** Possible alternate road routes depending on disruption	**Outbound information type:** Digital and Phone exchange of forecasts, order summary and dispatch report. **Outbound information route:** fiber optics and phone lines. Information backed up on geographically separated servers **Outbound information frequency:** Daily	**Relationship:** Long term collaboration **Power Imbalance:** High **Integration:** High **Investment in supplier sustainability:** High **Value Chain Collaboration:** High **Restrictions on supplier sourcing:** High **Penalties for late/sub-standard delivery:** High

The initial metrics in many ways mirror those of FDM1, in terms of transport types, routes, information flow and relationships with primary entities. However, because production is only for one retailer, volumes are somewhat lower. Additionally, differences in the ingredient make-up of a product, which include bacon and lettuce, add substantial complexity. This is because suppliers must be retailer approved, and the approved bacon supplier is located in Ireland, thus adding and extra shipping route into consideration, and one which is heavily exposed to short term (~24hours) disruption due to weather. This is typically long enough to substantially delay production, due to FDM2s limited inventory, but not enough to for costly air freight to arrive quickly enough to help. These metrics were developed into a hand drawn map which was then analysed based on the secondary network entity considerations proposed in FDM-RES Workbook Task 2A3 from which a number of questions arose as illustrated in Figure 10.8.

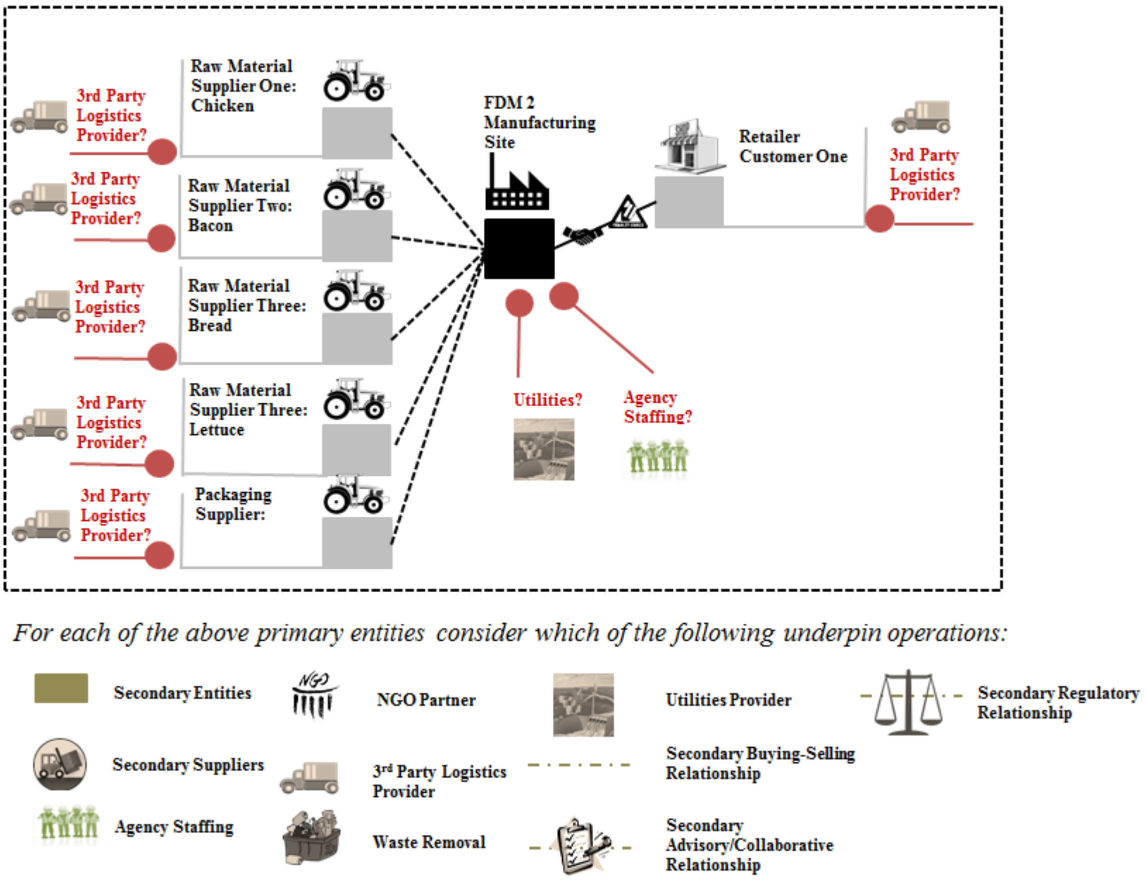

Figure 10.8: FDM2 Primary Entity Mapping Process.

As with FDM1 a major consideration for almost all of the primary entities was transport and utilities for FDM2s sites. However, off site storage was not cited as a key consideration as it was expected that suppliers would have arrangements in place for this. Instead, a major concern was identified as being availability of third partly logistics suppliers. Details for these entities were then collected in a similar way as for the primary entities, considering input criticality, material flow, information flow and relational links. The results can be found in Table 10.15.

Tasks 2B1/B2 concerned the evaluation of which of the identified exposure metrics were priority exposures. As a preliminary step to offer validation for the framework, FDM2 was asked to suggest of their own accord what they thought were their priority exposures

The first response was reliance on the **Road Network**. FDM2 is heavily reliant on it and with the short shelf life of produce, traffic delays mean that produce with a 5-day product life that must have a 3-5-day store life might be rejected by the retailer depot regardless of whether chilled chain was maintained. This also means that things such as the climate levy change and urban emissions restrictions are a constant risk source, particularly as much of the fleet is diesel.

Equally important for FDM2 are the **third-party labour suppliers** who supply the workforce. FDM1 is incredibly labour dependent- a highly motivated production line is one of their most valuable assets-and so anything that jeopardises the relationship such as the UK'S exit from the EU is a real concern.

As previously, these responses were then temporarily put to one side so that the framework guidelines for identifying priority exposure metrics could be tested. This was achieved via cross referencing of the exposure metrics collected in Tables 10.14 and 10.15 with the exposure metric evaluation table (See Table 8.1, Chapter 8). The priority exposure metrics as suggested by the framework are displayed in Table 10.16.

In total, seven high priority exposure metrics were identified for FDM2. Interestingly, whilst supply of chicken was a considerable concern for FDM1 in the first case study due to the long transport route, frequent requirement and no other alternatives, for FDM2, the smaller volumes required combined with their unique arrangements with suppliers to hold stock, means that this was not considered a priority exposure. However, FDM2's bread supplier did represent a major exposure point on three levels.

Table 10.15: FDM2 Secondary Supply Network Entity Exposure Metrics.

Secondary Supply Network Entities	Input Criticality	Material Flow	Information Flow	Relational Links
3rd Party Logistics Providers: **Numbers:** 3PLs connect all suppliers to FDM2. FDM2 have their own logistics to retailer. Retailer relies upon 3PL for depot to stores transport. **Geographic Location(s):** National Coverage **Alternatives that match product transport requirements:** High **Ability to change collection capacity at short notice:** High	**N/A**	**Inbound Transport Type:** Road, chilled and ambient lorry **Inbound Transport Volumes:** between 10 pallets for 7.5 tonne lorries and 26 for articulated lorries. **Inbound Transport Frequency:** hourly **Inbound Transport Route:** Various, road **Presence of alternative types/routes:** Possible alternate road routes.	**Inbound information type:** Digital and Phone exchange of forecasts, order summary and dispatch report. **Inbound information route:** fiber optics and phone. **Inbound information frequency:** Hourly	**Relationship:** Long term value chain collaboration **Power Imbalance:** low **Integration of operations:** High **Investment in supplier quality and sustainability:** low **Collaboration on cross-value chain issues:** High
FDM2 Utilities Providers **Location of supplier/infrastructure:** Utilities suppliers are all UK based, with backup physical routes for water, gas and electricity. **Presence of alternatives:** Yes, but they would likely share similar infrastructure.	**Peak capacity of supplier vs most extreme requirements of FDM:** Extremely unlikely that FDM1 would exceed capacity except in severe regional disruption	**Physical route:** Water/gas transported via underground pipes & electricity via overland lines. **Locations of reserves:** On site generators for 24 hours basic operations). Spare water tanks could be called in within 24 hours' notice.	**Inbound information type:** Digital and Phone exchange of forecasts, order summary and dispatch report. **Inbound information route:** fiber optics & phone. **Inbound information frequency:** Weekly	**Presence of Buying–Selling Relationship?** Yes **Level of Adversity:** Low **Interdependence:** Low **Level of Collaboration**: Low
Agency Staff Providers: **Numbers:** Multiple agency providers, but FDM2 prioritizes established partnerships **Geographic Location(s):** Europe wide **Alternatives that match requirements:** High but likely to be influenced by geopolitics	**N/A**	**N/A**	**Inbound information type:** Digital and Phone **Inbound information route:** fiber optics and phone lines. **Inbound information frequency:** Hourly	**Relationship:** Long term collaboration **Power Imbalance:** low **Integration of operations:** low **Investment in supplier quality & sustainability:** low **Collaboration on cross-value chain issues:** low

Table 10.16 Evaluation of identified exposure metrics identified by FDM2.

	Supply Network Entity	Supply Network Complexity	Input Criticality	Material Flow	Information Flow	Relational Links
Primary Supply Network Entities	Chicken Supplier	Low Priority Exposure	Low Priority Exposure	Low Priority Exposure	Low Priority Exposure	Low Priority Exposure
	Bread Supplier	PES3 High Priority Exposure	Low Priority Exposure	MFRM1 High Priority Exposure	Low Priority Exposure	RLH1High Priority Exposure
	Bacon Supplier	Low Priority Exposure	ICRM1 High Priority Exposure	MFRM1 High Priority Exposure	Low Priority Exposure	Low Priority Exposure
	Lettuce Supplier	PES1: High Priority Exposure	Low Priority Exposure	Low Priority Exposure	Low Priority Exposure	Low Priority Exposure
	Packaging Supplier	Low Priority Exposure	Low Priority Exposure	Low Priority Exposure	Low Priority Exposure	Low Priority Exposure
	FDM2	Low Priority Exposure	Low Priority Exposure	MFO1 High Priority Exposure	Low Priority Exposure	Low Priority Exposure
	Retailer Customer	Low Priority Exposure	Low Priority Exposure	Low Priority Exposure	Low Priority Exposure	Low Priority Exposure
Secondary Supply Network Entities	3rd Party Logistics	Low Priority Exposure	Low Priority Exposure	Low Priority Exposure	Low Priority Exposure	Low Priority Exposure
	FDM Utility Providers	Low Priority Exposure	Low Priority Exposure	Low Priority Exposure	Low Priority Exposure	Low Priority Exposure
	3rd Party Agency Staff Providers	SES4: High Priority Exposure	Low Priority Exposure	Low Priority Exposure	Low Priority Exposure	Low Priority Exposure

The first was the very specific nature and high volumes required of the bread products to match FDM2's own and retailer specifications, meaning that there were no alternatives (PES3, Table 10.2). The second was that the multiple daily deliveries were highly susceptible to road disruption (MFRM1, Table 10.2). The final concerned the fact that interdependence (due to high volumes and very specific product specifications) with the supplier was high but collaboration was relatively low, meaning that in the case of a major disruption such as a major bakery fire, FDM2 would struggle to find alternatives (RLH1, Table 10.2).

The presence of bacon in the sandwiches, which as a raw material takes approximately, 24 weeks to produce, means that it is difficult for the supplier to increase supply significantly at short notice (ICRM1, Table 10.2). Equally supplies of bacon from Ireland are highly dependent on ferries to take them across the Irish Sea to Manchester and in the event of bad weather which typically lasts for under 24 hours, air freight would be unlikely to be arranged in time to help (MFRM1, Table 10.2). The lettuce suppliers were also a concern because of their tight geographic clustering, particularly in Spain where lettuce is grown in the open and as such is particularly susceptible to bad weather of infestations. FDM2 described the chaos experienced in the winter of 2016/2017 when unseasonable hail storms destroyed much of the Spanish crop and due to geographic clustering of suppliers, alternatives were hard to find. The result was that supplies had to be air freighted in from California with obvious cost penalties.

Another high priority exposure metric concerned FDM2's outbound deliveries which not only occurred several times a day and were completely dependent on road conditions, but which also faced tight retailer penalties for non/late delivery. The final high priority exposure was agency staff suppliers, and this was something which the exposure metric evaluation table (Table 8.1, Chapter 8) struggled to accommodate. The most appropriate entry was 'Secondary Entity, Suppliers of Suppliers **SES4:** Highly specific product with few alternative suppliers'. This represented the fact that whilst there were numerous alternative agency staff providers, the willingness of workers to come to the UK was highly dependent on the current political and economic climate. With the anticipated British departure from the EU, availability of European agency staff is a major concern for FDM2. Findings from the FDM-RES Workbook high priority exposure reference table therefore would appear to closely mirror the two top priority exposure points that FDM2 identified, lending weight to its practical usefulness.

The next step, Task 2B2, proceeded to use the identified priority exposures to highlight potential resulting failure modes. This was achieved through cross referencing of the identified priority exposures with linked failure modes using the relational matrix in the FDM-RES Workbook (See Table 8.4, Chapter 8). The associated failure mode for each priority exposure is displayed in Table 10.17. Having used the FDM-RES Workbook to generate bespoke failure modes based on the users inputted priority exposure metrics, the case study process next moved on to FDM-RES Workbook Tasks 2C1 and 2C2 where the established Failure Modes were used to identify linked causal vulnerabilities.

Table: 10.17: FDM1 Failure modes based on their identified priority exposure metrics.

Priority Exposure Point	**Associated Failure Mode**
PES3	FM1, 2 and 5
PES1	FM1, 2 and 5
ICRM1	FM 1 and 2
SES4	FM1, 2 and 5
MFRM1	FM1, 2 and 3
MFO1	FM7 and FM10
RLH1	FM 1, 2, 3, 5 and 10

Task 2C1 began with the cross referencing of the failure modes identified in Table 10.17 with the linked underlying vulnerabilities, provided as a reference chart in the workbook and which can be found in Table 8.6 (Chapter 8). The suggested underlying causal vulnerabilities unique to FDM2 are shown in Table 10.18.

To validate this stage of the FDM-RES Workbook, FDM2 was also asked, prior to seeing the results, to rank the framework causal vulnerabilities (see Table 10.4) according to how significant a threat they were perceived to be. This was achieved via a Likert scale, with 5 being priority vulnerabilities, 4 being secondary vulnerabilities, 3 being non-important at present but projected to grow in importance in future, 2 being very limited exposure and 1 representing irrelevant vulnerabilities. FDM2 was also asked to identify the failure modes that they believed each vulnerability would lead to, thus helping to validate the FDM-RES Framework Vulnerability-Failure Mode linkages (see Table 8.6, Chapter 8). This also used a Likert scale of 1-5 with 5 representing certain cause-effect, 4-2 representing decreasing likelihood and 1 representing no linkage. The outcomes of this validation are also shown in Table 10.18 and full details results can be seen in Appendix 2.

Table 10.18: FDM2 Vulnerability sources, validation of exposure and failure mode likelihood.

Failure Mode	Associated Causal Vulnerability (s)		Exposure	Failure Mode Likelihood
FM1	**Mar.**	4. Variability in availability of raw materials	5	2
		5. Variability in demand	5	2
	Gov.	3. Political instability	3	3
		4. Import/export restrictions	5	5
	Inf.	1. Disruption to transport infrastructure	5	3
		3. Disruption to energy infrastructure	5	2
		4. Disruption to communications	5	2
	Soc.	1. Piracy/Terrorism	3	2
		2. War and conflict	3	2
		6. Criminal acts	5	5
		7. Industrial actions	2	2
	Env.	1. Natural disasters	5	4
		2. Biological factors	5	4
		3. Anthropogenic environmental hazards	3	3
		4. Unsustainable Primary Production	4	4
	VCRMP	4. Outsourcing of Processing Procedures	3	3
	VCLC	1. Poor reliability of external logistics providers	3	3
	VCIS	1. Lack of established, information sharing	5	2
	VCOMS	1. External company employee quality	2	3
		3. High concentration in supply chains	3	3
	OSRMP	1. Raw material/finished inventory storage issues	5	4
		6. Inability to react to changing circumstances	5	2
	OSLC	1. Inaccurate forecasting	5	4
		2. Lack of flexibility in internal distribution capacity	2	2
	OSIS	1. Breech in information/data security	5	4
		2. Breakdowns in internal information handling	2	2
		3. Absence of early warning detection systems	2	4
		2. Lack of strategic decision making	4	5
	OSOMS	5. Insufficient Corporate Social Responsibility	2	4
FM2	**Mar.**	4. Variability in availability of raw materials	5	2
		5. Variability in demand	5	2
	Gov.	3. Political instability	3	3
		4. Import/export restrictions	5	5
	Soc.	1. Piracy/Terrorism	3	2
		2. War and conflict	3	2
	Env.	1. Natural disasters	5	4
		2. Biological factors	5	4
		4. Unsustainable Primary Production	4	4
	VCRMP	1. Inconsistent Raw material quality& heterogeneity	3	3
	VCIS	2. Deliberate withholding of information	3	4
	OSIS	3. Absence of early warning detection systems	2	4
		1. Raw material/finished inventory storage issues	5	4
	OSRMP	6. Inability to react to changing circumstances	5	4
		1. External company employee quality	2	3

	VCOMS	2. Poor financial robustness of value chain partners	4	4
	OSOMS	2. Lack of strategic decision making	4	5
FM3	**Gov.**	1. Changes in Public Food Policy	5	2
		2. Private Food Policy	5	2
	Inf.	1. Disruption to transport infrastructure	5	4
		2. Disruption to water infrastructure	5	4
		4. Disruption to communications	5	3
	Soc.	3. Workforce health	3	4
		6. Criminal acts	3	5
	VCIS	1. Lack of established information sharing	5	4
		2. Deliberate withholding of information	3	2
	OSRMP	1. Raw material/finished inventory storage issues	5	4
		4. Insufficient capacity	5	3
	OSLC	1. Inaccurate forecasting	5	4
	OSIS	1. Breech in information/data security	5	4
		2. Breakdowns in information handling	2	3
	OSOMS	2. Lack of strategic decision making	4	3
		3. Absence of Business Continuity Planning	2	5
FDM5	**Fin.**	1. Market price fluctuation	5	3
		2. Currency exchange fluctuations	5	2
		3. Interest rate fluctuations	5	2
		4. Regional economic downturns	5	2
		5. Hostile takeover attempts	3	2
		6. Product liability	3	2
	Mar.	1. Market decline	4	3
		2. Competitive Innovation	5	3
		3. Competitor undercutting	5	4
	Gov.	1. Changes in Public Food Policy	5	2
		3. Political instability	5	2
		4. Import/export restrictions	5	5
	Soc.	1. Piracy/Terrorism	3	2
		2. War and conflict	3	2
		4. Proportion of Consumer income available for food	5	3
		5. Changing customer attitudes to consumption	5	2
		6. Criminal acts	5	5
		8. Relations with consumers/special interest groups	5	4
	Env.	4. Unsustainable Primary Production	4	4
	VCOMS	2. Poor financial robustness of value chain partners	4	4
		3. High concentration in supply chains	3	3
		4. High levels of power imbalance between actors	4	4
	OSOMS	1. Poor protection of intellectual property	2	5
FDM10	**Gov.**	2. Private Food Policy	5	2
	Inf.	1. Disruption to transport infrastructure	5	2
	Soc.	7. Criminal acts	3	5
		8. Relations with consumers/special interest groups	5	2
	Env.	3. Anthropogenic environmental hazards	3	2
	VCRMP	2. Raw material and product related hazards	3	4
	VCIS	2. Deliberate withholding of information	3	2
		3. Lack of value chain traceability	5	2
	VCOMS	1. External company employee quality	2	2
	OSRMP	1. Raw material/finished inventory storage issues	5	4

Excluding duplicate vulnerabilities associated with more than one failure mode, the FDM-RES Workbook identified 53 unique vulnerabilities facing FDM1. Of these 34 (64%) were identified as being of either priority or secondary importance to FDM2. Furthermore, 41 (43%) of the proposed linkages between a given failure mode and its causal vulnerability were identified as being either certain (score of 5) of very likely (score of 4). Having identified the organisations bespoke vulnerability sources, the case study moved on to Stage 3 of the FDM-RES Workbook and the identification of mitigating Resilience Elements.

10.6.2.3 FDM-RES Workbook Stage Three: Identification of Mitigating Resilience Elements

The aim of applying Stage 3 of the FDM-RES Workbook in a case study format was to test the ability of the FDM-RES Framework to identify relevant resilience elements and also to validate the linkages between causal vulnerabilities and resilience elements in a practical setting. This involved the implementation of FDM-RES Workbook Tasks 3B1 and 3C1.

This was implemented by cross referencing the high and secondary priority vulnerabilities identified in Stage 2 (i.e. Vulnerabilities with scores of 4 or 5 in Table 10.18) with the Resilience elements reference table contained in page 18 of the FDM-RES Workbook (Tables 9.3 and 9.4, Chapter 9). Results are shown in Table 10.19 below. As resilience elements can counter multiple vulnerabilities, it is possible to rank these elements by how many of FDM2's bespoke vulnerabilities they are able to mitigate. This is highlighted in Table 10.19 which shows how the top priority resilience element for FDM2 is SNR 12 Contingency Plans, due to its ability to mitigate 21 underlying vulnerabilities, closely followed by OR4 Early Warning, which mitigated 201 vulnerabilities and OR1 Flexibility and OR 18 Risk Management which both mitigated 18 vulnerabilities. To validate this stage of the FDM-RES Workbook, FDM2 was also asked, prior to seeing the results, to rank the causal vulnerabilities contained within the FDM-RES Framework taxonomy (see Table 10.4) according to how significant a threat they were perceived to be. This was facilitated using a Likert scale of 1-5, with 5 being fully implemented and no room for improvement, 4-3 being somewhat implemented but with room for improvement, 2 being of limited conceivable benefit and 1 being completely impractical.

Table 10.19: FDM2 priority resilience elements.

Order of Importance	Suggested Resilience Element	Number of associated underlying vulnerabilities	Feasibility Validation
1	**SNR 12**: Contingency Plans	21	5
2	**OR 4**: Early Warning	20	3
3	**OR 1**: Flexibility	18	4
3	**OR 12**: Risk Management	18	5
4	**OR 18**: Adaptive Management	16	3
5	**SNR 3**: Visibility	15	3
6	**OR 9**: Financial Strength	14	4
6	**OR 3**: Redundancy	14	2
7	**SNR 9**: Robustness	13	2
7	**OR 2**: Risk Aware Culture	13	3
7	**OR 5**: Agility	13	5
7	**OR 17**: Market Position	13	4
8	**SNR 14**: Network Complexity	12	4
8	**SNR 11**: Cohesion	12	4
9	**SNR 16**: Community Resources	11	4
10	**SNR 13**: Diversity	10	2
10	**SNR 4**: Adaptability	10	3
10	**SNR 1**: Collaboration	10	5
10	**SNR 2**: Flexibility	10	5
11	**OR 13** Business Continuity Management	9	5
12	**OR 16**: Knowledge Management	8	3
12	**OR 15**: Innovation	8	4
13	**OR 10**: Leadership Commitment	6	4
13	**SNR 6**: Redundancy	6	3
13	**OR 11**: Relationships	6	4
14	**SNR 5**: Velocity	5	5
14	**OR 14**: Human Resource Management	5	4
14	**SNR 7**: Node Criticality	5	4
15	**OR 6**: Security	4	4
15	**OR 7**: Efficiency	4	3
16	**SNR 10**: Trust	3	4
16	**OR 8**: Inventory Management	3	5
16	**SNR 8**: Established Communications Lines	3	5
17	**SNR 15**: Bargaining Power	2	4

Similarly to FMD1, the majority of resilience elements were described as being appropriate. In particular, resilience elements such as contingency planning, risk management and agility are ranked as being fully implemented. It was suggested there could be some room for improvement in visibility, knowledge management and efficiency. However, for the later, FDM2 noted that some products have very low conversion efficiency (e.g. only 13% of the original volume by weight of an avocado ends up in the finished product) yet it is accepted as the retailer is willing to pay for that inefficiency. Resilience elements of limited value were those related to redundancy, just as for FDM1.

10.6.2.4 FDM-RES Workbook Stage Four: Evaluation and Implementation of Resilience Elements

At this final stage, the case study procedure consisted of Tasks 1A1-1A2 which involved the evaluation of shortlisted resilience elements based on the impact on KPIs and the alignment with the type of resilience identified as a priority in Stage 1. It was not possible to actually implement a resilience strategy in the organisations as for the companies involved, participation was seen as exploratory only. However, this section involved collection of information on how the company in question would practically go about implementing the final resilience elements selection if they were in apposition to do so (i.e. Task 4B1).

The first stage of evaluation was to compare the longlist of resilience elements against the type of resilience identified in Stage1 of the FDM-RES Workbook as Engineering or Ecological types of resilience would be default exclude certain resilience elements that were in non-complimentary phases. However, as FDM1, identified that the type of resilience sought was 'adaptive' this therefore includes resilience elements designed to target all four phases and so no resilience elements were excluded at this Stage.

The next step in the evaluation was to cross reference resilience elements longlisted in Table 10.19 with the KPI Impact Matrix described on page 20 of the FDM-RES Workbook (See Table 9.6, Chapter 9). This followed the same procedure outlined in Case Study One. The results are displayed in Table 10.20

Table 10.20: Evaluation of FM2 Resilience Elements Shortlist based on impacts on KPIs.

FDM2 Priority KPIs	CE1,3,5,8 and 9; CS3,4 and 5; CENV2; SLE1-5; SLS 1,2 and 4; ES1 and 2; QE 1 and 2	First Choice Resilience Elements	Second Choice Resilience Elements
		OR 10, OR 8:	**OR 9, SNR 16, OR 14, OR16, OR6, OR7, OR12, OR13,OR18, OR11, OR5(i), OR5(ii), SNR11(i), SNR1, SNR10, SNR8(i), SNR12, SNR8(ii), SNR3**
FDM2 Secondary KPIs	CE2 and 7; EE1 and 2; QE3		

Table 10.20 highlights how OR10 (Presence of cohesive central leadership support) and OR 8 (Inventory Management) are the first-choice resilience elements for FDM2 due to the fact that they have only positive impacts on both primary and secondary KPIs identified by that organisation. As with case study one, very few priority elements had no cost associated and these did not best match the bespoke vulnerabilities faced by FDM2.

Resilience elements that appear as either first or second choice elements in Table 10.20 and which mitigate the highest number of vulnerabilities are selected first. As FDM2 is attempting to create an adaptive type of resilience, the phase of each selected resilience element was noted and the shortlisting was stopped when a top three elements associated with each phase of resilience had been identified as illustrated in Figure 10.9. As with FDM1 in the first case study, care was taken to discuss the practical implications of this step with participants from FDM2. Unlike FDM1, FDM2, which is a smaller organisation, highlighted how existing ERM was predominantly performed centrally and was not ingrained across different teams. They therefore thought that it would be unlikely that resilience elements would be assigned resources and staff time necessary to be implemented at an individual team level either. However, they did suggest that it would serve as a useful tool to flag what existing company resilience elements should continue to be prioritised.

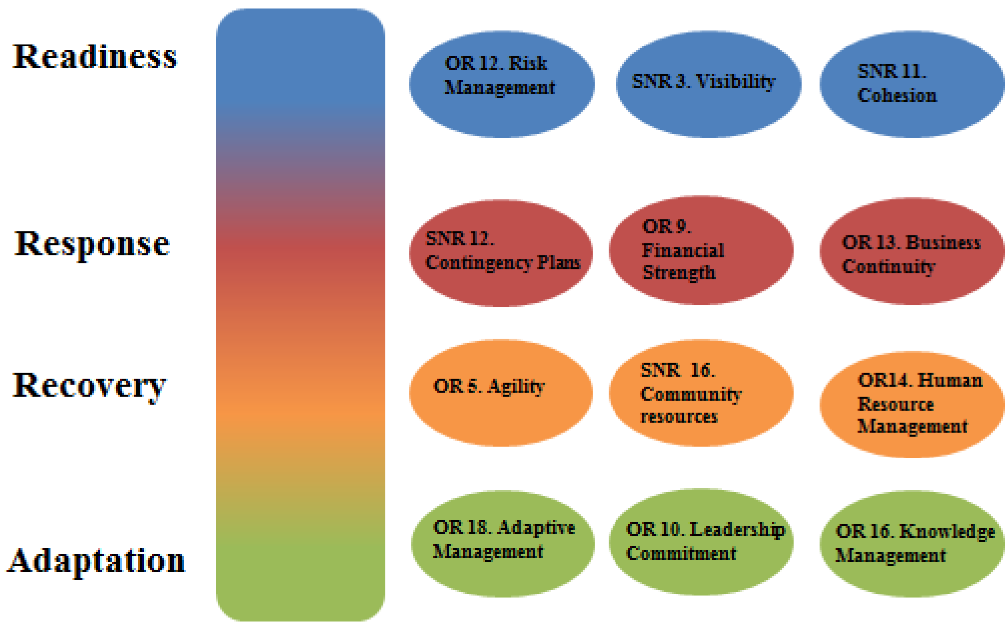

Figure 10.9: FDM2 Final Recommended Resilience Elements.

10.6.3 Case Study Two Conclusions

The aim of Case Study 2, as with case study one was partly to validate the FDM-RES Workbook in an industry setting and partly to test the conceptual rigour of the underlying FDM-RES Framework in different real-world situations. In this regard, FDM2 made for a good comparison with FDM1 as the former was a relatively smaller manufacturer, producing a very similar product, but supplying only one retailer and possessing far fewer sites (only two). This manifested in a number of subtle differences to how FDM2 implemented the FDM Workbook. For example, staff availability was much lower in FDM2 and to be able to complete the full FDM-RES Workbook, more and longer sessions were required so that the right people with the right knowledge could contribute.

In terms of responses, FDM2 slightly prioritised economic KPIs and questioning revealed that this was partly because FDM2 had less contact with primary producers and communities and so was less able to affect social and environmental KPIs. However, as a smaller organisation, it was also noted that there were less resources available to priorities these KPIs regardless (although pressure from their retailer customer seemed to be slowly changing this priority). Moving forward to the mapping of exposure metrics, the priority exposure metrics themselves ultimately shared similarities with FDM1 in the sense that material flow issues, particularly due to overseas suppliers or dependence on the road network were high priorities. However, FDM2 was notable in prioritizing labour, indicating how much of the UK FDM sector remains relatively un-automated and highly vulnerable to factors such as political decisions and pandemics which could impact labour availability. This is particularly true when it is considered that many of the resilience elements themselves utilise double shifting in order to increase capacity and agility. This finding also revealed a shortcoming in the FDM-RES Framework which was initially unable to categorise FDMs dependency on agency labour and thus required adaptation.

Ultimately, of the vulnerabilities identified by the FDM-RES relational matrix, 64% were validated as either being primary or secondary importance to FDM2. Whilst only 43% of the proposed vulnerability failure mode linkages were identified as being either definite or highly likely, all of the proposed linkages were identified as relevant by FDM2, even if they were not felt to be a priority at the given time. Thus, it is felt that this offers significant validation to the conceptual rigour of the underlying FDM-RES Framework. Equally, the majority of the resilience elements proposed to counter these vulnerabilities were also identified as being of relevance with FDM2 identifying that elements such as risk management and cohesion were already highly implemented within their value chain- to the point that they were unable to see what more they could do. However other suggested elements, particularly the adaptive elements such as knowledge management and adaptive management were less familiar to FDM2 and they saw significant potential for implementation.

10.7 Comparing Case Studies One and Two: Discussions and Findings

Having applied the FDM-RES Workbook to two different Food and Drink Manufacturing Organisations based in the UK and presented individual conclusions for each, this section now compares findings. In doing so, it draws out how the different nature of the company implementing the FDM-RES Workbook can influence outcomes as well as presenting a number of interesting comparisons concerning resilience in the UK Food and Drink Manufacturing Sector.

With regard to the types of resilience chosen, both organisations focussed on product lines and emphasised that they were not trying to make the product line resilient to one known historical disruption, but rather a plethora of unknowns, thus selecting the adaptive type of resilience in appreciation of the volatility both had experienced. In terms of KPIs selected to represent this type of resilience, there were a number of similarities. For example, both placed a low priority on the ability to hold inventory and even capacity was heavily restricted to adding more workers (e.g. ‘double shifting’) rather than having actual physical spare capacity in their facilities. This emphasises the importance of observation made in Chapter Four that the large retailers are passing on lean practices to manufacturers who traditionally might have had more of a stock holding role. In both case studies, the holding of spare raw material was now firmly the responsibility of suppliers. Equally, both FDM1 and FDM2 prioritised core KPIs that concerned service level, due to heavy contractual penalties they faced for late deliveries.

However, FDM1, with a larger product range with more specialised ingredients, was more exposed to disruptions in producing regions, and for this reason tended to put more emphasis on social and environmental aspects of the four KPI categories (cost, efficiency, service level and quality). Furthermore, it was noted by both FDM 1 and 2 that the retailers are increasingly pushing KPIs that reflect supply chain sustainability, in their efforts to give themselves an advantage over competitor retailer value chains. When it came to supply chain mapping in Stage 2 of the FDM-RES Workbook, both FDM 1 and 2 identified that major priority exposures were road closures and relations with specialist suppliers (bakeries in both cases). The bakeries also represent an interesting example, because as a result of tight retailer product specifications, the exact type of bread (in the high daily volumes required) is vital and yet bakeries are highly prone to fires due to the nature of their operations, with few like for like replacements available.

However, the scale of a given food manufacturer can also affect mapping findings, with the relatively larger FDM1 prioritising exposure to extreme weather in growing areas, whereas for FDM2 this was less of a priority because they had a much smaller product inventory with generally fewer items that could not be sourced elsewhere if needed. However, the disadvantage of this smaller scale was that whilst FDM1 could switch staff between its numerous sites in the event of a disruption, FDM2 could not do the same and so agency staffing was a major concern. This represents a broader trend that much of the UK chilled convenience food is un-automated and so many food and drink manufacturers are still exposed to labour shortages to some degree. This stage also identified some shortcomings in the FDM-RES taxonomy, in the sense that exposures such as third-party labour were not adequately covered in the secondary entity considerations proposed.

It was also found that company size influenced the types of vulnerabilities faced, the likelihood of these vulnerabilities resulting in linked failure modes and the suitability of different resilience elements to counter them. Broadly speaking, results for both case studies showed that over half of the vulnerabilities suggested using the FDM-RES Framework matrixes, were indeed high priorities for FDM1 and 2. In part this was to be expected as mapping had shown both FDM1 and FDM2 to be exposed to vulnerabilities such as financial turbulence, infrastructure disruption and environmental disruptions. However, there were numerous less obvious similarities which included the fact that neither ranked societal actions such as strikes highly because neither were unionised. On the other hand, both had been highly exposed to financial instability of value chain partners in the past. This was interesting in the sense that it often resulted in a lack of facility investment from that supplier which increased the likelihood of product defects of contamination.

However, whilst in ***theory*** both FDMs often shared similar vulnerabilities and potential failure modes, in ***practice***, aspects such as the size, bargaining power and nature of operations often influenced the actual exposure and impact. For example, FDM2 is in principle just as exposed to inconsistent raw material quality (VCRMP1) as FDM1, however in practice, more of its raw materials are heavily processed and so slight cosmetic fluctuations in supply have little impact whereas for FDM1 this was a major concern. Equally, in principle, both FDM1 and FDM2 are exposed to power imbalances in favour of the large retailers they supply. However, in practice, both FDM1 and FDM2 are large enough that they do not have many substantial competitors who could meet the retailer's specifications and the result is increasingly long-term partnerships.

In terms of the resilience elements the FDM-RES Framework suggested for both case studies, validation responses suggested that they were highly relevant. Whilst there were a few minor inconsistencies between FDM1 and FDM2, as a rule of thumb, both prioritised resilience elements that concerned collaboration, risk management planning and agility (e.g. OR12, OR13, OR4, SNR1, SNR10, SNR11, SNR5, OR6) whilst rejecting resilience elements associated with redundancy (e.g. OR 3, SNR6, SNR9,). It is likely that this is due to a predominant business model in the chilled food convenience sector of cutting back on all non-value adding activities, such as holding surplus stock.

10.8 Chapter Summary

This Chapter concerned the application of the FDM-RES Workbook in the form of case studies with two major UK FDMs. The Chapter described how the case study format was developed by two pilot studies before providing an overview of the two main case studies, the implementation process for each, and the justifications for the choice of each. The remainder of the chapter consisted of the application of each stage of the FDM-RES Workbook to each of the two case study organisations, with results for each step being presented, along with a number of insights into the practical nature of resilience in the UK Food and Drink Manufacturing Sector. Each case study concluded with a description of the main findings and the chapter itself concluded with a comparison of the two case studies, highlighting major similarities and difference as well as broader trends for the UK Food and Drink Manufacturing Sector.

Chapter 11: Concluding Discussion

11.1 Introduction

This chapter begins by discussing the major contributions of this thesis to the wider research field. The second part of the chapter analyses the research achievements in the context of the research aim, objectives and scope defined in Chapter 2.

11.2 Research Contributions

The research in this thesis has investigated how the topic of resilience can be conceptually and practically applied in the UK Food and Drink Manufacturing Sector. Its key contributions to wider knowledge are summarised below:

1. A Systematic review of the resilience literature has been completed in Chapter 3 to collect information on definitions of resilience, causal vulnerabilities and mitigating resilience elements. A number of authors have identified literature inconsistency in defining these areas and this review addresses this by presenting a comprehensive definition of resilience and synthesised taxonomies of vulnerabilities and resilience elements [37, 49, 55, 89]. Furthermore, many previous resilience studies proceed from the perspective of commercial performance [45, 52, 84]. Yet, Food and Drink Manufacturer resilience is intertwined with environmental and social resilience, in addition to supply chain and business resilience [29]. Therefore, the review reflected this by including resilience research from the fields of supply chain management, socio-ecological systems and environmental science in Chapter 3 and combining this with real-world FDM considerations in Chapter 4. As a result, the ultimate FDM-RES Framework and Workbook facilitated the enhancement of resilience that was not only more specific to FDM operations, but also which synergised company performance, population level food security and environmental sustainability.

2. Design of a conceptual framework in Chapters 7-9 which not only categorises the various resilience components identified in the review, but also develops the relationships between these components. Previously in the literature, a number of authors have explored how vulnerabilities can be countered by resilience elements but these have typically not been

conceptually linked [21, 22, 96]. This is significant because resilience elements typically have negative side effects and to minimise these, it is important that the correct resilience element is being selected for the vulnerability at hand. Yet this is not typically considered in existing works which select resilience elements [42, 48, 172, 272]. Furthermore, whilst a number of works in the literature have identified that resilience and sustainability are inextricably linked, the author was not able to identify any that had developed a mechanism by which the impacts of resilience strategies on sustainability could be measured [25-26, 90]. By measuring the impact of suggested resilience elements on environmental, social and economic pillars of the KPIS of Cost, Service Level, Efficiency and Quality, the FDM-RES Workbook is the first tool, to the authors knowledge, to functionally link resilience and sustainability.

3. Development of the FDM-RES Workbook practical tool set in Chapters 7-9, which provides the guidance, reference tables and workspace for a user to practically apply FDM-RES Framework in an industry setting. The tool enables a user to identify the scope and boundaries of the resilience they seek, to map out bespoke vulnerabilities, link these to mitigating resilience elements and to evaluate and implement these resilience elements. This approach addresses a number of limitations to existing resilience tools which, predominantly, are not contextually relevant to FDMs and which tend to focus on a select few resilience elements [21, 45, 47, 52]. A particular advantage is the ability to practically map an organisation’s supply network exposure thus providing a real-time understanding of vulnerabilities faced rather than relying on historical risk. This is important in today’s volatile supply chain operating environments and whilst supply chain mapping procedures have been proposed in the literature, none have been incorporated into a tool which proceeds to link identified vulnerabilities to specific countering resilience elements [84, 261]. Therefore, by conceptually linking specific supply chain exposure metrics to underlying vulnerabilities and finally to mitigating resilience elements and validating these within the FDM Sector, this thesis makes a substantial conceptual contribution to the field.

4. Practical application of this tool in two industry case studies, validating the practical usability of the FDM-RES Workbook and the conceptual rigour of the underlying FDM-RES Framework relationships. The case study approach also provided a substantial depth of information about how a company’s size, nature of operations (chilled convenience food in his case) and supply network situation can all influence the relevance of the results proposed by the FDM-RES Workbook.

11.3 Concluding Discussion

The aim of this thesis was "to provide a synthesised conceptual framework that is contextually specific to food and drink manufacturers and from this to develop a set of practical tools which can guide food and drink manufacturer resilience". This section analyses to what degree this aim was achieved, based on the comparison of the achievements of the thesis against the objectives and scopes set out in Chapter 2**.**

11.3.1 Literature Reviews

The aim of Thesis Research Objective 1 was to thoroughly review resilience as a concept (Thesis Research Objective 1A), to review resilience in relation to the UK FDM sector (Thesis Research Objective 1B) and finally to review existing tools designed to model and/or enhance resilience (Thesis Research Objective 1C).

Regarding Research Objective 1A, it was realised early on in the research that there were a large number of divergent works which were producing inconsistent resilience definitions, elements and vulnerabilities. To address this challenge, the SLR process was used in Chapter 3 to screen 1270 peer reviewed articles and refine this to a final review sample of 137 articles. Three key areas emerged from this review that underpin resilience as a concept and which were identified as being of major relevance to UK FDMs:

a) The way in which resilience is defined.

b) The resilience elements that are used to enhance resilience.

c) The strategies concerning how resilience elements are matched to specific negative events and evaluated for effectiveness and side effects.

Concerning application of the above three areas to FDMs and beginning with definitions, it was determined that the volatility global AFSNs are exposed to means that in situations where a FDM does not have absolute control, the adaptive definition is most appropriate. In terms of the resilience elements, despite 34 distinct elements being identified, 'flexibility' and 'redundancy' were the most commonly cited, with the remainder appearing in less than 10% of papers and thus being less well developed in terms of what they practically entailed. This was a challenge as many of these elements explore interactions and relations between organisations, communities and the natural environment, as well as their ability to adapt, thus being of high potential value to FDMs.

In terms of strategies available to support resilience elements, the SLR identified that in order to arrive at balanced resilience; it was important to link specific mitigating resilience elements to individual vulnerabilities. However, the review noted that few authors had attempted this and those that had did not consider the full 34 resilience elements identified in this SLR. Furthermore, few had proposed metrics by which vulnerabilities could be practically measured, or metrics which could facilitate the measurement of the impact of resilience elements on other KPIs within a company or on broader organisational sustainability.

Regarding Research Objective 1B, the review in Chapter 4 explored a range of technological and societal shifts that have influenced the scope and activities of FDMs in the UK over recent decades. From analysis of current FDM activities, 10 unique Failure Modes were proposed, which spanned from upstream suppliers to FDM internal operations, downstream customers and end consumers. The review also identified five classes of exposure metrics, concerning network complexity, input criticality, raw material flow, information flow and relational links between supply network entities which could be collected and used to practically map an FDM's exposure to the aforementioned failure modes.

Thesis Research Objective 1C reviewed a wide range of academic, industrial and Government sources to identify the state of the art in terms of how resilience had been modelled and practically influenced (i.e. using a tool of some sort). It was identified that the majority of tools, stemmed from Industry and Government where resilience was often subsumed within existing ERM and BCM schemes. Such schemes have the advantage of being tried, tested and relatively simple to implement. However, by nature they often fail to capture the full conceptual breadth of resilience as a distinct concept from risk. In Academia on the other hand, the trend was predominantly to develop predictive models, either based on simulation or mathematical approaches, which projected the impact of a given resilience element on predefined KPIs. Whilst useful due to the difficulty of applying traditional empirical techniques to systems as complex as supply chains, such approaches often consider a very limited range of resilience elements and these are rarely linked to a given vulnerability.

Therefore, it was clear from the review that there was a need to bring together the vast range of conceptual aspects of resilience, adapt them to a FDM context, and to develop a tool which could be used to accurately enhance resilience for FDMs. This tool should be relatively easy to implement, without requiring users to employ specialist staff or install complex software, be able to identify vulnerabilities in real-time and ideally use principles existing ERM approaches which a user may be familiar with.

11.3.2 Methodological Design and Framework Development

The first objective of Thesis Research Objective 2 was the development of a methodology that not only allowed synthesis of an inconsistent literature field into a concise conceptual FDM resilience framework, but that it also facilitated empirical measurement of FDM resilience. This was achieved via use of the 'research onion' model which guides a researcher in identifying how broad research philosophy can influence research approach, strategy and technique. Based on the a 'pragmatic' philosophy, an abductive research approach was employed which enabled the use of existing conceptual resilience underpinnings in the literature, but which facilitated the adaption of these using industry observations to generate more accurate FDM specific models. The SLR strategy was identified as optimal for ensuring breadth of literature contributions and overcoming inconsistencies. Based on the outcomes of the SLR synthesis, it was clear that the research technique required a mixed method case study approach to gather both qualitative information from industry experts (i.e. perceptions on relations between certain vulnerabilities and countering resilience elements), and quantitative measurements (i.e. the roles of locations, volumes and time in resilience). This methodology can therefore be said to have been successful in systematically identifying relevant literature concepts and enabling their synthesis into a unified framework.

The resulting FDM-RES Framework fulfilled the second part of Thesis Research Objective 2 and conceptually linked a FDM specific definition of resilience with vulnerabilities, the failure modes these vulnerabilities result in, the resilience elements that can mitigate these vulnerabilities and finally, the KPIs necessary to evaluate them. In doing so, not only does the FDM-RES Framework overcome many of the conceptual inconsistencies in the literature, but by exploring the relationships between concepts that had not previously been considered together in a FDM context, it effectively represents new knowledge.

One such example was the development of a synthesised taxonomy of five core resilience elements at an organisational level and five core resilience elements at a supply network level, each with numerous supporting resilience elements, representing the fact that some resilience elements were very broad in scope and naturally overlapped with several narrower scope resilience elements. The advantage of using this approach was that it linked less commonly known resilience elements for FDM operations, such as 'community resources' and 'cohesion' with better known elements, such as 'flexibility' and redundancy' thus reducing user bias and facilitating a closer fit between the vulnerability at hand and the optimal countering resilience elements.

Another aspect of new knowledge developed by this framework is the establishment of the relationship between exposure metrics, failure modes and underlying vulnerabilities, between vulnerabilities and mitigating resilience elements and finally between resilience elements and sustainability KPIs. This facilitates the accurate selection of resilience elements based on the real-time vulnerabilities they counter and on their projected side effects on organisational sustainability. This therefore represents an important first step to being able to practically synergise resilience with sustainability. Furthermore, structuring of the FDM-RES Framework in a similar way to ISO31000 models also means that this framework is inherently designed to be repeated, therefore facilitating an adaptive type of resilience where gains are cumulative over the course of multiple disruptions, reducing the severity of future disruptions.

A final strength of the FDM-RES Framework is that, whilst it was designed to specifically to address food manufacturing resilience, the biggest challenge associated with this research was actually adapting non-food system resilience concepts to suit a food system context. Therefore, with some minor contextual adaptations of the framework taxonomies, the FDM-RES Workbook should be easily utilised by other food value chain stages, such as primary production and retail.

11.3.3 Practical Tool Development

Thesis Research Objective 3 concerned the development of "practical tools based on the framework, complete with relevant qualitative and quantitative metrics to guide food and drink manufacturers in formulating resilience strategies". Based on this, the FDM-RES Workbook was designed to guide FDMs in applying the four stages of the FDM-RES Framework practically. The workbook format was chosen because, whilst it was recognised that there was a need for a tool that utilised real world rather than artificially generated data, data about the relationships between concepts such as vulnerabilities and resilience elements was lacking. The only way to practically obtain this data was to rely on the knowledge of industrial users. For this, the optimal format was a physical workbook consisting of guidelines, relational matrix referents tables and workspace.

A major distinction of this tool is its ability to measure real world exposure to vulnerabilities rather than perceptions of historical risk. By starting with known primary supply chain entities, the tool proposes a number of suggestions for secondary dependencies which might not normally be considered. This can then be compared with the taxonomy of high priority exposure points developed in the FDM-RES Framework to provide a real time snapshot of exposure- a significant advantage in volatile operating environments. By then focusing on failure modes, the subsequent suggestion of vulnerabilities that should be addressed is thus more refined. Whilst it is entirely up to users to rank suggested vulnerabilities and choose which they take forward, the detailed list of proposed vulnerabilities helps to counter exiting possible user bias by presenting vulnerabilities that might not have previously been considered.

Another major area of novelty is that the tool enables the user to outline the KPIs by which they would evaluate their resilience. This represents an important feedback loop by which, once a user has selected the resilience elements that best match their unique vulnerability exposure, they can evaluate this based on the side effects of those resilience elements, thus forming a highly effective evaluation process.

11.3.4 Case Studies

Case studies were undertaken as per Thesis Research Objective 4 “for validation and development of the aforementioned framework and associated tools”. To achieve this, whilst case studies were partly selected for consistency and comparability, care was also taken to select case studies with unique differences in terms of absolute size, product range and customers. Other considerations involved in the selection of the case studies were the need for operations to represent wider prevailing trends, thus enabling the findings to be more easily extrapolated to the wider UK FDM sector.

The case studies took the form of questionnaire-based implementation of the FDM-RES Workbook in a semi-structured interview setting, thus enabling practical testing of the usability of the workbook and further development of the workbook through the collection of empirical data.

There were four main sections, 1) Scope, Boundaries and KPIs, 2) Vulnerability Identification, 3) Establishment of Mitigating Resilience Elements and 4) Evaluation.

In terms of Scope, Boundaries and KPIs, both organisations focussed on product lines and emphasised that they were not trying to make the product line resilient to one known historical disruption, but rather a plethora of unknowns, thus selecting the adaptive type of resilience. In terms of KPIs selected to represent this type of resilience, there were a number of similarities. For example, both placed a low priority on the ability to hold inventory, and a high priority on workforce and service level, due to heavy contractual penalties for late deliveries. This emphasises the importance of observations made in Chapter 4 that pressure from the large retailers to lean operations is influencing the stock holding function of FDMs. However, it also highlights the crucial importance of manual labour in contemporary FDM operations.

In terms of vulnerabilities faced, a key finding was that whilst in ***theory*** FDMs might be exposed to a range of vulnerabilities and potential failure modes, in ***practice***, aspects such as the size, bargaining power and nature of operations of the manufacturer often influenced the actual exposure and impact. For example, FDM2 is in principle just as exposed to inconsistent raw material quality as FDM1, however in practice, more of its raw materials are heavily processed and so slight cosmetic fluctuations in supply have little impact whereas for FDM1 this was a major concern.

Regarding the resilience elements the FDM-RES Framework suggested for both case studies, validation responses from both participants suggested that they were highly relevant. Whilst there were a few minor inconsistencies between FDM1 and FDM2, as a general rule of thumb, both prioritised resilience elements that concerned collaboration, risk management planning and agility whilst rejecting resilience elements associated with redundancy. It is likely that this is due to a predominant business model in the chilled food convenience sector of cutting back on all non-value adding activities, such as holding surplus stock.

Taken together, not only do these findings offer unique insights into the practical nature of resilience in the UK Food and Drink Manufacturing Sector, but the findings were also highly useful in the development the FDM-RES Workbook and underlying FDM-RES Conceptual Framework. For example, a number of KPIs, vulnerabilities and resilience elements and the situation in which each were suggested by the FDM-RES workbook were modified to reflect the impact of user company size.

11.3.5 The Role of Resilience in Future UK Food Security

Whilst discussion, and by default, the majority of this thesis has focussed on resilience in the context of the titular FDM sector, it is important to remember that they are in turn a key part of the wider AFSN feeding the UK. This is in part, why being able to measure the impact of resilience strategies on sustainability KPIs is so important. It would not be in the interests of National Food Security if the resilience actions of individual companies undermined the long-term sustainability of the nation's AFSN. This is reflected in the synthesised definition of FDM resilience presented in Chapter 7:

"*The ability of Food and Drink Manufacturers to evolve in line with constantly changing operating environments, to the effect that the core functions of economic advantage and also the continued provision of key public food supplies, of the correct quality and volume and at the required times and locations, are buffered against all disruptions, whether anticipated or not. Depending on what aspect of a food manufacturers operations are to be made resilient, this may be achieved via resilience elements which facilitate the accurate anticipation of disruptions and postponement of their impact, and which enable rapid recovery in addition to the ability to actively learn from each disruption so that resilience is cumulative rather than reactive".*

By incorporating the priority of food security, the definition highlights the fact that for FDMs, focussing on organisational competitiveness alone will likely hide risk stemming from wider supply network exposure. By nature, it forces consideration of how resilience strategies implemented by one actor, impact overall supply network resilience. Furthermore, by incorporating the forth food security pillar of stability, the synergistic relationship between resilience and sustainability is highlighted. Therefore, it is crucial that when organisations attempt to enhance their resilience, for example by using the FDM-RES Workbook or other tools, that they consider impact not just on their own long-term sustainability but also impacts on their wider societal dependencies. For example, for some of the larger manufacturers with a high market share, decisions to replace ingredients due to supply being located in a volatile regions, could quite feasibly influence the dietary health of populations. The reverse is also true, for example, if Government plans for UK Food Security focus on sector wide diversity to reduce the risk of an individual company collapsing, this strategy could be antagonistic to attempts by companies at an individual level in that sector to enhance their resilience. It is hoped that the FDM-RES Framework descriptions of how resilience elements can be categorised from organisational as well as supply network perspectives, could help to provide insights from both Government and Industry perspectives.

11.3.6 Constraints and Limitations

As was noted in Chapter 3, the systematic application of resilience as a concept to FDMs or even AFSNs in general has not been previously attempted. This means that the relationships between a number of the failure modes, vulnerabilities, resilience elements and KPIs in the FDM-RES Framework are inevitably based on a small number of works in the supporting literature, supported by careful judgment from the author and supplemented by the expert advice of a number of industry experts. However, despite this constraint, application to industrial case studies strongly supported the validity of these relational links.

Another significant limitation is that whilst great care has been taken to develop the FDM-RES Framework with industry input, the time-consuming nature of the case study approach, which was vital for validating and developing the framework, means that only 2 case studies were conducted. Whilst further industry members were involved via interviews in the development of the FDM-RES Framework itself, this is still too few to claim that findings are statistically representative of the wider UK FDM sector.

Another important limitation is that application of the FDM-RES Workbook is a lengthy process, with both case studies taking 4-5 hours. Furthermore, it requires the specialist input of employees with a very thorough supply network knowledge and thus not just anyone can complete the FDM-RES Workbook. There is therefore a degree of uncertainty that this requirement limits usage to larger FDMs with more resources and staff availability to commit to its implementation.

Chapter 12: Conclusions and Further Work

12.1 Introduction

This Chapter presents the main research conclusions from this work and suggests a number of areas where work could be continued in future, both in terms of FDM, and by extension, food system resilience as a concept, as well as the evolution of practical tools with which to enhance resilience.

12.2 Research Conclusions

The major conclusions that can be drawn from this research are now described in detail:

1. Volatile supply networks need adaptive resilience

There is a significant and growing interest from academia, industry and government alike regarding resilience in a food system context. Evidence suggests that this is due to volatility and exposure to a wider than ever range of disruptions as a result of today's highly complex and low inventory food supply networks. FDMs are particularly exposed due to their low margins and small number of capital intensive sites. Given that there will always be some food items that cannot be sustainably produced in the UK, it is reasonable to suggest that the UK will always be somewhat dependent on international food supply networks. There is as such, a need to acknowledge that the UK can never be completely self-sufficient and that there is a need to accept the increased vulnerability stemming from interaction with wider food networks. This vulnerability can therefore only be dealt with through resilience efforts that involve not just anticipating and mitigating the impact of disruptions, but also the ability to learn from and adapt to evolving food systems.

2. Supply network mapping is vital in the development of accurate resilience strategies

In volatile operating environments, reliance on traditional ERM approaches which focus on high likelihood and high impact scenarios, often based on the historical experiences are insufficient to develop suitable resilience strategies. Instead a more accurate profile of exposure can be generated by focusing on the causal pathways or 'vulnerability' leading to a disruptive event. The FDM-RES framework presented in this thesis describes how entire supply networks can be practically mapped using Exposure Metrics and Failure Mode analysis to present a highly refined list of bespoke vulnerability sources.

3. Resilience elements are crucial for mitigating vulnerabilities but must be carefully matched

Identified vulnerability sources can be countered by resilience elements which are specific and measurable mitigating actions. However, these resilience elements often have a cost in terms of side effects elsewhere and therefore cannot be applied without being carefully matched to identified vulnerabilities. The FDM-RES Framework in this thesis not only presents a novel, unified taxonomy of 34 multidisciplinary resilience elements complete with FDM specific actions for each, but it proposes the linkages between each specific resilience element and the exact vulnerability which it counters ensuring that resilience is 'balanced'.

4. Resilience strategies must be synergistic with sustainability at a company wider supply network level

There is a growing body of research suggesting that it is impossible to be sustainable in the long run without an element of resilience, yet it is possible to be highly resilient without being sustainable. This is of particular relevance to FDM operations which are closely intertwined with social and environmental dependencies and dependants. Therefore, there is a real need when designing resilience strategies from an FDM perspective to be able to measure the broader impacts of resilience elements not just on traditional economic KPIs, but also on social and environmental KPIs too. The FDM-RES Framework therefore breaks new conceptual ground by proposing a FDM specific taxonomy of sustainable resilience KPIs.

5. Resilience components, such as Vulnerabilities and Resilience Elements, must be considered in unison and not in isolation

The reviews conducted as part of this research have identified that in order to attain a level of resilience that is viable in the long term, the definition used, the accurate identification of vulnerabilities and the selection of countering resilience elements are vital concepts which must be considered in unison. These three components have often been investigated in isolation in the literature and yet by doing so, it is likely not only that vulnerabilities might be missed, but that the resilience elements employed are unlikely to be optimally suited to the deal with these vulnerabilities. Furthermore, if resilience elements are not evaluated for effects on efficiency and sustainability, their use could conceivably open up disruption risks in new areas, thus worsening long term resilience. By incorporating a mapping process complete with a taxonomy of real-time exposure metrics to identify vulnerabilities, by developing the linkages between specific vulnerabilities and countering resilience elements and evaluating these using sustainability KPIs it is hoped that the FDM-RES Framework and Workbook will help to establish a new universal standard in modelling and enhancing resilience.

6. Resilience at a company level and at a national food sector level is different but related.

Resilience at a FDM level prioritises company viability whereas at a UK level, resilience prioritises the viability of the entire Food and Drink Manufacturing Sector as a key pillar in the provision of food to its population. A major difference is that, whilst at a National scale, the loss of individual FDMs to changing operating environments is acceptable provided there is enough diversity to maintain overall sector function, for the FDMs going out of business, this is not resilience. Therefore, there is the potential for conflict, for example, if all FDMs were to approach resilience from only a commercial competitiveness perspective, they could potentially damage national level resilience, perhaps by limiting raw material supplies for other FDMs, or decreasing the nutritional quality of food available to a population. Therefore, it is important that this intertwined relation is considered by both industrialists and policy makers when acting to enhance their respective resilience to ensure synergy rather than antagonism.

7. Suitable resilience strategies are strongly influenced by individual company factors.

The case study application of the FDM-RES Workbook with two major UK FDMs revealed a number of practical considerations. The first is that factors such as the size and value chain position of a FDM will have a real impact on whether vulnerabilities and countering resilience elements, that may be relevant in principle, are actually relevant in practice. For example, for larger, well established FDMs, financial robustness can significantly increase the range of possible resilience elements available (for example, economic viability of air freighting in alternative supplies) compared to smaller companies. This means that suggestions given by any tool, whilst important for capturing resilience considerations that might not have been considered otherwise, will only ever be guidance. By implication therefore, there is a need and opportunity for further iterations of this research to consider SME FDMs, which, whilst making up the vast majority of the UKs Food and Drink Manufacturing Industry, are often much more constrained by resource and capital in terms of how they respond to disruption.

12.3 Recommendations for Future Work

Given the highly exploratory nature of this research combined and its topicality from a national food security perspective, the author proposes the following avenues for building on this research.

1. The need for further empirical research investigating the relationships between resilience concepts

To date, whilst there has been growing interest in resilience as a topic, due to the difficulties of studying resilience at a supply chain level, the majority of research models have tended to use artificially generated data and rarely focus on ways to actually implement the resilience suggestions they generate. There is therefore, a need for further empirical validation of accurate vulnerability mapping techniques, of the relationships between specific vulnerabilities and how resilience elements are evaluated for effectiveness and side-effects. The FDM-RES Framework presents an important first step in this direction by proposing some of the aforementioned relationships based on literature observations and industry interviews. By utilising the established ERM structure, the FDM-RES workbook also facilitates practical application of the framework conceptual principles. However, the FDM-RES Framework and Workbook have only been applied in a relatively small number of case studies in a single Food Manufacturing sector. There is therefore a real opportunity for further qualitative validation and development of the taxonomies and relational linkages contained in thesis in a range of other sectors.

2. Quantitative validation at a UK FDM sector wide scale

In addition to the need for further qualitative research identified in the previous recommendations, there is also an opportunity to expand the findings of this research quantitatively, to aid in their representability of the wider UK FDM sector. This could be achieved by using the case study findings to produce a streamlined version of the FDM-RES Workbook which could be completed in approximately 30 minutes (as opposed to the several hours taken per company in this research). This would make the research more suitable for a survey-based approach which could provide the volume of responses to statistically validate the FDM-RES Framework at a FDM sector wide scale. Furthermore, the better understanding of the relationships between FDM-RES Framework concepts gained from the case studies in this thesis should mean that questions can be simplified in surveys, thus making them more accessible to respondents who will not have the researcher at hand to ask questions.

3. Further development of the FDM-RES Framework to consider the impact of resilience strategies on wider supply network partners

Whilst the FDM-RES Workbook is highly novel in its consideration of the impacts of the resilience strategies it proposes on sustainability, it was felt to be beyond the scope of this thesis to attempt to also model the impacts of resilience on supply chain partners. In principle this could form an important development of Stage Four, the Evaluation Process. The is particularly pertinent given that findings from this research strongly suggest that FDMs are increasingly moving towards highly collaborative value chain partnerships with retailers and even suppliers. In such relationships, the ability to be able to gauge the impact of company resilience strategies on long term partners is vital. This will likely require substantial empirical qualitative validation to begin with, based on the experiences of industry experts, for example, to identify what effect changing ingredient suppliers has on the wider market. These could then be measured quantitatively at scale to gain sector representativeness and then incorporated into the evaluation stage of resilience enhancement tools.

4. Further development of the FDM-RES Workbook into a software-based tool

Once the relations between the FDM-RES Framework concepts have been validated at a sector wide level, for example, via quantitative survey validation, one way of potentially speeding up the process would be to convert the relational matrixes and guidance, which are currently presented in the FDM-RES Workbook, into a software tool. This could be as simple as an automated database in Microsoft Excel which would save the user having to cross reference the various exposure metrics, failure modes, vulnerabilities and resilience elements with relational matrixes thus decreasing user time. Of course, once the research was at a point where the relational links within the FDM-RES Framework were quantitatively validated at a sector scale, and enough was known about how different company contexts effected the results, the software could move from a database to a simulation model, projecting a wide range of possible vulnerabilities, mitigating resilience elements and wider side-effects of these elements.

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Appendices

Appendix 1:	FDM1 Case Study Questionnaire
Appendix 2:	FDM2 Case Study Questionnaire
Appendix 3:	Journal paper ***Resilience in Agri-Food Supply Chains: A Critical Analysis of the Literature and Synthesis of a Novel Framework***
Appendix 4:	Conference paper ***An Overview of Resilience Factors in Food Supply Chains***
Appendix 5:	Book chapter ***Forging New Frontiers in Sustainable Food Manufacturing***

Appendix 1: FDM1 Questionnaire Response

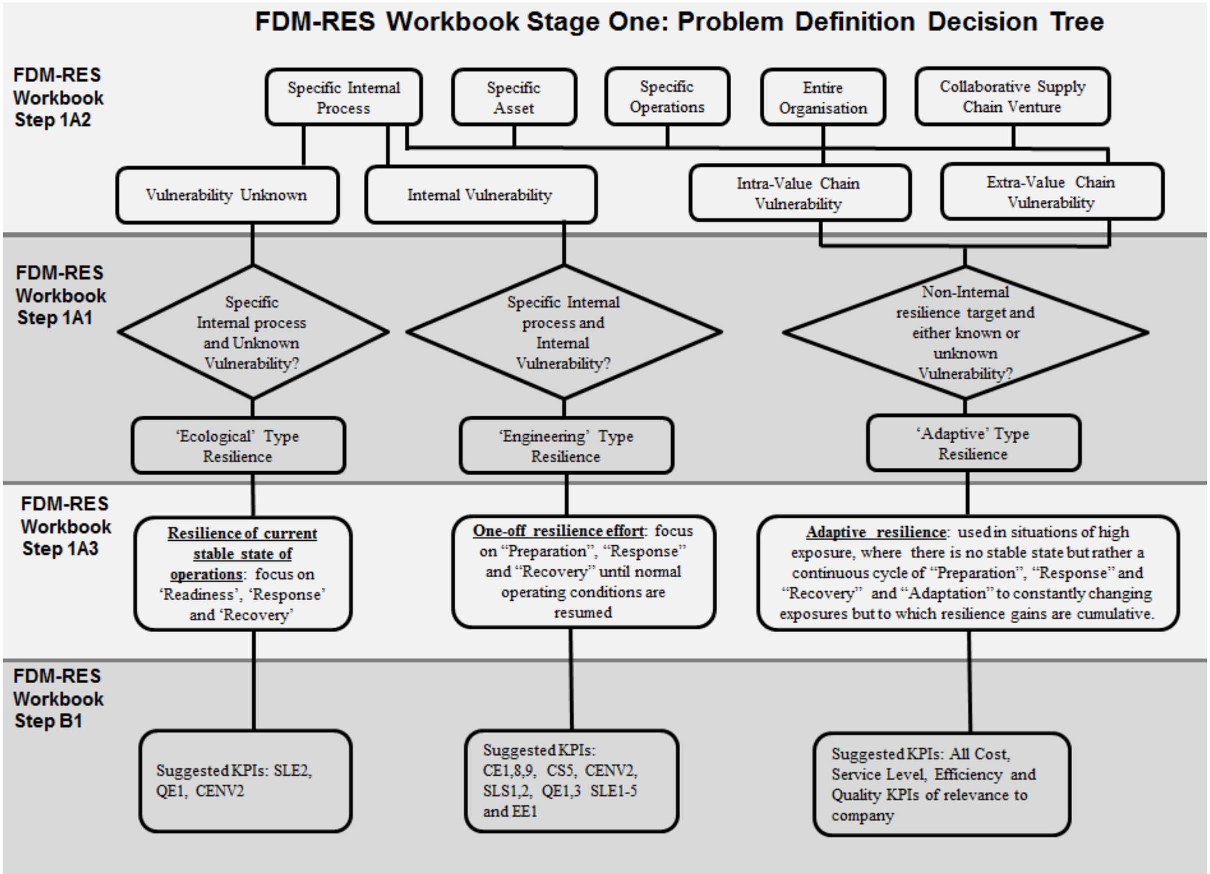
FDM-RES Workbook Stage 1: Problem Definition

The aim of this section is to identify what it is that your organisation wishes to make resilient, the type of resilience which is being sought and the scope of activities involved. It also establishes the Key Performance Measure that reflect the type of resilience being sought.

FDM-RES Workbook Step 1A

Tasks 1A2, 1A1 and 1A3

Please use the decision tree below to indicate what it is that is being made resilient and provided details in the space below.



Notes about the type of product being made resilient

Product: Chicken, Bacon and Mayonnaise sandwich line	
What different actors do you work with in your supply chain? (E.g. suppliers, customers, competitors, service providers, Government)	Key Customers: A large number of UK multiples in addition to well-known high street cafes and private label manufacturers. Others: Contract labs, enforcement bodies, trade bodies (chilled food association), research associations (Campden BRI) 3PL: Some own logistics but use a huge range of others in order to meet the diverse requirements of different divisions.
What is your relationship with each of these, for example, buyer, seller or collaboration?	Retailers: Long term partnerships which link FDM1 to retailer sourcing codes whilst allowing FDM1 significant autonomy in sourcing. Customers: long term relationships with collaboration of forecasts/risks
Do you have any specific infrastructure requirements? (e.g. energy or water)	Energy is a key issue as sites use such a vast amount that back up generation for any meaningful length of time is impossible Water also a key issue with limited reserves Roads are a major dependency as so much of the food is chilled and delay risks retailer rejection (Snow was a major disruption in 2008). Effluence disposal is another key consideration Labour is a major issues and good relations with agency providers are vital. Even so, recent diplomatic events and the associated currency fluctuations have impacted EU workers' wages. As a result, automation is a major issue, not for efficiency, so much as to save labour.
Would you describe any of the organisations who you work with as representing a **critical node**? (E.g. in the sense that many companies are dependent on them and/or there are few alternatives)?	Regional Distribution Centres and upstream frozen warehouse consolidators (handle the import licenses as part of service)
How is **information** transmitted between you and the organisations you work with in the supply chain? (for example, is it digital, by phone or by paper and how frequently)	Mostly digital, some phone. Strong internal security protocols and off site/cloud storage In particular, the risk of fire (given the nature of factory operations) means that fire proof safes are used)
How is **material** moved from one point in the supply chain to others? For example, consider:	Ship: both EU RoRo and International LoLo (Southampton) Road: from port to consolidator, consolidator to factory and factory to regional and local distribution centres, as well as some direct to store. No rail/air freight unless an emergency due to cost.

FDM-RES Workbook Step 1B

Task 1B1

The next step concerns the KPIs which your organisation would use to assess resilience. Please fill out the following table using the following scoring mechanism.

Scoring Mechanism

5 = Priority KPIs,

4 =Secondary KPIs,

3 = KPIs which are not important at present but are projected to grow in importance in future,

2 = Nice to have KPIs

1 = Unimportant KPIs

KPI	KPI Sub-Pillar: Economic (E)	Score	KPI Sub-Pillar: Social (S)	Score	KPI Sub-Pillar: Environmental (ENV)	Score	Notes
Cost (C)	**(CE1)** Raw Material Cost	**5**	**(CS1)** Human Rights Standards of Suppliers	**4**	**(CENV 1)** Environmental Standards of Suppliers	**3**	**CENV1**: Expected that suppliers would be doing this already
	(CE2) Utilities cost (water, electricity, gas, waste disposal)	**5**	**(CS2)** Social impact of utility generation and disposal	**2**	**(CENV 2)** Environmental legislation compliance	**5**	**CE4**: Low priority as the company attempts to shift capacity to less busy days.
	(CE3) Inventory Carrying Cost	**3**	**CS3)** Job Satisfaction	**3**			
	(CE4) Spare Capacity Cost	**1**					
	(CE5) Staff Cost	**4**	**(CS4)** Fair Salary	**2**	**(CENV3)** Natural Capital Valuation	**2**	**N/A**
	(CE6) Gross Value added	**5**	**(CS5)** Labour Relations	**3**			
	(CE7) Market Concentration	**4**	**(CS6)** Regional employment	**2**	**(CENV4)** Environmental risk management procedure	**4**	**CS7:** Outreach is a priority, particularly STEM ambassadors, and is directly linked to recruiting skilled staff.
	(CE8) Profit margins	**3**					
	(CE9) Net Profit	**3**	**(CS7)** Philanthropy and Local Community Investment	**5**			
Service Level (SL)	**(SLE1)** Order Fulfilment Time	**5**	**(SLS1)** Regular Review of Worker Rights	**4**	**(SLENV1)** End of Life Planning and Circular Economy	**4**	**SLE1:** A major priority is not to short on deliveries as the retailer will subtract this from
	(SLE2) Contract	**4**					

	Fulfilment						next payment **SLENV1:** Prioritisation given to redistribution via staff shop and distribution of bread crusts to animal feed. Care is taken to ensure that packaging is recyclable, and that food goes for AD. Final resort is energy recovery for other waste.
	(SLE3) Customer Responsiveness	**4**	**(SLS 2)** Occupational Health and Safety	**5**			
			(SLS 3) Employee Diversity: and Equal Opportunities	**3**			
	(SLE4) Customer Satisfaction	**5**	**(SLS 4)** Corporate Attitude to risk management	**4**			
	(SLE5) Traceability of incoming raw materials.	**5**					
Efficiency (E)	**(EE1)** Raw Material to Finished Product Conversion Rate	**2**	**(ES1)** Employee Appraisal and Development Systems	**4**	**(EENV1)** Energy, Water and Raw Material Efficiency during Manufacturing	**4**	**EE1** For many products yield is low, for example, avocados for M&S is 13%.
					(EENV2) Emissions Related to Manufacturing	**4**	**N/A**
	(EE2) Employee productivity	**4**	**(ES2)** Average Employment Retention Rate	**4**			
			(ES3) Corruption	**2**			
Quality (Q)	**(QE1)** Safety of Goods	**5**	**(QS1)** Health and Nutrition of Goods	**4**	**(QENV1)** Animal Welfare	**5**	**N/A**
	(QE2) Shelf Life	**5**					
	(QE3) Product Reliability and Convenience	**4**	**(QS2)** Private labelling standards that go beyond legislative requirements	**4**	**(QENV2)** Production Certification Schemes that go beyond legislative requirements	**2**	**N/A**
			(QS3) Societal benefit of product	**2**			
			(QS4) Smell and Noise Reduction	**2**	**(QENV3)** Presence of emissions reduction and resource efficiency enhancement targets	**2**	**N/A**

FDM-RES Workbook Stage 2: Identification of Vulnerabilities

This section involves the mapping of key entities within the supply network which support production of the listed product in order to identify the unique vulnerabilities facing your organisation.

FDM-RES Workbook Step 2A

Tasks 2A1, 2A2 and 2A3

Please answer the following questions:

1. Primary Entities involved (direct value chain partners). Please mark entities for which there are no alternatives with an*.

   a. Raw material suppliers = buyer/ seller

   b. Packaging suppliers = buyer/ seller

   c. Non- resale suppliers = buyer/ seller

2. Secondary Entities (third party dependencies such as logistics, shipping, storage, utilities etc.). Please mark entities who for which there are no alternatives with an*.

   a. Transport inbound/ outbound = collaborative

   b. Utility suppliers = buyer/ seller

   c. Offsite storage = buyer/ seller

3. Please indicate next to the above answers what type of relationship exists with that entity (i.e. buyer-seller, collaborative, competitive)

4. What are the main raw material inputs? For each, what, roughly is the:

   a. Lead time (from order to arrival at manufacturing line) = weekly forecast/ 24 hour confirmation

   b. Supplier ability to increase/decrease supply (i.e. low, medium or high) = Bread high, chicken medium (large stock in supply chain but 12-week shipping time). Mayo high (short manufacturing time)

   c. Opportunities to source elsewhere (i.e. number of alternatives) = Bread very limited, specialist manufacturers and very high volumes. Chicken readily available from multiple sources unless flavoured. Mayo readily available and could be made by FDM1.

   d. Water/energy requirements and backup availability (i.e. low or high) = possible to tanker in water and hire generators at 24 hours notice.

6. For each raw main raw material coming into the factory what are the:

    a. Transport type/volume/frequency/time road transport = Pallet quantities, generally daily or more frequent (bread) deliveries

    b. Transport route/alternatives = Road only

5. For each raw main raw material coming into the factory what are the:

    a. Transport type/volume/frequency/time road transport = pallet quantities, generally daily or more frequent (bread) deliveries

    b. Transport route/alternatives = Road only

6. For each finished product leaving the factory what are the:

    a. Transport type/volume/frequency/time = Road, pallet quantities, hourly or more frequent despatch

    b. Transport route/alternatives = Road only

7. For each of the following supply chain stages, what is the type, route and frequency of information exchange? (I.e. is it by phone or electronic, is it hourly or weekly)

    a. Suppliers = Daily

    b. Internal = Daily

    c. Customers = Daily

8. Considering all of the supply chain state variables above, which do you think are the biggest risk areas?

a) Road Closures,

b) Bakery Fire and Temporary Closure and;

c) Extreme weather Events in Growing Areas

FDM-RES Workbook Steps 2B and 2C

Tasks 2B1, 2B2, 2C1, 2C2

Please rank the vulnerabilities in the following table using the scale below:

5 = Priority vulnerabilities, **4** = Secondary vulnerabilities, **3** = Vulnerabilities which are not important at present but projected to grow in importance in future, **2**= Vulnerabilities to which your organisation faces very limited exposure, **1**= Vulnerabilities which are irrelevant to your organisation

For each, please rank the likelihood of it leading to one of the failure modes listed below using the following scale:

5= Certainty that this vulnerability will result in this failure mode, **4**= Reasonable certainty that this vulnerability will result in this failure mode, **3**= Some certainty that this vulnerability will result in this failure mode, **2**= Unlikely that this vulnerability will result in this failure mode, **1**= This vulnerability is not linked to this failure mode.

Failure Mode	***Description/Characteristics***
FM1. Raw Material Shortage	All manner of upstream disruptions which limit raw material availability from the focal FDMs perspective.
FM2. Raw Material Sub-Standard Quality	All manner of upstream disruptions, which, whilst not necessarily halting raw material supply to the FDM, significantly affect the quality of raw materials received (e.g. size and credence factors)
FM3. Unable to produce/ Scrap/Rework	Occurs when a product is unable to move beyond the FDM production line, whether because production could not be attempted in the first place, because the final product needed to be reworked, or because the finished product was unfit for any other use thus requiring scrappage.
FM4.Labour Shortage	Refers to any factor(s) which limit labour availability at FDM sites
FM5: Loss of process economic viability	Factors leading to a particular process becoming commercially untenable for the FDM. Examples include raw materials simply not being profitable, wider market saturation or evolving consumer trends.
FM6: Loss of Site	Refers to any number of disruptions which either prevent or severely hinder operations at a particular plant.
FM7: Unable to Deliver	Goods are finished to specification but are prevented from being sold by various internal or downstream disruptions that prevent packing, loading or delivery.
FM8: Legally enforced cessation of specific operations	Situations which could result in a regulatory body forcing the FDM to cease operations in response to major legislative violations, for example, environmental breaches, significant health and safety concerns, or major incidents of food contamination.
FM9. Sub-Standard Product Quality and Possible Reject	Any disruptions which, whilst not forcing a scrap/rework, do impact on the final quality and may result in concessionary rates or penalties being applied by the customer.
FM10: Product Recall	This failure mode refers to any disruption(s) which result in food either being rejected at the retailer depot, or food which has made it onto retailer shelves or consumers' homes, being recalled.

Extra-Supply Chain Vulnerabilities								
Step1.Categorising food manufacturer vulnerabilities				Step 2. How likely is it that this vulnerability will result in the associated failure mode?				
Vulnerability class	Vulnerability	Exposure (1 -5)	What failure modes are associated with this vulnerability?	Never 1	2	3	4	Certain 5
Financial (Fin)	1. Market price fluctuation.	5	FM5 if duration is long enough.			FM5		
	2. Currency exchange fluctuations.	5	FM5 if duration is long enough.			FM5		
	3. Interest rate fluctuations.	5	FM5.		FM5			
	4. Regional economic downturns.	5	FM5 (in theory but in practice the manufacturer is producing fairly essential food).		FM5			
	5. Hostile takeover attempts.	1	FM5 (in theory but in practice the manufacturer is so well established that this is unlikely to ever happen).		FM5			
	6. Product liability.	3	FM3, 5, 7, 9 and 10 (in theory but there is a very real risk that it would close the company).					FM3, 5, 7,9 and 10
Market (Mar)	1. Market decline.	2	FM5 (in practice supply lots of retailers so that a decline in market for a particular product or retailer is balanced by gains elsewhere.		FM5			
	2. Competitive Innovation.	2	FM5 (but difficult market to enter due to large well-established manufacturers).		FM5			
	3. Competitor undercutting.	2	FM5 (unwritten rule between 3 largest manufacturers not to undercut).		FM5			
	4. Seasonal variability in availability of raw materials (growing seasons, profitability of crop).	5	FM1, FM2, FM9 Growers changing crop for profitability is rarely an issue as it is built into the contract, however, seasonality is more of a challenge because it can only be predicted to a degree, for example, disruptions to UK salad crops means continuing to take from Spain when insect counts will have built up. Equally, prawns migrate depending on weather and might move out of the range of trawlers. Can get around by					FM1, 2, 9

			building more processing centres in Greenland.					
	5. Variability in demand (seasonal, promotional and bullwhip).	5	FM1, FM2, FM4, FM9 (For a period can get suppliers to pull forward stock, but this means a smaller size and the longer this goes on, the less viable it gets. Another issue is product delisting in terms of reworking stock and specific packaging) Sea lice on salmon example means early harvest and decreased weight thus scarcity and higher cost.					FM 1, 2, 4, 9
Governance (Gov)	1. Changes in Public Food Policy (e.g. production efficiency targets, health and nutrition.	3	FM3, FM5 and FM10 (in reality, the manufacturer in question works closely with the trade bodies who advise government and warning would be so far in advance that these FMs would not happen).		FM3, 5 10			
	2. Private Food Policy (e.g. strict customer requirements on appearance, colour, shape and delivery time)*.	3	FM, 1, 2, 3, 7 9 and 10 (real risk of adulteration of ingredient if demand is high enough, for example, onion in garlic, used nutmeg residue).		FM10	FM 3, 7 and 9	FM 1,2	
	3. Political instability (regime changes, corruption).	4	FM 1, 2, 5 ,9. Risk of supplier collapse in affected area e.g. Crimea example. This is serious enough that the manufacturer would try to engineer out geographically isolated supplies.					FM 1,2,5, 9
	4. Import/export restrictions.	3	FM 1, 2 and 5. It could be a health or sanction related embargo. The sudden nature could make it hard to find a supplier as everything is made to demand.					FM 1, 2 and 5.
Infrastructure (Inf)	1. Disruption to transport infrastructure (ports, roads, railways, airports).	5	FM1 (Majority of raw materials are delivered by road), FM3 (after approximately a 24hour window, if products were undeliverable, or lacking key finishing ingredient), FM4 (due to dependency on a large volumes of manual labour making it to work), FM9 (It is possible this could be linked to substitution of ingredients depending on where the transport disruption occurred but even more likely that it will be due to manpower issues, in which case quality will be			FM3, FM4, FM9	FM1, FM10	FM7

			sacrificed for numbers to avoid retailer penalties), FM7 (an example would be snow at large centralised plants allowing inward deliveries but preventing outbound deliveries up the steep incline), FM10 (if the loss of quality was high enough, although there is likely to be some understanding for short term disruptions).					
	2. Disruption to water infrastructure.	2	The issue is likely to be a drop in water pressure rather than lack of water and therefore the problem will likely be cleaning related thus potentially resulting in FM9 and FM10 (if no action is taken pre-factory gate and someone subsequently gets ill).			FM10	FM9	
	3. Disruption to energy infrastructure (oil supply/price, electricity grid, gas supply).	4	The most likely outcome is a localised power failure, possibly due to a fire, which either prevents certain production processes, or damages storage conditions, leading to FM3. However, if the energy crisis was national, such as rolling power cuts or fuel restrictions, then FM1, 2, 4, 7 and 9 could all result.		FM 1, 2, 4, 7 and 9		FM3	
	4. Disruption to communications infrastructure (cables, radio masts, satellites).	4	FM 1 is possible but would be less likely as supply chains usually work several months ahead. FM 3 and 7 given short shelf life of finished goods.	FM 1				FM 3 and 7
Societal (Soc)	1. Piracy/Terrorism.	5	Such incidents are difficult to prepare for and when they happen, not only cause specific ingredient shortages, but can lead to reduced quality of supplies from alternative suppliers (FM2), reduced ultimate product quality (FM9) and potentially even loss of economic viability (FM5) for certain products if the disruption goes on for long enough.			FM5		FM 1, 2 and 9
	2. War and conflict.	5	Similar as above. FM1, 2, 5 and 9.			FM5		FM 1, 2 and 9
	3. Workforce health (e.g. flu pandemic).	5	Factors affecting workforce health can range from a major pandemic (which would particularly hit manual labour intensive industries) to individual cases of food			FM 3 and 10		FM4

			transmissible diseases. The former would likely result in FM4 and the later potentially in FM 3 or 10 depending on when it was detected.					
	4. Proportion of Consumer income available for food purchase.	1	In practice, food prices rising to the point where they are unaffordable to people in the UK is unlikely and hasn't been seen by manufacturers so far. However, in principle it could lead to FM5.		FM5			
	5. Changing customer attitudes to consumption (e.g. health, lifestyle and fashion foods).	1	In principle there is a possibility that completion could result in a particular product no longer being economically viable, yet in practice this is very unlikely as retailers would ultimately be the ones to decide whether to pay or not.		FM5			
	6. Criminal acts (such as fraud data hacking and sabotage).	5	Depending on the potential severity of the criminal act could involve FM 1,2,3, 5, 6, 7, 9 and 10.			5 and 6	1,2,3, 7, 9 and 10	
	7. Industrial actions (such as strikes).	2	The potential outcome of a such action, even if unlikely, would be significant on FM4 and 7.					FM 4 and 7
	8. Poor relations with consumers and special interest groups.	5	Avoidance of specific ingredients/suppliers leading to either FM1 or potentially FM5 if alternatives are not economically viable. FM10 is also possible if a negative story breaks and the product is still on the shelf.			FM5, FM10	FM1	
Environmental (Env)	1. Natural disasters (both Geological and Meteorological such as earthquakes, drought etc.).	5	This is a vulnerability that is frequently experienced by FDM1 and failure modes can include FM1, 2, 5, 6 and 9.			6	5	FM1, 2 and 9
	2. Biological factors (e.g. livestock disease, pests).	5	This is a vulnerability that is frequently experienced by FDM1, for example mildew on crops, and failure modes can include FM1, 2, 5 and 9.					FM1, 2, 5 and 9.
	3. Anthropogenic environmental hazards (such as air pollution, land contamination).	2	Unexpected contamination means FM 1 as a most likely outcome, followed by FM 3, 7 and 10 if detected late and finally FM 2 and 9 if it was not a major threat to consumer health (Unlikely).		7 and 10	3, and 9	1	
	4. Unsustainable Primary Production.	2	FM 1, 2, 3, 5 and 9.		FM 1, 2, 3, 5 and 9			

The next step explores vulnerabilities faced within your organisation's supply chain but outside of your organisation.

Value Chain Vulnerabilities								
Step1.Categorising food manufacturer vulnerabilities				Step 2. How likely is it that this vulnerability will result in the associated failure mode?				
Vulnerability class	Vulnerability	Exposure (1 Never-5 Very Likely)	What failure modes are associated with this vulnerability?	Never 1	2	3	4	Very Likely 5
Raw Material and Production (VCRMP)	1. Inconsistent Raw material quality and heterogeneity.	4	FM 2 and 9. This is a considerable Exposure as different FDM1 sites find that different varieties of a single ingredient type, such as beef mince, can affect production processes and also cook out quality.					FM 2 and 9
	2. Raw material and product related hazards (shelf life, cross contamination, handling requirements).	5	This is a considerable exposure, particularly in terms of allergens. Equally, the presence of bone in fish, due to supplier inability to detect them without specialist x ray equipment. The most common outcome would be a tiny point contamination, e.g. a single prawn dropping into another filling tray, leading to FM9. If someone gets ill as a result, FM10 could also occur.			FM10		FM9
Logistic Control (VCLC)	1. Reliability of external logistics providers.	2	FM1, FM7. Company uses 3PL providers for all inbound suppliers as it would be far too complex to try to send their own to pick up the myriad range if ingredients. All own logistics for outbound. 3PL requirements are written into contract and poor performers are replaced so exposure is nominally low.					FM1, 7
	2. High levels of geographically distant, outsourcing for which there is no alternative.	4	Potentially high as FDM1 is reliant on a number of suppliers to perform basic processing such as cubing chicken which they cannot do themselves. If they were to go out of business, it could be a challenge to quickly find someone who can process to the same standard. FM1 (not FM2 as unprocessed versions of the same ingredient effectively cannot be used).					FM1

	3. Strict customer requirements (in terms of lead times and quality).	5	FM3, 7 and 9.			FM9	FM3, 7	
	1.Lack of established, secure and integrated information sharing infrastructure.	5	High exposure because so much of the internal process scheduling is automated and it couldn't be done via the phone in the event of a software breakdown. Any significant damage to ICT infrastructure would result in FM 1, 3 and 9 as well as potentially FM10 based on the severity of FM5.			FM10		FM1, 3, 9
Information System (VCIS)	2. Deliberate withholding of information.	3	FM 2, 3, 9 and 10. In principle, supply chains post farm gate are long term partnerships and so it is in everyone's interest that information that is crucial to supply chain functionality is transmitted. However, breakdowns do sometimes occur, particularly when one party has something to hide, e.g. fipronil in eggs. By nature, on the rare occasions information is deliberately withheld, the ultimate consequences when it is found out will be.					FM 2, 3, 9 and 10
	3. Lack of ability to trace food across the value chain.	3	FM 1, 3, 7 and 10. In light of recent scandals, there is a higher incidence of chemical checks as opposed to reliance on paper trails and this has reduced exposure somewhat but is still only spot checks. Upon detection of a significant defect, failure modes would include.					FM 1, 3, 7 and 10
Organisational Management Structure (VCOMS)	1. Low level of training & experience in other company's employees.	4	FM: 1, 2, 10. Much of the scheduling is automated and so the main area where other company's staff can have an impact is by dispatching an incorrect batch and/or cross contaminating batches. However, the manufacturer is careful to rule out suppliers who handle other potentially allergenic or undesirable ingredients to begin with and all incoming batches are checked. Yet it is impossible to completely remove risk.		FM 2, 10			FM 1
	2. Poor financial	5	This occurs more than once every 5 years. However,		FM 1		FM 2,5	

	situation of value chain partners (exposure to bankruptcy or takeover).		warning is usually high and signs might include requesting payment in advance. However, dealing with this situation is difficult because you don't want to blacklist such suppliers and thus push them over the edge when they might otherwise have recovered. Another scenario is a takeover in which case there may be ramifications for the economic viability of a product. Unlikely to be FM1 but potentially FM 2 if alternative suppliers are inferior and 5 if it effects the cost/quality significantly.					
	3. High concentration in supply chains (i.e. actors serving as both suppliers and competitors in different contexts).	4	Increasingly common with vertical integration and also joint ventures which are held together only by shared economic interests and vulnerable to takeovers etc. FM 1 and 5 (more likely that cost of any change in relations will damage economic viability rather than availability of raw materials.		FM1		FM5	
	4. High levels of power imbalance between actors (contractual fairness and level of lock in)*.	2	Whilst 10 years ago this might have been true of retailers and manufacturers, increasing contract lengths now mean that it is in the interest of both parties to make the relationship work. However, this is not necessarily true of farmers whose relationship with downstream actors is dictated by glut/shortages in produce driving price. FM5 (tight margins do mean that any if care is not taken to work collaboratively by both parties then economic viability will likely be damaged).			FM5		

The final step explores vulnerabilities stemming from within your organisation itself.

Organisation Specific Vulnerabilities								
Step1.Categorising food manufacturer vulnerabilities				Step 2. How likely is it that this vulnerability will result in the associated failure mode?				
Vulnerability class	Vulnerability	Exposure (1 Never-5 Very Likely)	What failure modes are associated with this vulnerability?	Never 1	2	3	4	Very Likely 5
Raw Material and Production (OSRMP)	1. Challenges related to storing raw materials/finished inventory.	2	FM1, 2, 3, 4, 5, 6, 7 and 8. Low as all key storage systems are wired/alarmed. The companies only experience in this area was a complete cooling system failure- something that is very rare. If a disturbance were to affect the manufacturer's inventory then the effects would likely be catastrophic, including.					All FM's
	2. Product failure to comply with environmental legislation.	2	Exposure is perceived as relatively low due to internal safeguards such as the air flotation system tank which removes solids from effluence, thus acting as a buffer for downstream effluence treatment works. Minor breaches will likely result in a fine i.e. ammonia leaks, but more substantial or persistent breaches could result in FM 8.			FM8		
	3. Product failure to comply with Health and Safety Legislation.	3	Exposure is perceived as relatively low due to internal safeguards (such as HS training/audits/guards on equipment and reporting of near misses) yet accidents do happen, particularly when staff ignore rules. If the company is deemed to be at fault then FM 8 could occur.			FM8		
	4. Insufficient capacity to meet changing order requirements.	5	FM 3, 7 and 9. Exposure is high due to staff serving as a bottleneck. Whilst they can do long shifts and weeks to meet extra demand, the manufacturer has found that staff will often then take off time the following week causing a complete crash in capacity. Furthermore, capacity in the form of					FM 3, 7 and 9

			managers who have broader production process. understanding as opposed to more limited product specific skills such as that of production line workers are often cut to save money leading to disastrous consequences in times of disruption.					
	5. Inability to react to changing circumstances (ability to quickly substitute raw materials or ramp up production/ decrease lead time).	5	FM 1, 2 and 9. However, reacting to such changes is something the food manufacturer in question has significant experience of, for example possessing streamlined audits that anonymously just check critical control points, thus being much quicker than standard audits and facilitating rapid switch od suppliers.		FM 1, 2 and 9			
Logistics Control (VCLC)	1. Inaccurate forecasting (e.g. subjective decision making).	5	FM 1 , 3and 4 (whilst exposure is high, this is such a common occurrence that highly effective guards have been put in place by the food manufacturer which effectively minimise the impact).		FM1, 3, 4			
	2. Lack of flexibility in internal distribution capacity (form, volume, transit time, traceability).	2	FM 7. Identified as being a major issue for food manufacturers as food retailers ordering reacts to end of day stocks thus creating bull whip effect in scheduling, something that is particularly pronounced for short shelf life foods. This problematic enough that the food manufacturer pays staff to work from the food retailers site and correct such orders.		FM7			
Information System (OSIS)	1. Breech in information/data security (espionage, cyberattack, hardware failure).	5	FM 1, 3 and 7.					FM 1, 3 and 7
	2. Breakdowns in internal information sharing (reports reach correct staff, prompt response to customer complaints).	2	Potentially FM: 1, 2, 3, 4, 7 and 9. However, comprehensive guidelines and policy on what to do in different situation, who should be the one distributing information etc. are covered within BCM thus significantly reducing exposure to this challenge.		FM: 1, 2, 3, 4, 7 and 9.			
	3. Poorly	2	The food manufacturer			FM 2,		FM 1

	developed early warning detection systems.		actively subscribes to reporting organisations such as 'Food Industry Information Network' (FIINS), Eurofins and food forensics which provide up to date information on developing potential problems. However, things can still be missed and breakdowns could most likely effect FM 1 but also FM 2, 3, 9 and 10.			3 9 and 10		
Organisational Management Structure (VCOMS)	1. Poor protection of intellectual property.	2	FM5. The food manufacturer saw this as a relatively low risk due to contractual procedures.				FM5	
	2. Flawed strategic decision making.	4	FM 1, 2, 3 and 9. This was listed as a significant exposure due to the presence of numerous competing objectives between teams, for example, value vs. safety, with the effect being that many products launched are actually harder to manufacturer then anticipated.			FM 2, 3 and 9		FM1
	3. Absence of, or ineffective Contingency Planning (backup power, contingency plans).	2	Potentially all failure modes.					All
	4. Poor human resource utilisation (suitable staff training, knowledge retention).	3	FM 9. This is a known exposure which the company has attempted to rectify by reintroducing their graduate scheme and enhancing agency staff training in light of previous disruptions. There is also considerable flexibility in staff being able to attend sister sites when needed.			FM9		
	5. Restricted Corporate Social Responsibility Programme.	2	FM 1, 4.			FM 1 and 4		

Section 4: Resilience Practices

Please indicate the types of resilience practices used by your organisation. If they have been used in response to a specific failure mode then please indicate what this was. Finally, please indicate the effectiveness of the resilience practice in mitigating the failure mode

In House Management Practices						
Resilience Practice	Metrics	Presence of this resilience practice in your organisation (1 Not present-5 Fully implemenented)	Failure Mode Targeted	Effectiveness of resilience practice (1 Minimal Effect- 5 Complete Control	Impact of Resilience practice on KPIs (please put the relevant KPI code in each column with a 1-5 in brackets next to it (1= minimal effect, 5= major effect)	
					Positive effect	Negative Effect
Flexibility	Ability to switch procurement between suppliers.	5. (contract of at least two suppliers in most cases). However, there are trade-offs between KPIs so that if you switch for cost you might accept lower service level (i.e. delivery frequency or length), and equally true for quality.	FM 1, 2 and 8	5	CE1,7, 8 SLE1, 2, 3, 4 and 5 QE1, 2 and 3 QS2 and 3 QENV1 and 2	CE1,7, 8 CENV 1, 3, 4 and 5 SLE1, 2, 3, 4 and 5 QE 2 and 3 QENV 3
	Existence of product substitutes.	5. Whilst there are very few technical issues that would limit the substitution of ingredients, because of the way foods are labelled, it is effectively impossible to substitute down, only up e.g. normal to organic or barn to fee range. Would normally delist rather than substituting down.	FM 1, 2, 3 and 8	5	SLE1, 2, 3, 4 and 5 QE1-3 QS1-3 QENV1-3	SLENV1 CE1,7 CENV 1, 3, 4 and 5
	Ability of production line to accept substitute ingredients.	5. Technically easy but see above.	FM 1, 2, 3 and 8	5	SLE1, 2, 3, 4 and 5 QE1-3 QS1-3 QENV1-3	SLENV1 CE1,7 CENV 1, 3, 4 and 5
	Possibility of outsourcing process.	3. In normal situations, this is something that you would only do if it positively affected all KPIs, however in a disruption situation you might accept some negative impact on KPIs provided it prevented FM8.	FM 8 and 10	5		CE1,CE7,CENV1, 3,4 AND 5
	Ability to switch production sites.	5. (very important and generally expected by retailers as part of BCM process) Would predominantly be used in response to a catastrophic event such as fire. This might also be used if one site is	FM 4, 5, 9 and 10	3	SLE2,	CE1, 2, 3, 4 and 8 CENV 3 and 4 SLE1,3, 4 SLENV 1 EE1 and 2

		underperforming significantly and you wanted to just leave them with basic processes while focussing more complex activities on better performing sites.				EENV 1 and 2
	Ability to switch staff and equipment between sites	5. This would include technical staff as well as fillers and equipment that was fairly portable, such as slicers, graters and pumps.	FM 4, 5, 9 and 10	3	SLE1, 2, 4 and 5 EE1 and 2 QE1-3	EE2 SLE1(at original site)
	Availability of easily accessible financial assets.	5. As a large manufacturer this is not a problem.	FM 1,2,4, 7, 8 and 9	5	SLE2	CE8
	Broad staff skillsets, high company knowledge retention and the ability of staff to fulfil multiple roles.	5. This is something the manufacturer is actively investing in due to past unplanned resignations having destabilising effect on whole teams leading to multiple further resignations.	FM 4 and 5	3	SLE1-5 SLS 1-4 SLENV1 CS4 EE1 and 2 ES1-3 EENV1-2 QE1-3	CE8
	Customer communications and/or product differentiation to aid recovery in the event of a disruption.	5.	FM 1,2, 7, 8 and 9	3	CE6 and 8 SLE3 and 4	CE5
	Manipulation of market share, and product differentiation to take advantage of disruption to others.	5. The company has in the past taken over brands when they have failed or launched new product lines to meet retailer requirements, however, sometimes there is an initial cost in terms of product margins, particularly if it exceeds production line capacity.	NA but would be broader supply chain shortages or competitors going out of business		CE6, CE8, CS5	CE1-5 and 7
A2 Risk Aware Culture	Infrastructure in place to manage risk such as Business Continuity and Enterprise Risk Management.	5.	ERM: FM 1-9 BCM:FM 10	3	CE8 CS5 CENV2 and 5 SLE1-5 SLS2 and 4 SLENV1 QE1-3 QS4	CE8 minor

	Presence of Information and Physical Security.	5. (for example data is backed up via hard copy sent by taxi and site requires card access, is security fenced and gated and with regular security tests such as staged break ins).	FM 5, 6, 7 and 10	3	QE1 SLE2 SLS2 and 4	CE8
	Efficiency standards such as six sigma.	5.	FM 5	5	SLE1 EE1 and 2 QE1-3	
	Presence of strong and inspiring leadership support for resilience strategies.	5. The manufacturer identified that this was something that was actively encouraged as part of company cultures and cited sharing of resilience related news as an example.	ALL	5	CS1,3 4, 5 AND 6 CENV 1-5 SLE1-5 SLS1-4 SLENV 1 EE1-2 ES1-3 EENV1-2 QS1-3 QENV1-3	
	Active learning from the outcome of past disruptions.	5. The manufacturer highlighted that the ability to learn increase cumulatively with company size as you have exposure to a wider range of negative events but also more resources to adapt with.	ALL	5	CE8 CS3 and 4 CENV 1-5 SLE 1-5 SLS1-4 SLENV1 EE1-2 ES1-3 EENV 1-2 QE2 and 3 QS1-4 QENV 1-3	
A3 Redundancy	Ability to increase production capacity.	5. This could happen in response to higher than predicted orders but this is not a failure mode in its self. This increase in capacity is achieved through using extra staff on overtime to increase efficiency and decrease set up times thus shorten shift times.	FM 2, 3 and 7	5	CE8 SLE1 and 2	CE1-4 EENV1 QS4
	Ability to call upon spare inventory.	5. This varies depending on the ingredient. The manufacturer does not hold much stock but suppliers often hold stock in 2rd party cold stores which can be pulled forward. For example, there are 24 hours of bread, about a weeks' worth of	FM 2, 3, 5 and 7	5	SLE1 and 2	CE3 and 4 CENV1 SLENV1 EE1 EENV1 QE3 QS4

		chicken (as it has to be shipped from Thailand) and 2-3 days lettuce. Beyond this, the manufacturer can ask to pull from primary producers, but this means harvesting early thus securing smaller yields.				
A4 Early Warning Systems	Foresight to extend preparation time.	4. This can be achieved to a high level by communication with suppliers, industry bodies such as the CFA, and Quarterly horizon scanning. However, there is only so much you can do as issues such as long-term peanut contamination in Chinese garlic powder, or the recent 2 sisters scandal highlight.	ALL	3	SLE1-5 CE1-2 CS4 CENV1-5 SLS4 QE1	CE8 (minor)
	Relations between teams and impact on communication and the flow of information.	5. This is important and established by a clear system of leadership with instructions as to who communicates with who	ALL	4	CE1-4 CS4 CENV1,2, 3 and 5 SLE1-5 SLS1-4 SLENV1 EE1-2 ES1-3 EENV1-2 QE1-3 QENV1-3	None
A5 Agility	Ability to reduce production times.	5. increase staff numbers for short time periods.	FM 6	4	SLE1-4	CE8
	Ability to reduce set up times.	5	FM 6	4	SLE1-4	CE8
	Ability to reduce shift change over times.	5	FM 6	4	SLE1-4	CE8
	Poor company attitude to adapting and joint decision making.	3. This is only really a problem when the manufacturer acquires new companies and is integrating them.	FM 3 and 5	5	N/A	CE8 CENV2-5 SLE1-5 SLS 2 and 4 SLENV1 EE1 and 2 EENV1-2 QE1-3 QS4 QENV2 and 3

The next step explores management practices employed by your organisation to help manage your broader supply chain in order to meet your KPIs on a day to day basis.

Supply Chain Management Practices						
Resilience Practice	Metrics	Notes Presence of this resilience practice in your organisation (1 Not present-5 Fully implemenented)	Failure Mode Targeted	Effectiveness of resilience practice (1 Minimal Effect- 5 Complete Control	Impact of Resilience practice on KPIs (please put the relevant KPI code in each column with a 1-5 in brackets next to it (1= minimal effect, 5= major effect)	
					Positive effect	Negative Effect
B1 Collaboration	Integration of systems with suppliers/clients.	5. Full integration of retail order systems with supplier specifications and manufacturer production scheduling software. Also, a linked complaints analysis software from retailer to supplier.	FM 1,2 and 5	5	SLE1-5 SLENV1	N/A
	Coordination of activities, including product design, with suppliers/clients.	5. Products are inherently designed with the retailer and often pull in the supplier too so that all parties are sure of the others needs and capabilities relating to volumes and specs.	FM 1,2 and 5	5	CE1-8 CS15 CENV1-5 SLE1-5 SLENV1 QE1-3 QS1-3 QENV1-3	N/A
	Sharing of risk with supply chain suppliers/clients.	3. There is underwriting but not really sharing with supply chain partners. However, this is mitigated somewhat by the security of contractual supply rather than the spot market.	FM 1 and 10	5	CE8	CE7
	The ability to coordinate responses to disruptions and adapt alongside partners.	5. In the event of a serious supply chain wide disruption a cross partner crisis team would be set up as everyone wants a mutually acceptable fix ASAP.	FM 1, 2, 4, 5 and 10	5	SLE1-5 QE1-3	N/A
	Active encouragement of trust with supply chain partners and avoidance of asymmetric supply chain relationships.	5. For larger food manufacturers, the situation with retailers has become much more collaborative in recent years and this extends to suppliers too. However, larger manufacturers tend to avoid smaller suppliers	FM 8	4	SLE1-5 QE1-3	CE1-2

		who might not have the financial reserves to pay for the worked value of a shipment if problems are found. If it can't be avoided, they try to ensure small suppliers are only small volume low value products.				
	Development of strategic partnerships with supply chain partners.	5. Strategic relationships were identified as a long-term trend in FSCs as they offered much more stability over spot market relationships.	FM 1,2, 5 and 8	5	CE1 and 7 CS1 and 2 CENV1-5 SLE1-5 SLENV1 QE1-3 QS1-3 EMV1-3	N/A
	Standardisation of materials and processes with supply chain partners.	3. There are shared standards for a number of key products such as IR bacon and pasteurised milk.	FM 2,5	4	QE1	
B2 Flexibility (presence of alternative supply chain options)	Existence of alternative supply chain carriers.	5. There are a significant range of 3pl providers who could be called upon at short notice.	FM 1	5	SLE1-3	CE8
	Ability to postpone contracts.	3. There is some ability to ask suppliers to store (albeit at slight cost) if under using. There is also some potential to rewrite if oversupplying provided the supplier could find another buyer.	FM 1, 2 and 8	3	CE1-3	N/A
	Presence of alternative suppliers/clients.	5. There are always two suppliers as a contingency.	FM 1,2 and 8	5	SLE1-2	CE1-4 CENV1 QE3
	Selection of suppliers/clients based on flexibility of capacity.	5. This is inbuilt into the auditing process when new suppliers are selected.	FM 1	3	SLE1-4	CE1-2
B3 Velocity (the ability to react rapidly)	Ability to increase frequency of deliveries.	5. This was identified as being of crucial importance. It is written into supplier contracts that they must be able to replace rejected orders rapidly and if manufacturer related, they their own logistics arm can be called upon at little extra cost.	FM 1, 6	5	SLE1-4	Negligible

	Geographic proximity to customers.	3. Not really an issue on a UK scale as the furthest they could be is a few hours away.	FM 3 and 6	3	SLE1-4 but minimal	
	Geographic proximity to suppliers.	5. Identified as being crucial- suppliers in UK are preferred. International suppliers tend to be used for high volume low complexity products where there is plenty in the system used by other manufacturers and thus unlikely to be delisted rapidly.	FM 1	4	SLE1-5	CE1-2
	Presence of risk management strategies throughout operations of all supply chain partners.	5. This is something that is actively sought in initial contract audit. Absence is strongly linked to catastrophic failures such as Findus crispy pancakes.	FM 1,2	5	CENV1 SLE1-5 QE1 and 2 QS1 QENV1	N/A
B4 Visibility (ability to see things from one end of the supply chain to the other)	Shared forecasting with suppliers/clients.	5.	FM 1,2,5	5	CE1-4 SLE1-3 QE2	CE1-4 SLENV1 EENV1-2
	Creation of integrated and efficient value chain communication and information systems.	5.	FM 1,2,3,4, 5 and 6	5	CE1-4 SLE1-3 QE2	N/A
	Creation of material traceability systems.	5 This is something that has progressed significantly since the horse meat scandal. All meats can now be traced back to farm within 4 hours using standardised reports generated at the point of slaughter/cutting.	FM 2, 5, 7 and 9	5	SLE4-5 QE1	N/A
B5 Redundancy	System wide design of emergency back up and storage facilities.	2. 3pl chilled storage available within 24 hours.	FM 3	4	SLE1-2 QE1	CE8
	Existence of alternative pathways between you and your suppliers/clients.	2. Major problem as being UK based, this involved motorways of which there are very limited alternatives. However, there are slightly more options if considering international freight.	FM 1, 6	2	SLE1-2 QE1-2	CE2

Appendix 2: FDM2 Questionnaire Response

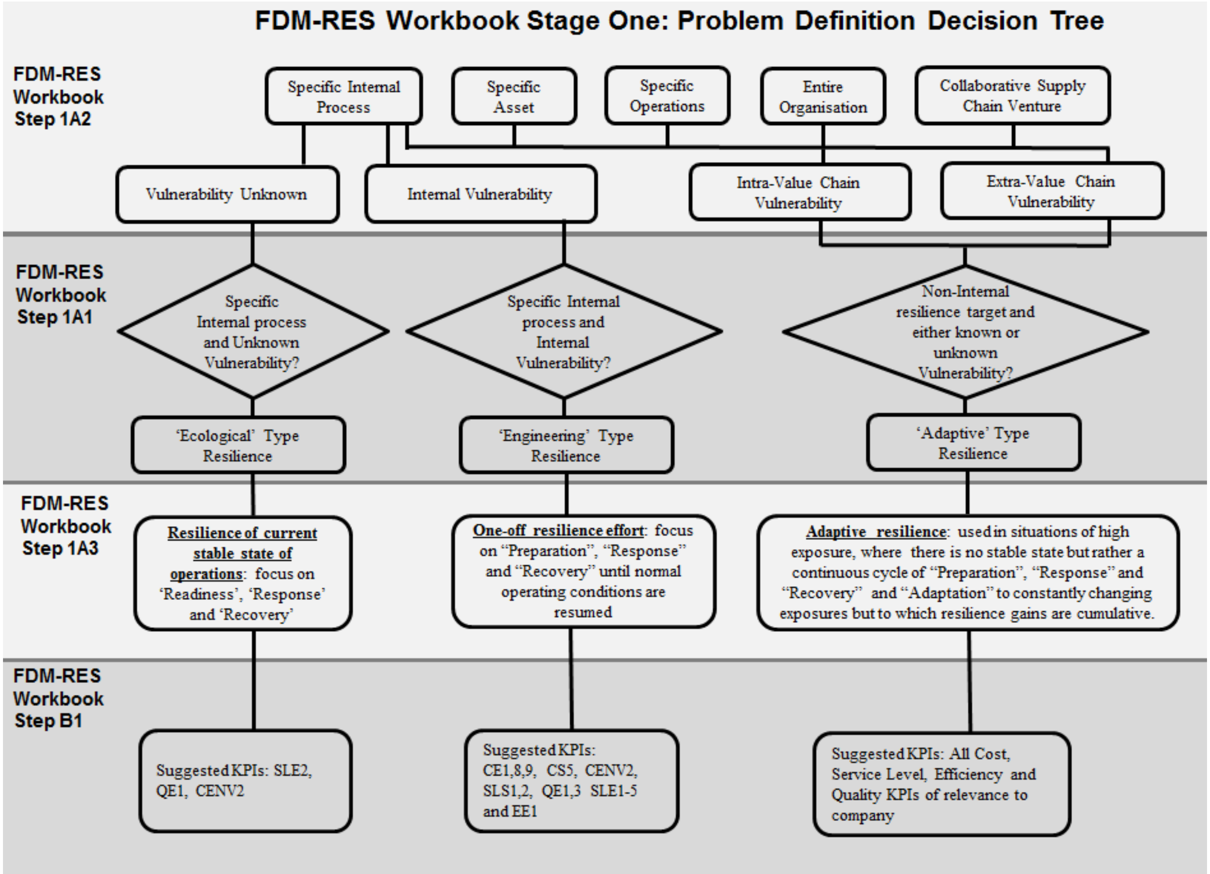
FDM-RES Workbook Stage One: Problem Definition

The aim of this section is to identify what it is that your organisation wishes to make resilient, the type of resilience which is being sought and the scope of activities involved. It also establishes the Key Performance Measure that reflect the type of resilience being sought.

FDM-RES Workbook Step 1A

Tasks 1A2, 1A1 and 1A3

Please use the decision tree below to indicate what it is that is being made resilient and provided details in the space below.



Notes about the type of product being made resilient

Product: Chicken, Lettuce and Bacon Sandwich to one major retailer	
Organisation Background	Member of a large Consortium which includes 18 other chilled and ambient food manufacturers. Two sites in the Midlands and vertically integrated chilled logistics arm of operations. Operations include: Chilled Fresh Food to Go. Sandwiches, Pasta, Prepared Salads, Chilled Meals, Retail only (no wholesale or catering). Branded and Own Label Geographic Scope: UK, Europe and SE Asia Employees: 33-34 (5 in preparation, 22 in production line, 3 in dispatch packaging, 2 in distribution loading and cooling and 1-2 in intake.

FDM-RES Workbook Step 1B

Tasks 2B1 and 2B2

The next step concerns the KPIs which your organisation would use to assess resilience. Please fill out the following table using the following scoring mechanism.

Scoring Mechanism

5 = Priority KPIs,

4 =Secondary KPIs,

3 = KPIs which are not important at present but are projected to grow in importance in future,

2 = Nice to have KPIs

1 = Unimportant KPIs

KPI	KPI Sub-Pillar: Economic (E)	Score	KPI Sub-Pillar: Social (S)	Score	KPI Sub-Pillar: Environmental (ENV)	Score	Notes
Cost (C)	**(CE1**) Raw Material Cost	**5**	**(CS1)** Human Rights Standards of Suppliers	**3**	**(CENV 1)** Environmental Standards of Suppliers	**3**	**CS3** is a huge priority. Staff morale is a major issue as staff are such an important asset and perform quite tiresome roles. Therefore, regular HR meeting and Exit Interviews are important. As there is no union, it is vital to keep the labour agencies on board. **CE3** is high but there is only so much the manufacturer can do. There is significant reliance on suppliers to maintain enough stock to match order fulfilment lead time. **CE4** Minimal spare capacity. However, the facilities, being quite new, were specifically designed to keep things like bottlenecks to a minimum. **CE6** is increasing due to retailer pressure to capture market share on their own brand convenience chilled foods. **CENV 1-4** are fairly low due to supply chain position- these areas are outside of FM1's direct control. However, they are rising, partly in line with Tesco policy. An exception is CENV 2, local planning which is a much higher consideration.
	(CE2) Utilities cost (water, electricity, gas, waste disposal)	**4**	**(CS2)** Social impact of utility generation and disposal	**3**	**(CENV 2)** Environmental legislation compliance	**5**	
	(CE3) Inventory Carrying Cost	**5**	**CS3)** Job Satisfaction	**5**			
	(CE4) Spare Capacity Cost	**2**					
	(CE5) Staff Cost	**5**	**(CS4)** Fair Salary	**5**	**(CENV3)** Natural Capital Valuation	**3**	
	(CE6) Gross Value added	**3**	**(CS5)** Labour Relations	**5**			
	(CE7) Market Concentratio n	**4**	**(CS6)** Regional employment	**2**	**(CENV4)** Environmental risk management procedure	**3**	
	(CE8) Profit margins	**5**					
	(CE9) Net Profit	**5**	**(CS7)** Philanthropy and Local Community Investment	**1**			
Service Level (SL)	**(SLE1)** Order Fulfilment Time	**5**	**(SLS1)** Regular Review of Worker Rights	**5**	**(SLENV1)** End of Life Planning and Circular Economy	**3**	
	(SLE2) Contract Fulfilment	**5**					
	(SLE3) Customer Responsivene	**5**	**(SLS 2)** Occupational Health and	**5**			

	ss		Safety				
			(SLS 3) Employee Diversity: and Equal Opportunities	**3**			
	(SLE4) Customer Satisfaction	**5**	**(SLS 4)** Corporate Attitude to risk management	**5**			
	(SLE5) Traceability of incoming raw materials and outgoing produce	**5**					
Efficiency (E)	**(EE1)** Raw Material to Finished Product Conversion Rate	**4**	**(ES1)** Employee Appraisal and Development Systems	**5**	**(EENV1)** Energy, Water and Raw Material Efficiency During Manufacturing	**3**	**ES2** high retention of staff but this limits progression activities which paradoxically is the main reason to leave. Redeployment is a group strategy and regular redeployments between SB sites happen both for career progression and as a resilience aspect.
	(EE2) Employee productivity	**4**	**(ES2)** Average Employment Retention Rate	**5**	**(EENV2)** Emissions Related to Manufacturing	**3**	
			(ES3) Corruption	**1**			
Quality (Q)	**(QE1)** Safety of Goods	**5**	**(QS1)** Health and Nutrition of Goods	**3**	**(QENV1)** Animal Welfare	**3**	
	(QE2) Shelf Life	**5**					
	(QE3) Product Reliability and Convenience	**4**	**(QS2)** Private labelling standards that go beyond legislative requirements	**3**	**(QENV2)** Production Certification Schemes that go beyond legislative requirements	**3**	
			(QS3) Societal benefit of product	**3**			
			(QS4) Smell and Noise Reduction	**2**	**(QENV3)** Presence of emissions reduction and resource efficiency enhancement targets	**3**	

FDM-RES Workbook Stage Two: Identification of Vulnerabilities

This section involves the mapping of key entities within the supply network which support production of the listed product in order to identify the unique vulnerabilities facing your organisation.

FDM-RES Workbook Step 2A

Tasks 2A1, 2A2 and 2A3

Please answer the following questions concerning the supply network supporting production of the aforementioned product.

1. Primary Entities involved (direct value chain partners). Please mark entities for which there are no alternatives with an*.

   a. Bread Supplier = buyer/seller

   b. Bacon Suppliers = buyer/seller

   c. Chicken Suppliers = buyer/seller

   d. Lettuce Suppliers = buyer/seller

   e. Packaging Suppliers = buyer/seller

   f. Retailer = long term partnership

2. Secondary Entities (third party dependencies such as logistics, shipping, storage, utilities etc.). Please mark entities who for which there are no alternatives with an*.

   a. Transport inbound/outbound = long term partnership

   b. utility suppliers = buyer/seller

   c. third party labour supplier = buyer/seller

3. Please indicate next to the above answers what type of relationship exists with that entity (i.e. buyer-seller, collaborative, competitive)

4. What are the main raw material inputs? For each, what, roughly is the:

a. Lead time (from order to arrival at manufacturing line)

Chicken- 10 weeks, Bacon-2-3 days, Lettuce 1-2 days, Bread-~ 1day

b. Supplier ability to increase/decrease supply (i.e. low, medium or high)

Chicken- yes, but by culling early. Bacon-some ability due to higher shelf life but limited. Lettuce- some but limited due to growing time. Bread- high due to short production time

c. Opportunities to source elsewhere (i.e. number of alternatives)

Bacon and chicken hard due to sourcing criteria. Bread hard due to characteristics. Lettuce a little easier but depends on season

d. Water/energy requirements and backup availability (i.e. low or high)

Energy and Water are important. They do have back-up generators and water reservoirs but it is questionable how long these would last in regional/national scale disruptions.

5. For each inbound and outbound material, what are the:

Chicken

a. Transport type/volume/frequency/time- ship freight from Thailand in pallets of up to 1500kg each. Delivery take approximately 12 weeks and is staggered to arrive twice weekly at the supplier deport near Southampton from where it is collected by FM2 daily in their own chilled artic lorries which on average collect 14 -15 pallets daily

b. Transport route/alternatives

Ship can be substituted for air freight at vastly higher cost. Road can only be substituted for other road links.

Bacon

a. Transport type/volume/frequency/time- ship freight from Ireland takes 2-3 days. Arrives daily, also in pallets of 1500kg at supplier depot in Manchester. FDM1 collects approx. 10 pallets daily which is delivered by chilled articulated lorry (owned by FDM2) to the factory

b. Transport route/alternatives

Ship can be substituted for air freight at vastly higher cost. Road can only be substituted for other road links.

Lettuce

By road daily direct to FDM2 Factory. Takes approximately 2-3 hours in ambient 7.5 tonne lorries which carry on average 10 pallets

b. Transport route/alternatives = only road

Bread

By road two-three times daily direct to FDM2 Factory. Takes approximately 2-3 hours in ambient articulated lorries which carry on average 20 pallet

b. Transport route/alternatives = only road

6. For each finished product leaving the factory what are the:

Chicken Bacon Sandwich:

a. Transport type/volume/frequency/time: articulated chilled lorry, hourly dispatch, 2-3 hours to retailer depot in batches of 2,500 sandwiches in pallet form.

b. Transport route/alternatives = only road

Packaging

a. Transport type/volume/frequency/time: articulated lorry, weekly dispatch, 2-3 hours to FDM2 Factory at approximately 15 pallets.

b. Transport route/alternatives = only road

7. For each of the following supply chain stages, what is the type, route and frequency of information exchange? (I.e. is it by phone or electronic, is it hourly or weekly)

a. Suppliers: daily electronic/phone

b. Internal: daily electronic/phone

c. Customers: daily electronic/phone

8. Considering all of the supply chain state variables above, which do you think are the biggest risk areas?

Road Network is a critical node. The manufacturer is heavily reliant on it and with the short shelf life of produce, traffic delays mean that produce with a 5-day shelf life that must have a 3-5 day shelf life might be rejected by the retailer depot regardless of whether chilled chain was maintained. This also means that things such as the climate levy change and urban emissions restrictions are a constant risk source, particularly as much of the fleet is diesel. Another major critical node is the third-party labour suppliers who supply the workforce. FM1 is incredibly labour dependent- a highly motivated production line is one of their most valuable assets-and so anything that jeopardises the relationship such as Brexit is a real concern.

FDM-RES Workbook Steps 2B and 2C

Please rank the following vulnerabilities using the following scale:

5= Priority vulnerabilities, **4**= Secondary vulnerabilities, **3**= Vulnerabilities which are not important at present but projected to grow in importance in future, **2**= Vulnerabilities to which your organisation faces very limited exposure, **1**= Vulnerabilities which are irrelevant to your organisation.

For each, please rank the likelihood of it leading to one of the failure modes listed below using the following scale:

5= Certainty that this vulnerability will result in this failure mode, **4**= Reasonable certainty that this vulnerability will result in this failure mode, **3**= Some certainty that this vulnerability will result in this failure mode, **2**= Unlikely that this vulnerability will result in this failure mode, **1**= This vulnerability is not linked to this failure mode.

Failure Mode	***Description/Characteristics***
FM1. Raw Material Shortage	All manner of upstream disruptions which limit raw material availability from the focal FDMs perspective.
FM2. Raw Material Sub-Standard Quality	All manner of upstream disruptions, which, whilst not necessarily halting raw material supply to the FDM, significantly affect the quality of raw materials received (e.g. size and credence factors)
FM3. Unable to produce/ Scrap/Rework	Occurs when a product is unable to move beyond the FDM production line, whether because production could not be attempted in the first place, because the final product needed to be reworked, or because the finished product was unfit for any other use thus requiring scrappage.
FM4.Labour Shortage	Refers to any factor(s) which limit labour availability at FDM sites
FM5: Loss of process economic viability	Factors leading to a particular process becoming commercially untenable for the FDM. Examples include raw materials simply not being profitable, wider market saturation or evolving consumer trends.
FM6: Loss of Site	Refers to any number of disruptions which either prevent or severely hinder operations at a particular plant.
FM7: Unable to Deliver	Goods are finished to specification but are prevented from being sold by various internal or downstream disruptions that prevent packing, loading or delivery.
FM8: Legally enforced cessation of specific operations	Situations which could result in a regulatory body forcing the FDM to cease operations in response to major legislative violations, for example, environmental breaches, significant health and safety concerns, or major incidents of food contamination.
FM9. Sub-Standard Product Quality and Possible Reject	Any disruptions which, whilst not forcing a scrap/rework, do impact on the final quality and may result in concessionary rates or penalties being applied by the customer.
FM10: Product Recall	This failure mode refers to any disruption(s) which result in food either being rejected at the retailer depot, or food which has made it onto retailer shelves or consumers' homes, being recalled.

Extra-Supply Chain Vulnerabilities								
Step1.Categorising food manufacturer vulnerabilities				Step 2. How likely is it that this vulnerability will result in the associated failure mode?				
Vulnerability class	Vulnerability	Exposure (1 -5)	What failure modes are associated with this vulnerability?	Never 1	2	3	4	Certain 5
Financial (Fin)	1. Market price fluctuation.	5	FM 5			FM5		
	2. Currency exchange fluctuations.	5	FM5		FM5			
	3. Interest rate fluctuations.	5	FM5		FM5			
	4. Regional economic downturns.	5	FM5		FM5			
	5. Hostile takeover attempts.	3	FM5		FM5			
	6. Product liability.	3	FM 3,7,8,9,10					FM 3,7,8, 9,10
Market (Mar)	1. Market decline.	4	FM5			FM5		
	2. Competitive Innovation.	5	FM5			FM5		
	3. Competitor undercutting.	5	FM5				FM5	
	4. Seasonal variability in availability of raw materials (growing seasons, profitability of crop).	5	FM 1,2		FM1		FM2	
	5. Variability in demand (seasonal, promotional and bullwhip) .	5	FM 1,2		FM1		FM2	
Governance (Gov)	1. Changes in Public Food Policy (e.g. production efficiency targets, health and nutrition.	5	FM 3,5		FM 3,5			
	2. Private Food Policy (e.g. strict customer requirements on appearance, colour, shape and delivery time)*.	5	FM 3,5,9, 10		FM 3,5, 10	FM 9		
	3. Political instability (regime changes, corruption).	3	(limited exposure due to supply routes) FM 1 and 2			FM 1 and 2		
	4. Import/export	5	FM 1,2 and 5					FM 1,

	restrictions.							2 and 5
Infrastructure (Inf)	1. Disruption to transport infrastructure (ports, roads, railways, airports).	5	FM 1, 3and 7, 10. The manufacturer is UK based apart from Belfast and so transport infrastructure considers mostly motorways and ferries. As inbound is 3PL and less frequent than outbound, risk is less.		FM 10	FM 1	FM 3, 7	
	2. Disruption to water infrastructure.	5	FM 3 and 7. There are water tanks on site and it would be possible to arrange for water tankers at short notice. Vital for washing food and cleaning production lines.				FM 3 and 7	
	3. Disruption to energy infrastructure (oil supply/price, electricity grid, gas supply).	5	FM 1, 3 and 7. Lots of contingency plans such as generators and spare diesel on site mean that it would have to be a significant impact on a national scale to really pose a threat.		FM 1, 3 and 7			
	4. Disruption to communications infrastructure (cables, radio masts, satellites).	5	FM 1 ,3, 4 and 7. Relatively low exposures as there are numerous contingency options ranging from multiple phone internet routes in to using mobile phones and even paper scheduling. The later would avoid collapse but would seriously slow operations. As order and delivery scheduling is arranged in advance, the biggest risk would be staff scheduling for the next day but even this is low.		FM 1, 3 and 7	FM 4		
Societal (Soc)	1. Piracy/Terrorism.	3	FM 1,5		FM 1,5			
	2. War and conflict.	3	FM 1,5		FM 1,5			
	3. Workforce health (e.g. flu pandemic).	3	FM 3, 4 and 9		FM 9	FM 4	FM 3	
	4. Proportion of Consumer income available for food purchase.	5	FM 5. Whilst this could lead to FM5, there would be an extensive range of			FM 5		

			investigating whether it was a localised retailer shelving fault of wider supply chain issue before deciding to delist a process.					
	5. Changing customer attitudes to consumption (e.g. health, lifestyle and fashion foods).	5	FM 5. This is usually something that can be predicted far enough in advance so that product lines can evolve gradually rather than abruptly being delisted.		FM 5			
	6. Criminal acts (such as fraud data hacking and sabotage).	3	FM 1,3, 5, 6, 7, 10. Unlikely and there are safeguards in place such as security on what can be bought onto production lines by staff, metal detectors and firewalls. However, if something did happen the outcome would almost certainly be a major failure mode.			FM 5	FM 6	FM 1, 3, 7 and 10
	7. Industrial actions (such as strikes).	2	FM 1 and 2. Low as non-unionised. It would have to be strikes upstream but then the manufacturer would temporarily lay on alternative transport routes/suppliers.		FM 1	FM 2		
	8. Poor relations with consumers and special interest groups (e.g. customer communication, brand image, consumer confidence).	5	FM 5, 10. Exposure is very high and failure rate of products is also high. As new products are often agreed with the retailer, then this is not an FM5 in a true sense but even so it is still costly and to mitigate the manufacturer often puts on consumer trials.		FM 10		FM 5	
Environmental (Env)	1. Natural disasters (both Geological and Meteorological such as earthquakes, drought etc.).	5	FM 1,2.				FM 1 and 2	
	2. Biological factors (e.g. livestock disease, pests).	5	FM 1, 2, 3 and 10.			FM 3 and 10	FM 1,2	
	3. Anthropogenic	3	FM 1, 3 and 10		FM 3	1		

	environmental hazards (such as air pollution, land contamination).		(depending on when exposed).		and 10			
	4. Unsustainable Primary Production (Land use, loss of biodiversity, climate change).	4	FM 1 2and 5. This is a growing exposure as increasingly retailer "global concern" species such as tuna/prawns and crayfish are having sourcing regulations placed on them. Therefore, to meet these criteria the supplier pool is smaller and there may be issues concerning quality and waste levels.				FM 1 2and 5	

The next step explores vulnerabilities faced within your organisation's supply chain but outside of your organisation.

Value Chain Vulnerabilities								
Step1.Categorising food manufacturer vulnerabilities				Step 2. How likely is it that this vulnerability will result in the associated failure mode?				
Vulnerability class	Vulnerability	Exposure of your organisation to this vulnerability (1 Never- 5 Very Likely)	What failure modes are associated with this vulnerability?	Never 1	2	3	4	Very Likely 5
Raw Material and Production (VCRMP)	1. Inconsistent Raw material quality and heterogeneity.	3	FM 1, 2, 3 and 9. Low as many of the ingredients used are processed and so external ascetics are of limited importance, however, in some cases, things like bigger tomatoes can lead to poor sandwich fit and possible soggy bread.		FM 1, 3	FM 2, 9		
	2. Raw material and product related hazards (shelf life, cross contamination, handling requirements).	3	FM1, 3 and 10.				FM1, 3 and 10	
Logistic Control (VCLC)	1. Reliability of external logistics	3	FM 1 and 2. Generally low and			FM 1 and 2		

	providers.		underperforming 3PLs can relatively easily be changed.					
	2. High levels of geographically distant, outsourcing for which there is no alternative.	3	FM 1 and 2.			FM 1 and 2		
	3. Strict customer requirements (in terms of lead times and quality).	5	FM 3 and 9.			FM 3	FM 9	
Information System (VCIS)	1. Lack of established, secure and integrated. information sharing infrastructure.	5	FM 1,2,3,4,9,7. Exposure is high and this does occur about 2-4 times a year. However, unless it is a severe regional issue, the worst cases scenario would be paper scheduling which would be slow but likely not lead to failure modes.				FM 1,2,3 and 9	FM 4,7
	2. Deliberate withholding of information.	3	FM 1,2,3,7, 9, 10. Low exposure as supply chain is generally very collaborative. However, when a supplier is struggling they may change supplier without passing on this information or fall behind on infrastructure investment leading to quality issues.		FM 3, 7 and 10	FM 9	FM 1,2	
	3. Lack of ability to trace food across the value chain.	5	FM 1, 4 9 and 10. High exposure due to short shelf life but this is an ingrained procedure and is mothing the manufacturer is good at, having highly streamlined recruitment and audit processes.		FM 1, 4, 9 and 10			
Organisational Management Structure (VCOMS)	1. Low level of training & experience in other company's employees.	2	FM 1,2,3,7,9,10. Generally low but catastrophic events can happen such as new staff misusing bread machine resulting in metal contamination.		FM 3,7, 9 and 10	FM 1,2		
	2. Poor financial situation of value chain partners (exposure to	4	FM 1,2,3,5,7,9 and 10. This is generally something that would be picked up in initial				FM 1,2,3, 5,7, 9 and	

	bankruptcy or takeover).		supplier selection audits.				10	
	3. High concentration in supply chains (i.e. actors serving as both suppliers and competitors in different contexts).	3	FM 1 and 5. However, identified as a growing risk. Last 5-6 years have seen retailers driving collaboration in the supply chain, therefore seeing competitors becoming suppliers (i.e. good for retailer product consistency) which is good for efficiency but potentially also monopolisation too.			FM 1 and 5		
	4. High levels of power imbalance between actors (contractual fairness and level of lock in)*.	4	FM 5.				FM 5	

The final step explores vulnerabilities stemming from within your organisation itself.

Organisation Specific Vulnerabilities								
Step1.Categorising food manufacturer vulnerabilities				Step 2. How likely is it that this vulnerability will result in the associated failure mode?				
Vulnerability class	Vulnerability	Exposure of your organisation to this vulnerability (1 Never-5 Very Likely)	What failure modes are associated with this vulnerability?	Never 1	2	3	4	Very Likely 5
Raw Material and Production (OSRMP)	1. Challenges related to storing raw materials/finished inventory (for example, storage requirements and ability to maintain ambient conditions).	5	FM 1,2,3,10.. Not a problem for ambient but chilled and particularly frozen are major considerations, particularly at Christmas as site inventory is at a premium. It is possible to fix via hiring out freezer capacity, but this must be done at least 6 months in advance to secure optimum site.				FM 1,2,3, 10	
	2. Product failure to comply with environmental legislation.	2	FM 8.				FM 8	
	3. Product failure to	2	FM 8.				FM 8	

	comply with Health and Safety Legislation.							
	4. Insufficient capacity to meet changing order requirements.	5	FM3, 4,7 and 9. Site physical spare capacity low but sister site allows the opportunity to flex thus mitigating this risk. The main threat is labour which if it could not be sourced, would slow the line leading to potentially.			FM 3, 4,7 and 9		
	5. Inability to react to changing circumstances (ability to quickly substitute raw materials or ramp up production/ decrease lead time).	5	FM 1, 2,4 and 9. High exposure due to short shelf life but this is an ingrained procedure and is mothing the manufacturer is good at, having highly streamlined recruitment and audit processes.				FM 1,2 4 and 9	
Logistics Control (VCLC)	1. Inaccurate forecasting (e.g. subjective decision making).	5	FM 1,2,3,4 and 9. There are lots of processes that provide forecasts, in house and from retailers and updated regularly with increasing accuracy. However, they do break down sometimes. Too high a forecast can lead to.				FM 1,2,3, 4 and 9	
	2. Lack of flexibility in internal distribution capacity.	2	FM 1,2,3,7. Minimal as manufacturer have their own logistics arm to call upon.		FM 1,2,3, 7			
Information System (OSIS)	1. Breech in information/data security (espionage, cyberattack, hardware failure).	5	FM 1,3. Information security is high, consisting of cloud back-ups, email warnings and regular tests.				FM 1,3	
	2. Breakdowns in internal information sharing.	2	FM 1,2,3,4,7 and 9.			FM 1,2,3, 4,7 and 9		
	3. Poorly developed early warning detection systems.	2	FM 1,2,3,4,5,6,7,8,9, 10.				FM 1,2,3, 4,5,6, 7,8,9, 10	
Organisational Management Structure (VCOMS)	1. Poor protection of intellectual property.	2	FM5.				FM5	
	2. Flawed strategic decision making (e.g. high level of	4	FM 1, 2, 3 and 9.			FM 2, 3 and 9		FM1

	bias, poor interpersonal skills, lack of cohesion between departments and limited risk awareness).							
	3. Absence of, or ineffective Contingency Planning (backup power, contingency plans).	2	Potentially all failure modes.					All
	4. Poor human resource utilisation (suitable staff training, effectiveness of knowledge transfer between staff levels, knowledge retention).	3	FM 9.			FM9		
	5. Restricted Corporate Social Responsibility Programme	2	FM 1, 4				FM 1 and 4	

Section 4: Resilience Practices

Please indicate the types of resilience practices used by your organisation. If they have been used in response to a specific failure mode, then please indicate what this was. Finally, please indicate the effectiveness of the resilience practice in mitigating the failure mode.

In House Management Practices						
Resilience Practice	Metrics	Presence of this resilience practice in your organisation (1 Not present-5 Fully implemenented)	Failure Mode Targeted	Effectiveness of resilience practice (1 Minimal Effect- 5 Complete Control	Impact of Resilience practice on KPIs (please put the relevant KPI code in each column with a 1-5 in brackets next to it (1= minimal effect, 5= major effect)	
					Positive effect	Negative Effect
Flexibility	Ability to switch procurement between suppliers.	5. Contract of at least two suppliers in most cases. However, there are trade-offs between KPIs so that if you switch for cost you might accept lower service level (i.e. delivery frequency or length), and equally true for quality.	FM 1, 2 and 8	5	CE1,7, 8 SLE1, 2, 3, 4 and 5 QE1, 2 and 3 QS2 and 3 QENV1 and 2	CE1,7, 8 CENV 1, 3, 4 and 5 SLE1, 2, 3, 4 and 5 QE 2 and 3 QENV 3
	Existence of product substitutes.	5. Whilst there are very few technical issues that would limit the	FM 1, 2, 3 and 8	5	SLE1, 2, 3, 4 and 5 QE1-3	SLENV1 CE1,7

		substitution of ingredients, because of the way foods are labelled, it is effectively impossible to substitute down, only up e.g. normal to organic or barn to fee range. Would normally delist rather than substituting down (therefore almost always negatively impacting on cost.			QS1-3 QENV1-3	CENV 1, 3, 4 and 5
	Ability of production line to accept substitute ingredients.	5. Technically easy but see above.	FM 1, 2, 3 and 8	5	SLE1, 2, 3, 4 and 5 QE1-3 QS1-3 QENV1-3	SLENV1 CE1,7 CENV 1, 3, 4 and 5
	Possibility of outsourcing process	3. In normal situations, this is something that you would only do if it positively affected all KPIs, however in a disruption situation you might accept some negative impact on KPIs provided it prevented FM8.	FM 8 and 10	5		CE1,CE7,CENV1, 3,4 AND 5
	Ability to switch production sites.	5. (very important and generally expected by retailers as part of BCM process) Would predominantly be used in response to a catastrophic event such as fire. This might also be used if one site is underperforming significantly and you wanted to just leave them with basic processes while focussing more complex activities on better performing sites.	FM 4, 5, 9 and 10	3	SLE2,	CE1, 2, 3, 4 and 8 CENV 3 and 4 SLE1,3, 4 SLENV 1 EE1 and 2 EENV 1 and 2
	Ability to switch staff and equipment between sites.	5. This would include technical staff as well as fillers and equipment that was fairly portable, such as slicers, graters and pumps.	FM 4, 5, 9 and 10	3	SLE1, 2, 4 and 5 EE1 and 2 QE1-3	EE2 SLE1(at original site)
	Availability of easily accessible financial assets.	5. As a large manufacturer this is not a problem.	FM 1,2,4, 7, 8 and 9	5	SLE2	CE8
	Broad staff skillsets, high company	5 This is something the manufacturer is actively investing in due to past	FM 4 and 5	3	SLE1-5 SLS 1-4 SLENV1	CE8

	knowledge retention and the ability of staff to fulfil multiple roles.	unplanned resignations having destabilising effect on whole teams leading to multiple further resignations.			CS4 EE1 and 2 ES1-3 EENV1-2 QE1-3	
	Customer communications and/or product differentiation to aid recovery in the event of a disruption.	5.	FM 1,2, 7, 8 and 9	3	CE6 and 8 SLE3 and 4	CE5
	Manipulation of market share, and product differentiation to take advantage of disruption to others.	5. The company has in the past taken over brands when they have failed or launched new product lines to meet retailer requirements, however, sometimes there is an initial cost in terms of product margins, particularly if it exceeds production line capacity.	NA but would be broader supply chain shortages or competitors going out of business.		CE6, CE8, CS5	CE1-5 and 7
A2 Risk Aware Culture	Infrastructure in place to manage risk such as Business Continuity and Enterprise Risk Management.	5.	ERM: FM 1-9 BCM:FM 10	3	CE8 CS5 CENV2 and 5 SLE1-5 SLS2 and 4 SLENV1 QE1-3 QS4	CE8 minor
	Presence of Information and Physical Security.	5 (for example data is backed up via hard copy sent by taxi and site requires card access, is security fenced and gated and with regular security tests such as staged break ins).	FM 5, 6, 7 and 10	3	QE1 SLE2 SLS2 and 4	CE8
	Efficiency standards such as six sigma.	5.	FM 5	5	SLE1 EE1 and 2 QE1-3	
	Presence of strong and inspiring leadership support for resilience strategies.	5. The manufacturer identified that this was something that was actively encouraged as part of company cultures and cited sharing of resilience related news as an example.	ALL	5	CS1,3 4, 5 AND 6 CENV 1-5 SLE1-5 SLS1-4 SLENV 1 EE1-2 ES1-3 EENV1-2 QS1-3 QENV1-3	
	Active learning from the outcome of past disruptions.	5. The manufacturer highlighted that the ability to learn increase cumulatively with	ALL	5	CE8 CS3 and 4 CENV 1-5 SLE 1-5	

		company size as you have exposure to a wider range of negative events but also more resources to adapt with.			SLS1-4 SLENV1 EE1-2 ES1-3 EENV 1-2 QE2 and 3 QS1-4 QENV 1-3	
A3 Redundancy	Ability to increase production capacity.	5. This could happen in response to higher than predicted orders but this is not a failure mode in tis self. This increase in capacity is achieved through using extra staff on overtime to increase efficiency and decrease set up times thus shorten shift times	FM 2, 3 and 7	5	CE8 SLE1 and 2	CE1-4 EENV1 QS4
	Ability to call upon spare inventory.	5. This varies depending on the ingredient. The manufacturer does not hold much stock but suppliers often hold stock in 2rd party cold stores which can be pulled forward. For example, there are 24 hours of bread, about a weeks' worth of chicken (as it has to be shipped from Thailand) and 2-3 days lettuce. Beyond this, the manufacturer can ask to pull from primary producers but this means harvesting early thus securing smaller yields.	FM 2, 3, 5 and 7	5	SLE1 and 2	CE3 and 4 CENV1 SLENV1 EE1 EENV1 QE3 QS4
A4 Early Warning Systems	Foresight to extend preparation time.	4. This can be achieved to a high level by communication with suppliers, industry bodies such as the CFA, Quarterly horizon scanning.	ALL	3	SLE1-5 CE1-2 CS4 CENV1-5 SLS4 QE1	CE8 (minor)
	Relations between teams and impact on communication and the flow of information.	5. This is important and established by a clear system of leadership with instructions as to who communicates with who.	ALL	4	CE1-4 CS4 CENV1,2, 3 and 5 SLE1-5 SLS1-4 SLENV1 EE1-2 ES1-3 EENV1-2 QE1-3 QENV1-3	None
A5 Agility	Ability to reduce	5. The approach here is	FM 6	4	SLE1-4	CE8

	production times.	similar to that for capacity in that it involves increasing staff numbers but it would involve doing so for shorter periods.				
	Ability to reduce set up times.	5.	FM 6	4	SLE1-4	CE8
	Ability to reduce shift change over times.	5.	FM 6	4	SLE1-4	CE8
	Poor company attitude to adapting and joint decision making.	3. This is only really a problem when the manufacturer acquires new companies and is integrating them.	FM 3 and 5	5	N/A	CE8 CENV2-5 SLE1-5 SLS 2 and 4 SLENV1 EE1 and 2 EENV1-2 QE1-3 QS4 QENV2 and 3

The next step explores management practices employed by your organisation to help manage your broader supply chain in order to meet your KPIs on a day to day basis.

Supply Chain Management Practices						
Resilience Practice	Metrics	Notes Presence of this resilience practice in your organisation (1 Not present-5 Fully implemenented)	Failure Mode Targeted	Effectiveness of resilience practice (1 Minimal Effect- 5 Complete Control	Impact of Resilience practice on KPIs (please put the relevant KPI code in each column with a 1-5 in brackets next to it (1= minimal effect, 5= major effect)	
					Positive effect	Negative Effect
B1 Collaboration	Integration of systems with suppliers/clients.	5. Full integration of retail order systems with supplier specifications and manufacturer production scheduling software. Also, a linked complaints analysis software from retailer to supplier.	FM 1,2 and 5	5	SLE1-5 SLENV1	N/A
	Coordination of activities, including product design, with suppliers/clients.	5.Products are inherently designed with the retailer and often pull in the supplier too so that all parties are sure of the others needs and capabilities relating to	FM 1,2 and 5	5	CE1-8 CS15 CENV1-5 SLE1-5 SLENV1 QE1-3 QS1-3 QENV1-3	N/A

		volumes and specs.				
	Sharing of risk with supply chain suppliers/clients.	3. There is underwriting but not really sharing with supply chain partners. However, this is mitigated somewhat by the security of contractual supply rather than the spot market.	FM 1 and 10	5	CE8	CE7
	The ability to coordinate responses to disruptions and adapt alongside partners.	5. In the event of a serious supply chain wide disruption a cross partner crisis team would be set up as everyone wants a mutually acceptable fix ASAP.	FM 1, 2, 4, 5 and 10	5	SLE1-5 QE1-3	N/A
	Active encouragement of trust with supply chain partners and avoidance of asymmetric supply chain relationships.	5. For larger food manufacturers, the situation with retailers has become much more collaborative in recent years and this extends to suppliers too. However, larger manufacturers tend to avoid smaller suppliers who might not have the financial reserves to pay for the worked value of a shipment if problems are found. If it can't be avoided, they try to ensure small suppliers are only small volume low value products.	FM 8	4	SLE1-5 QE1-3	CE1-2
	Development of strategic partnerships with supply chain partners.	5. Strategic relationships were identified as a long-term trend in FSCs as they offered much more stability over spot market relationships with much more potential for social and environmental KPIs too.	FM 1,2, 5 and 8	5	CE1 and 7 CS1 and 2 CENV1-5 SLE1-5 SLENV1 QE1-3 QS1-3 EMV1-3	N/A
	Standardisation of materials and processes with supply chain partners.	3. There are shared standards for a number of key products such as IR bacon and pasteurised milk.	FM 2,5	4	QE1	
B2 Flexibility (presence of alternative	Existence of alternative supply chain carriers.	5. There are a significant range of 3pl providers who could be	FM 1	5	SLE1-3	CE8

supply chain options)		called upon at short notice.				
	Ability to postpone contracts.	3. There is some ability to ask suppliers to store (albeit at slight cost) if under using. There is also some potential to rewrite if oversupplying provided the supplier could find another buyer.	FM 1, 2 and 8	3	CE1-3	N/A
	Presence of alternative suppliers/clients.	5. There are always two suppliers as a contingency.	FM 1,2 and 8	5	SLE1-2	CE1-4 CENV1 QE3
	Selection of suppliers/clients based on flexibility of capacity.	5. This is inbuilt into the auditing process when new suppliers are selected.	FM 1	3	SLE1-4	CE1-2
B3 Velocity (the ability to react rapidly)	Ability to increase frequency of deliveries.	5. This was identified as being of crucial importance. It is written into supplier contracts that they must be able to replace rejected orders rapidly and if manufacturer related, they their own logistics arm can be called upon at little extra cost.	FM 1, 6	5	SLE1-4	Negligible
	Geographic proximity to customers.	3. Not really an issue on a UK scale as the furthest they could be away is a few hours.	FM 3 and 6	3	SLE1-4 but minimal	
	Geographic proximity to suppliers.	5. Identified as being crucial- suppliers in UK are preferred. International suppliers tend to be used for high volume low complexity products where there is plenty in the system used by other manufacturers and thus unlikely to be delisted rapidly.	FM 1	4	SLE1-5	CE1-2
	Presence of risk management strategies throughout operations of all supply chain partners.	5. This is something that is actively sought in initial contract audit. Absence is strongly linked to catastrophic failures such as Findus crispy pancakes.	FM 1,2	5	CENV1 SLE1-5 QE1 and 2 QS1 QENV1	N/A
B4 Visibility (ability to see things from one end of the	Shared forecasting with suppliers/clients.	5.	FM 1,2,5	5	CE1-4 SLE1-3 QE2	CE1-4 SLENV1 EENV1-2
	Creation of	5.	FM 1,2,3,4,	5	CE1-4	N/A

supply chain to the other)	integrated and efficient communication and information systems with supply chain partners.		5 and 6		SLE1-3 QE2	
	Creation of material traceability systems.	5. This is something that has progressed significantly since the horse meat scandal. All meats can now be traced back to farm within 4 hours using standardised reports generated at the point of slaughter/cutting.	FM 2, 5, 7 and 9	5	SLE4-5 QE1	N/A
B5 Redundancy	System wide design of emergency back up and storage facilities.	2. 3pl chilled storage available within 24 hours	FM 3	4	SLE1-2 QE1	CE8
	Existence of alternative pathways between you and your suppliers/clients.	2. Major problem as being UK based, this involved motorways of which there are very limited alternatives. However, there are slightly more options if considering international freight	FM 1, 6	2	SLE1-2 QE1-2	CE2

Appendix 3: Journal Paper

Resilience in Agri-Food Supply Chains: A Critical Analysis of the Literature and Synthesis of a Novel Framework

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Resilience in agri-food supply chains: a critical analysis of the literature and synthesis of a novel framework

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Abstract

Purpose – Resilience in agri-food supply chains (AFSCs) is an area of significant importance due to growing supply chain volatility. While the majority of research exploring supply chain resilience has originated from a supply chain management perspective, many other disciplines (such as environmental systems science and the social sciences) have also explored the topic. As complex social, economic and environmental constructs, the priority of resilience in AFSCs goes far beyond the company specific focus of supply chain management works and would conceivably benefit from including more diverse academic disciplines. However, this is hindered by inconsistencies in terminology and the conceptual components of resilience across different disciplines. The purpose of this study is to use a systematic literature review to identify which multidisciplinary aspects of resilience are applicable to AFSCs and to generate a novel AFSC resilience framework.

Design/methodology/approach – This paper uses a structured and multidisciplinary review of 137 articles in the resilience literature followed by critical analysis and synthesis of findings to generate new knowledge in the form of a novel AFSC resilience framework.

Findings – Findings indicate that the complexity of AFSCs and subsequent exposure to almost constant external interference means that disruptions cannot be seen as a one-off event; thus, resilience must concern the ability to not only maintain core function but also adapt to changing conditions.

Practical implications – A number of resilience elements can be used to enhance resilience, but their selection and implementation must be carefully matched to relevant phases of disruption and assessed on their broader supply chain impacts. In particular, the focus must be on overall impact on the ability of the supply chain as a whole to provide food security rather than to boost individual company performance.

Originality/value – The research novelty lies in the utilisation of wider understandings of resilience from various research fields to propose a rigorous and food-specific resilience framework with end consumer food security as its main focus.

Keywords: Sustainability, Resilience, Food industry, Systematic literature review, Food security, Supply chain disruptions

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1. Introduction

It is increasingly accepted that supply chains in all forms face increasing volatility across a range of business parameters from energy cost, to raw material availability and currency exchange rates (Norrman and Jansson, 2004; Neiger et al., 2009; Christopher and Holweg 2011; Vlajic et al., 2013). Agri-food supply chains (AFSCs), which include all steps involved in production, manufacturing and distribution of food until its final consumption, not only share these general risks but also face their own unique vulnerabilities due to the limited shelf life of food, and variability in quality and availability of raw materials as organic products (Dani and Deep, 2010). There is evidence that these vulnerabilities may become more pronounced in future. For example, the quality and quantity of raw ingredients in many parts of the world will likely be challenged by an increased incidence of extreme weather linked to climate change (Karl, 2009; ESRC Public Policy Seminar, 2012; Allison et al., 2009). Moving beyond the projected impacts of climate change, the global population is expected to increase to over 9 billion by 2050, with much of the growth in current population projected to be in urban areas (Kastner et al., 2012). As many parts of the globe become wealthier, they are increasingly witnessing a dietary transition towards greater amounts of meat, dairy and more heavily processed foods (Suweis et al., 2015).

This is often associated with negative impacts on dietary health and, with increasing pressure on environmental resources, is required to produce these types of food (Popkin, 1999; Godfray et al., 2010). Herein lies a major challenge referred to as a "perfect storm" by many (Benton et al., 2012; Ingram et al., 2013). Not only are we likely to require more food to feed the world's growing population but also our ability to produce and deliver this food without disruption is likely to be constrained. It is widely projected that extreme weather volatility, energy price fluctuations and logistics restrictions, particularly in urban areas, will result in increased risk of disruption (Morgan, 2016; McMichael et al., 2007). In the past, food systems designed for economic efficiency, now must be re-evaluated for resilience.

The current issue and full text archive of this journal is available on Emerald Insight at: www.emeraldinsight.com/1359-8546.htm

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This is broadly understood to refer to the ability of an entity or system to react to disruptions (both foreseeable and unforeseeable) in such a way that core function is maintained (Barroso et al., 2011). However, the contexts in which resilience is currently being explored are diverse, ranging from engineering (Pimm, 1984) and ecological systems science (Holling, 1973) to psychology (Luthar et al., 2000), supply chain resilience (SCRES) (Christopher and Peck, 2004) and community resilience (King, 2008). This has resulted in a fragmented and sometimes inconsistent research field. For example, depending on the research context, the "definition" and thus overall goal of resilience can vary widely. Furthermore, there is often inconsistency in the physical "Elements"; for example, spare inventory or alternate suppliers, which are suggested to help make an entity resilient. In turn, the "Strategies" (i.e. how an entity decides which "element" to use in a given situation) used by entities are often highly variable. The terms "Definition", "Elements" and "Strategies" have been carefully worded so as to be consistent with terms identified as key principles of resilience in the literature (Christopher and Lee, 2004; Hohenstein et al., 2015; Pereira et al., 2014; Kamalahmadi and Parast, 2016).

This fragmentation has not gone unnoticed, particularly in the supply chain management (SCM) field. Ponomarov and Holcomb (2009), in their extensive review, consider a number of the different definitions and propose a synthesised, comprehensive definition of SCRES. Hohenstein et al. (2015) develop this and systematically identify commonly cited "elements" and the phases of disruption in which they are useful. Building on this, Kamalahmadi and Parast (2016) developed the concept of resilience elements by considering strategies by which an organisation could implement such resilience elements.

Where many of the aforementioned works have tended to focus on organisational competitive advantage (even if it is in the context of a wider supply chain) in the face of adversity, the focus of attempts to enhance resilience in AFSCs should concern the unbroken flow of safe and appropriate food to end consumers in the face of disruption (Tendall et al., 2015). This means that any resilience definitions, elements and strategies will likely need to be adapted to suit an AFSC context. One possible way of achieving this would be to expand SCM understandings of resilience to consider other research perspectives on resilience such as community resilience and ecological systems resilience; both of these areas not only play a key role in supporting AFSCs but also are likely to suffer if AFSCs fail (Falkowski, 2017). This is particularly relevant for resilience "elements" because SCM works have tended to focus on the most commonly cited ones, particularly flexibility and redundancy (Hohenstein et al., 2015). Yet there are many less commonly explored "elements" of resilience, particularly from non-SCM perspectives, such as "adaptive management" and "community resources", that would feasibly be useful in designing an AFSC-specific understanding of resilience (Smith et al., 2016; Sinclair et al., 2014; Milestad and Darnhofer, 2003).

This work therefore seeks to address these gaps through the following core review question:

Q1. How can the multidisciplinary concept of resilience be applied to AFSCs?

To answer this question, a holistic approach is taken to review the literature for definitions, elements and strategies that are important for resilience in AFSCs (including understandings from SCM, operations management, ecological systems and social systems). The findings are then synthesised into a food security-orientated framework for implementing resilience in developed world AFSCs.

As such, the paper is structured as follows. First, the methodology which describes the systematic literature review (SLR) process in detail is presented. The paper then proceeds to descriptively analyse the resilience literature to identify broad trends in the approaches of different research fields to resilience before focussing in detail on the fit of the literature to the identified review question and its associated sub-questions. Next, the results of the SLR are applied to

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contemporary AFSC structures to generate a holistic framework that defines and considers AFSC-specific resilience elements and strategies. Finally, the implications of the review findings in terms of both supply chain theory and practice are considered before concluding remarks, and recommendations for future research are presented.

2. *Methodology*

The requirements for selecting the methodology were that it must enable the identification, analysis and synthesis of secondary data from a broad range of disciplines into a holistic understanding based on fit to a specific review question. For this reason, the SLR process was chosen. The SLR approach differs from more general literature reviews in terms of comprehensiveness (ensuring that all relevant material is included), specificity (identification of salient points through fit to carefully selected review questions) and transparency/replicability (adding reliability to findings) (Tranfield et al., 2003). Crucially, the SLR approach also enables synthesis of ideas which not only aids wider scholarly dissemination of key concepts and advances the research field but also effectively creates new knowledge, thus being of equal value to new research (Rousseau et al., 2008; Light and Pillemer, 1986). With this in mind, the review methodology used in this paper followed the method of Denyer and Tranfield (2009) and consisted of five distinct steps which are outlined in Figure 1 and which are now described in detail.

2.1 Step1: Review Question Formulation

The first step in an SLR is the formulation of a specific, purposeful, review question to determine the scope and focus of the review. The aim of this review is to comprehensively identify definitions, elements and strategies for resilience and to develop a holistic framework for how they apply to AFSCs. Hence, this review aims to address Q1. To help structure the answer to this question, three sub questions have been identified as follows:

Q1.1. What definitions of resilience are appropriate for describing AFSCs?

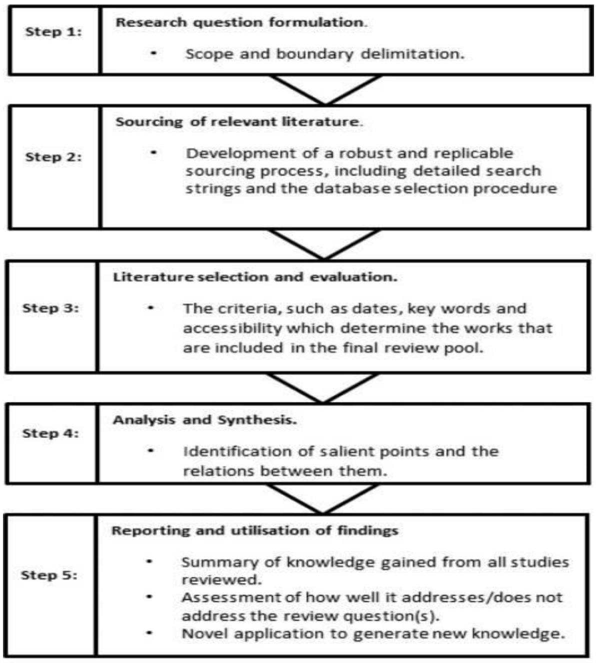
Q1.2. What resilience elements and strategies can be applied to AFSC resilience?

Q1.3. How can appropriate definitions, elements and strategies be conceptually linked to provide a food security focussed framework of AFSC resilience?

2.2 Step 2: Locating Relevant Literature

The purpose of this phase is to design search criteria in such a way as to ensure the identified literature is comprehensive enough to capture all salient points relevant to the review question (Denyer and Tranfield, 2009). One of the key research gaps driving this review was the need to cover a variety of fields relevant to AFSCs, not simply SCM, and therefore avoiding bias in selection was vital. Therefore, the following multi-database, cross-disciplinary online citation services were used: Google Scholar, Web of Science, ProQuest, Science Direct, Wiley Online, Emerald and Scopus.

Figure 1: Systematic review methodology



Source: Adapted from Denyer and Tranfield (2009)

Consistent with a number of other SLRs in the area of resilience, this paper used a number of defined keywords as search criteria as summarised in Table I. The search was performed in December 2016, and the search for keywords was restricted to title and abstract. Keywords were initially selected based on the authors' collective knowledge of the field which enabled them to draw up a long list of terms commonly associated with resilience in the literature. Following standard SLR practice (Hohenstein et al., 2015; Kamalahmadi and Parast, 2016), these were critiqued and validated through consultation with other research colleagues allowing us to arrive at the shortlist presented in Table I.

Search strings were composed of primary keywords and secondary keywords. The primary search phrase used in all databases was either "Community", "Socio-Ecological System" or "Supply Chain". Each primary search phrase was accompanied by AND "resilience/resiliency". In addition, each search involved a secondary keyword which was one of either: "Risk/Risk Management", "OR Vulnerability", "OR Volatility", "OR Security", "OR Mitigation" or "OR Business Continuity". These variations were run exhaustively, e.g. "Community" AND "Resilience" AND "Security".

2.3 Step 3: Literature Selection and Evaluation

From the initial search criteria, this review sourced a total of 1,270 articles. To maintain transparency and to ensure fit of identified material to the review question, stringent selection criteria were applied to this initial search pool. While material was not limited by publication date, materials were restricted to those published in the English language. Additionally, in line with other SLRs in the area of resilience (Hohenstein et al., 2015; Kamalahmadi and Parast, 2016), material was limited to peer reviewed publications as an indicator of the academic rigour of identified literature (Light and Pillemer, 1986).

Once duplicates, non-peer reviewed results and non-English publications were excluded, and the remaining pool numbered 239 articles. Scanning of Introductions and Conclusions provided a better understanding of the fit of the material to the review question and its associated sub-questions. At this stage, 104 articles were excluded due to either being inaccessible (six articles), or being beyond the scope of AFSC-relevant resilience definitions, elements and strategies. Work cited in all accepted articles was also scanned for titles that matched the keyword criteria. In total, this provided a final review size of 137 articles (Figure 2).

2.4 Step 4: Analysis and Synthesis

The objective of this stage was to analyse and synthesise the final literature pool of 137 articles to identify new knowledge about the multi-disciplinary concept of food SCRES that would not have been apparent from reading each of the papers individually.

Table I: Literature sourcing key words

Primary phrases	Secondary phrases	Database search strings
Supply chain AND resilience/resiliency Community AND resilience/resiliency Socio-ecological AND resilience/resiliency	Risk/risk management OR Vulnerability OR Volatility OR Security OR Mitigation OR Business continuity	Primary and secondary keywords were applied in databases as follows. Searching within abstract and title: Key word: ONE of either Supply chain/community/socio-ecological system AND: Resilience/resiliency AND: Risk/risk management OR vulnerability OR volatility OR security OR mitigation OR business continuity

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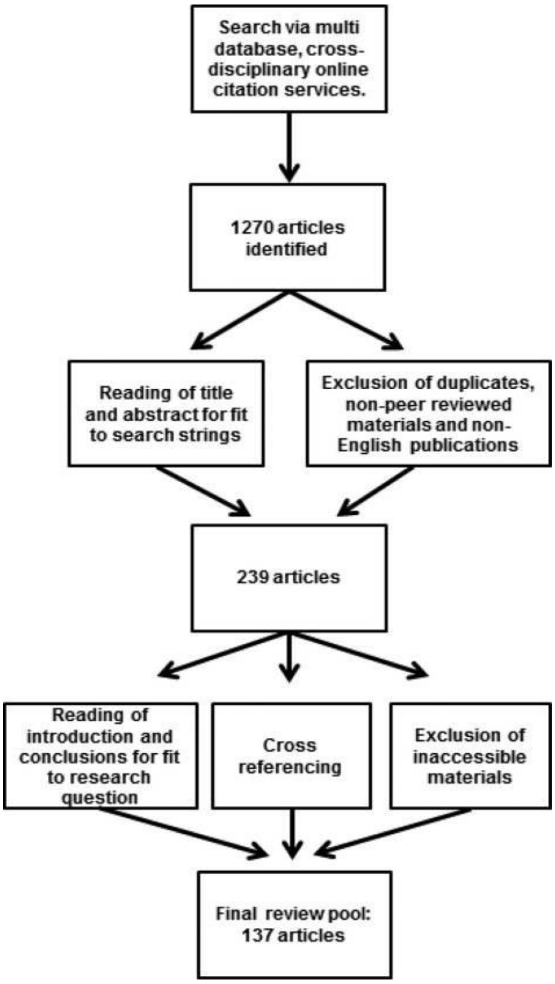
Figure 2: Review process for literature selection and evaluation



Analysis was conducted using a Microsoft Excel spreadsheet to record summaries of the positions of each of the 137 articles regarding the key resilience concepts of definition, elements and implementation strategies. Synthesis was achieved via an integrative approach which compared multidisciplinary works for convergent, divergent and co-evolving understandings of the aforementioned resilience concepts and used the results to build a synergistic conceptual framework of food SCRES. This was chosen over alternative approaches to synthesis, such as aggregative approaches as evidence suggests it better suits heterogeneous source material (Rousseau et al., 2008).

2.5 Step 5: Reporting and using the findings.

In this stage of an SLR, the findings from the analysis of the entire review pool, the relationships between salient concepts and the extent to which this information has addressed the review questions are reported (Denyer and Tranfield, 2009). Typically, synthesised findings can also be applied in a novel context to help generate new understandings of the relationships between concepts that may have been studied in isolation in the literature. In the context of this paper, Section 3 reports the findings of the review in relation to the review question and sub-questions. It proceeds to then synthesise and apply the findings in the form of a holistic framework that models resilience in AFSCs.

3. Findings

This section presents the analysis and synthesis of the final literature pool of 137 articles. First, to understand how resilience as a concept has developed over time and across multiple disciplines, a descriptive analysis of articles by publication date, publication journal, subject area and methodology is performed. The literature is then investigated more specifically from the perspective of each of the three review sub-questions. Finally, the salient concepts from each of the review sub-questions are unified in a novel framework modelling key concepts relating to resilience in AFSCs.

3.1 Descriptive analysis

Table II highlights that 40 per cent of the final 137 works reviewed originated in one of the leading seven journals of which Supply Chain Management: An International Journal and

International Journal of Production Economics were the most popular. All of the aforementioned journals represent either the fields of SCM or operations management, in which the priority of resilience efforts tended to focus on business continuity and particularly competitiveness of individual actors (Hohenstein et al., 2015; Pereira et al., 2014; Elleuch et al., 2016a, 2016b). Indeed, when all publication sources are considered, 75 percent of all articles considered in this review have an SCM or operations management origin.

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Table II. Review material by source

Academic journal	Authors	No. Papers	%
Supply Chain Management: an International Journal	Scholten and Schilder (2015), Scholten et al. (2014), Pereira et al. (2014), Johnson et al. (2013; Leat and Revoredo-Giha (2013), Gligor and Holcomb (2012), Jüttner and Maklan (2011), Aramyan et al. (2007), Taylor and Fearne (2006), Barratt (2004), Finch (2004)	11	8.1
International Journal of Production Economics	Kamalahmadi and Parast (2016), Pal et al. (2014), Vlajic et al. (2012), Schmitt and Singh (2012), Trkman and McCormack (2009), Thun and Hoenig (2011), Blome and Schoenherr (2011), Tang and Musa (2011), Wagner and Neshat (2010), Tang (2006), Sharifi and Zhang (1999)	11	8.1
International Journal of Production Research	Munoz and Dunbar (2015), Ho et al. (2015), Tukamuhabwa et al. (2015), Gunasekaran et al. (2011), Kim et al. (2015), Wagner and Neshat (2012), Spiegler et al. (2012), Diabat et al. (2012), Wu et al. (2013)	9	6.6
International Journal of Physical Distribution & Logistics Management	Durach et al. (2015), Wieland and Wallenburg (2013), Christopher and Holweg (2011), Skipper and Hanna (2009), Peck (2005), Norrman and Jansson (2004), Christopher and Lee (2004), Van der Vorst and Beulens (2002)	8	5.8
Journal of Business Logistics	Pettit et al. (2013), Boone et al. (2013), Zsidisin and Wagner (2010), Pettit et al. (2010), Zacharia et al. (2009), Wagner and Bode (2008), Manuj and Mentzer (2008), McKinnon (2006)	8	5.8
Journal of Operations Management	Ambulkar et al. (2015), Kim et al. (2015), Braunscheidel and Suresh (2009), Neiger et al. (2009), Swafford et al. (2006)	5	3.6
International Journal of Logistics: Research and Applications	Colicchia and Strozzi (2012), Dani and Deep (2010), Peck (2005), Tang (2006), Jüttner et al. (2003)	5	3.6
The International Journal of Logistics Management	Ponomarov and Holcomb (2009), Christopher and Peck (2004), Sheffi (2001)	3	2.2
International Journal of Operations and Production Management	Stevenson and Spring (2007), Ritchie and Brindley (2007), Hoek et al. (2001)	3	2.2
International Federation of Automatic Control	Elleuch et al. (2016a, 2016b), Elleuch et al. (2016a, 2016b), Ivanov et al. (2015)	3	2.2
Global Environmental Change	McDaniels et al. (2008), Milman and Short (2008), Folke (2006)	3	2.2
Production Planning & Control: The Management of Operations	Colicchia et al. (2010), Asbjornslett (1999), Vlajic et al. (2013)	3	2.2
Transport Research	Fahimnia and Jabbarzadeh (2016), Lam and Bai (2016), Yang and Xu (2015)	3	2.2

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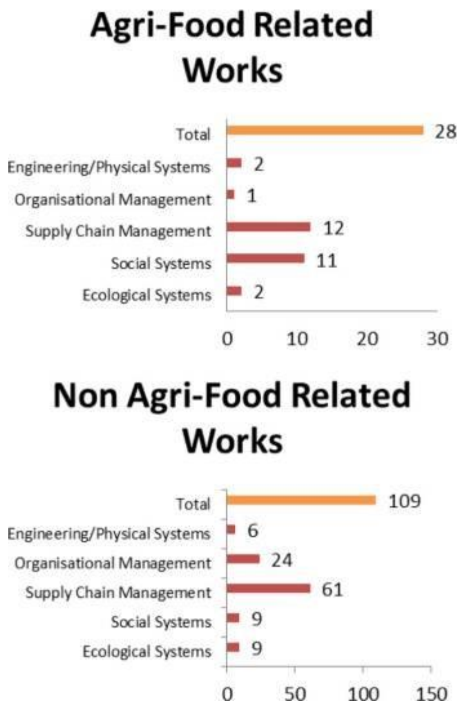
Other	Paloviita et al. (2016), Manning and Soon (2016), Annarelli and Nonino (2016), Tendall et al. (2015), Suweis et al. (2015), Caschili et al. (2015), Todo et al. (2015), Macfadyen et al. (2015), Fałkowski (2015), Gölgeci and Ponomarov (2015), Habermann et al .(2015), Rodriguez-Nikl (2015), Aigbogun et al. (2014), Brandon-Jones et al. (2014), Carvalho et al. (2014), Soni et al. (2014), Redman (2014), Allen et al. (2014) Dubey et al. (2014), Smith et al. (2014), Ingram et al. (2013), Kirwan and Maye (2013), Sinclair et al. (2014), Davoudi et al. (2012), Ghadge et al. (2012), Azevedo et al. (2012), Carvalho et al. (2012a, 2012b), Ponis and Koronis (2012), Carvalho et al. (2012a, 2012b), Barthel and Isendahl (2013), Carvalho et al. (2012a, 2012b), Berle et al. (2011), Rose (2011), Giannakis and Louis (2011), Derissen et al. (2011), Cimellaro et al. (2010), Higgins et al. (2010), Ford (2009), Stecke and Kumar (2009), Neureuther and Kenyon (2009), Bakshi and Kleindorfer (2009), Ratick et al. (2008), King (2008), Wagner and Bode (2008), Lodree and Taskin (2008), Folke (2006), Walker et al. (2006), Tomlin (2006), Fiksel (2003), Faisal and Banwet. (2006), Manyena (2006), Jüttner (2005), Lebel et al. (2006), Kleindorfer and Saad (2005), Fraser et al. (2005), Cox and Chickssnd (2005), Carvalho et al. (2005), Sheffi and Rice (2005), Fiksel (2003), Milestad and Darnhofer (2003)	62	45.2

However, less common but still important sources of resilience literature were found in journals from a range of other disciplines which included ecological systems, social systems and engineering/physical systems as outlined in Figure 3. These alternative disciplines are an important source of resilience research, particularly publications with a focus on social systems, where the priority of resilience tends to be on the adaptive capacity of complex systems (Tendall et al., 2015; Milestad and Darnhofer, 2003). The authors feel that this supports the previous contention that existing works which explore resilience from an SCM and/or operations management perspective, with their focus on individual business continuity and competitive advantage, are not always readily transferrable to the topic of AFSCs.

Another notable observation is that all of the articles reviewed were published post-2000 with 65 per cent being published post-2010, suggesting that interest in the application of resilience as a concept is recent and growing phenomena. Evidence suggests that this is in response to a number of wide ranging and unexpected disruptions including Hurricane Katrina, the Icelandic eruptions at Eyjafjallajökull in 2010, the Fukushima nuclear disaster, as well as major terrorist incidents such as the 9/11 attacks in America and the 7/7 attacks in the UK (Kinsey et al., 2007; Sheffi, 2001; Scholten et al., 2014; Christopher and Lee, 2004).

Figure 4 analyses the literature according to its adopted methodology. Methodology is classified according to four categories borrowed from Natarajarathinam et al. (2009): conceptual/theoretical, analytical, empirical and applied. The term conceptual/theoretical refers to works which synthesise or develop existing understanding of SCRES but which are not supported by any empirical work. Literature reviews are classed within this category. Works involving substantial simulation or mathematical modelling of a real-world supply chain issue with specified parameters fall within the analytical category.

Figure 3 Analysis of literature by research context and specificity to AFSCs



Articles that involve the collection of real world data and its evaluation are classed as empirical. Finally, case studies, interviews and other forms of gathering thoughts and opinions are classed as applied. Ultimately, the most common form of methodological approach was conceptual/ theoretical which accounted for 52 (38 per cent) of the reviewed articles. The authors of this review concur with Hohenstein et al. (2015) that this represents the importance of theory building in what is still a relatively new research area. Encouragingly, in recent years, there have been an increasing number of empirical works, case-specific applied works and mathematical analysis-based works which suggests that the focus is moving away from defining resilience towards trying to understand what its functional “elements” are. However, a large number of such works attempt to measure or model resilience based on a very small number of commonly cited “elements”, particularly flexibility and redundancy; for example, Braunscheidel and Suresh (2009), Skipper and Hanna (2009) and Datta et al. (2007).

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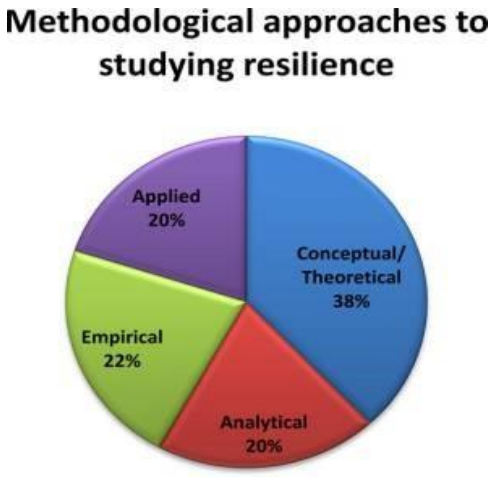
Figure 4 Methodological approaches taken to investigating resilience in the literature



This descriptive analysis of the resilience literature will now be used as a base from which to explore each of the review sub-questions individually.

3.2 Addressing Q1.

This section addresses review sub-question one by exploring how resilience has been defined as a concept by different research fields (Figure 3). Resilience can best be thought of as an umbrella term for a range of linked factors that help ensure continuity in the face of disruption (Tendall et al., 2015). Before exploring the concept in more detail, it is important to provide clarity on the relationship between resilience and the

similar terms of "sustainability" and "robustness" which investigation suggests are sometimes used interchangeably. Using the definition of sustainability outlined in the Brundtland Report: "meeting the needs of the present without compromising the ability of future generations to meet their own needs", sustainability can be described as a normative measurement for assessing long-term performance against ideal environmental, economic and social standards (Derissen et al., 2011).

By contrast, resilience is more of a descriptive methodology concerning short-term ability to withstand and/or adapt to disturbance (Tendall et al., 2015). As such, it is a key attribute for any organisation with long-term sustainability goals in complex systems with ever-changing drivers. Thus, an organisation can be resilient and unsustainable, but not sustainable without the presence of resilience, as it would be too susceptible to short-term derailment from excessive exposure to disruption. Robustness is another term which is related to resilience and frequently used interchangeably. However, the two are separate terms, with robustness prioritising strength to withstand disturbances, whereas resilient systems include flexibility to adapt to disturbance (Asbjornslett, 1999; Jüttner et al., 2003). In this way, it is possible to see robustness as a component of resilience, and in turn, resilience as a short-term enabler of long-term sustainability (McDaniels et al., 2008). To summarise, while these terms would therefore appear to be synergistic, it is erroneous to use them interchangeably (Redman, 2014).

Moving on to focus on resilience, while a relatively new addition in the context of SCM and AFSCs in specific, it is by no means a new concept. The term has Latin origins, stemming from the word "resi-lire", meaning to spring back and was first used by physicists to describe the stability of materials and their ability to resist external shocks (Manyena, 2006). It entered popular use in the field of Ecology in the 1960s and from there began to be translated to a range of new subject fields aided by a seminal article by Crawford Stanley Holling in 1973 (Holling, 1973). This article divided resilience into two distinct definitions that are commonly used today: engineering resilience and ecological resilience.

In the engineering definition, resistance to disturbance and the speed by which the system returns to a state of equilibrium are the marks of resilience. The phrase "a state of equilibrium" refers to the notion of optimal day to day operations (Rose, 2011). Heavy emphasis is placed on return time, efficiency, constancy and predictability, which it is claimed are the marks of a sound engineering design and hence the name (Holling, 1996). In the ecological definition,

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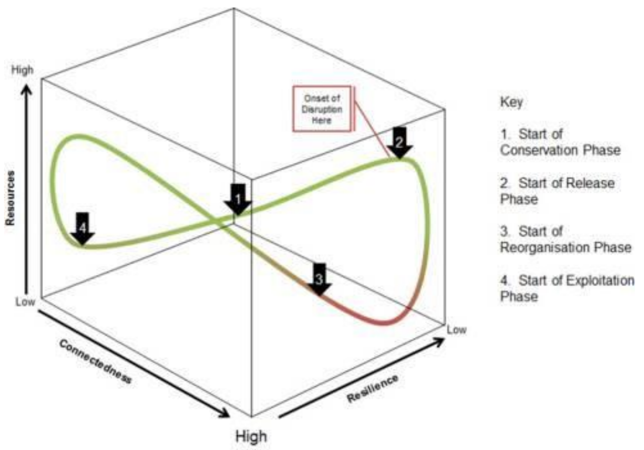
resilience is also measured by resistance to disturbance and speed of return to a state of equilibrium, but this definition also accepts that there are multiple possible equilibriums that the system could flip into depending on the magnitude of the disturbance.

It has been pointed out that a major shortcoming of both the engineering and ecological definitions of resilience is that they presume closed systems within which different actors can establish states of equilibrium. This is clearly not the case in something as complex as a food system where intertwined social, environmental, economic and political factors drive constant change across key operating parameters. In response to this, several authors have proposed a third definition of resilience which has been termed “Evolutionary” or “Adaptive” Resilience (Walker et al., 2006; King, 2008; Folke, 2006; Ambulkar et al., 2015). For consistency, we use the term adaptive resilience from now onwards in this review.

Adaptive resilience describes complex social–ecological systems where the interactions between different scales (for example, from individual species, to forests, to entire ecosystems), periods (referred to as temporal scales) and geographic distances (referred to as spatial scales) are all considered vital for overall system resilience. As such, there cannot be a “state of equilibrium” because external interference is continuous. Instead, resilience is something that is cyclical and cumulatively developed by a continual process of adaptation and learning from ongoing disturbances. It has been proposed that this continuous adaptive cycle has four distinct stages: exploitation, conservation, release and reorganisation as shown in Figure 5 (Allen et al., 2014; Walker et al., 2006).

The first phase is exploitation, which in the context of a business, is marked by use of readily available resources to form structure and core business priorities. An example might be that of a new start-up company with a novel product and market dominance.

Figure 5: The adaptive cycle of system dynamics



Source: Adapted from information provided by Walker *et al.* (2006) (reviewed) which in turn is based on previous work by Gunderson, 2001) (not reviewed)

However, as an organisation grows, it will eventually reach a point where its size binds ever larger quantities of resources and its connectivity increases cross-scale interactions, known as the conservation phase. The existence of the phase is supported by evidence collected by Peck (2005) in multi-sectorial supply chain interviews. An example view expressed by a consultant in Electronics Manufacturing is:

> It’s when the supply chain is supposed to be in the established steady state that it is most vulnerable, because that’s the point when it’s most susceptible to external effects. That’s when most people are trying to optimise and reduce control limits to reduce the variability of the process, but external risks may have changed the original scenario. (Peck, 2005).

In AFSCs in specific, this phase has been likened to contemporary drives towards intensification of agriculture and centralisation of factories and distribution centres, representing accumulation of capital and growing interconnectivity. Other assets bound up in AFSCs include significant amounts of land, water, carbon and other nutrients embodied in food (Fraser et al., 2005). Whether from the perspective of an entire food system or a single business within the existing system, this phase is where susceptibility to disturbance is at its highest because so many assets are tied up in the current way of doing things and connectivity means exposure is at its highest.

There is the potential for significant loss of resources if a big enough disturbance occurs, and this is known as the "Release" phase. This does not necessarily comprise pure financial loss, but might also concern loss of resources bound up in no longer tenable business structures. The business does not necessarily collapse at this point, but there will need to be some sort of adaptation (the Reorganisation Phase) at which point the cycle begins again (Davoudi et al., 2012).

Influencing the adaptive cycle are three components: "resilience" (capacity to absorb change), "adaptability" (capacity to evolve a given form of operation) and "transformability" (ability to completely change an untenable system of operation). These are effectively control mechanisms with which an organisation can influence the adaptive cycle stages (Figure 5). The adaptive cycle also differs from the engineering and ecological definitions of resilience by its underlying consideration of "Panarchy" (Allen et al., 2014). This represents complexity in a system where disruptions do not necessarily have to originate within the same period or geographic proximity as the focal organisation. This means that the relationships between cause and effect of a disturbance do not necessarily have to be linear. As such, small influences such as the input of single staff members in the face of disruption can have just as much, or even more, impact than large scale interventions. Such unpredictability challenges the adequacy of conventional risk management tools, such as extrapolation of past trends as a way of forecasting future events (Trkman and McCormack, 2009). The key differences between the engineering, ecological and evolutionary definitions of resilience are summarised in Table III.

In Table IV, the review pool is analysed according to which of the three definitions authors adopt. In total, 48 of the 137 articles being reviewed offered a definition for resilience.

Table III Comparison of engineering, ecological and adaptive definitions of resilience

Criteria for comparison	Engineering definition of resilience	Ecological definition of resilience
Definition	'The ability of a system to return to an equilibrium or steadystate after a disturbance' (Walker et al., 2006; Fiksel, 2003; Folke 2006)	'The magnitude of the disturbance that can be absorbed before the system changes its structure' (Tendall et al., 2015; Fiksel, 2003; Folke, 2006)
Stance on equilibrium	Focus is on returning to existing equilibrium as soon as possible (Folke, 2006; Elleuch et al., 2016a, 2016b)	Acceptance of multiple possible equilibriums, change to which could either be forced or presented as a possibility by disruption. Focus therefore is on is on identifying the optimal equilibrium state which may or may not have been the original (Fiksel, 2003; Folke, 2006; Manyena, 2006)
Stance on the nature of disturbances	Disturbance is external with linear and proportional cause/ effect ratio (Davoudi et al., 2012)	Disturbance is external with linear and proportional cause/ effect ratio (Davoudi et al., 2012; Ford 2009; Barthel and Isendahl 2013)
Key attributes	Return time, efficiency, constancy and predictability (King, 2008)	Thresholds of disturbance that will lead to new system. Persistence and adaptability (Folke, 2006; King, 2008; Lebel et al., 2006; Redman, 2014)

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Table IV: Categorisation of reviewed literature by resilience definition

Food Specificity?	Context	Author	Definition	Engineering	Ecological	Adaptive
Food Specific	Social Systems	Milestad and Darnhofer (2003)	"The magnitude of disturbance that can be experienced before a system moves into a different state with different sets of controls"		X	
		Smith et al. (2016)	"The existence, development, and engagement of community resources by community members to thrive in an environment characterised by change, uncertainty, unpredictability, and surprise and to develop new trajectories for the community's future"			X
		Tendall et al. (2015)	"Capacity over time of a food system and its units at multiple levels, to provide sufficient, appropriate and accessible food to all, in the face of various and even unforeseen disturbance"			X
		Sinclair et al. (2014)	''The capacity of a system to absorb disturbance and reorganise so as to retain essentially the same function, structure, identity and feedbacks''			X
		Macfadyen et al. (2015)	"Here we talk about resilience in terms of production variability and the ability of agro-ecosystems to maintain stability in production levels even in the face of disturbances"	X		
		King (2008)	"A system's ability to adapt and respond to external impacts on a system"			X
	Supply Chain Management	Carvalho et al. (2012a, 2012b)	"Supply Chain resilience is concerned with the system's ability to return to its original state or to a new, more desirable, one, after experiencing a disturbance, and avoiding the occurrence of failure modes"		X	
		Ivanov et al. (2015)	"Resilience refers to the capacity of organizations or systems to return to full functionality in the face of disruption"	X		
		Yang and Xu (2015)	"The ability of a system to return to its original state or move to a new and more desirable state after being disturbed, or to adapt existing resources and skills to new situations and operating conditions, in order to survive despite withstanding a severe and enduring impact"			X
		Fałkowski (2015)	"The term "resilience" refers to the ability of a system to maintain output close to potential in the aftermath of shocks or, alternatively, the ability of a system to return to its original state after being disturbed"	X		
		Leat and Revoredo-Giha (2013)	"Resilience aims at developing the adaptive capability of the chain to prepare for unexpected events and to respond to disruptions and recover from them"			X
		Manning and Soon (2016)	"Strategic resilience is not about responding to a single crisis or rebounding from a setback, it encompasses anticipating and reacting to secular trends that can permanently impair the earning			X

			power of the core business”			
	Organisational Management	Higgins et al. (2010)	“Resilience is the capacity of a system to recover from disturbance and maintain its structure function and controls with the human element of socio-ecological systems able to proactively avoid or benefit from such disturbances”			X
Non-Food Specific	Social Systems	Milman and Short (2008)	“Resilience includes more than maintaining given system characteristics; it includes the adaptive capacity of the system—its ability to adapt to stresses and changes and to transform into more desirable states”			X
		Ponomarov and Holcomb (2009)	“The adaptive capability of the supply chain to prepare for unexpected events, respond to disruptions and recover from them by maintaining continuity of operations at the desired level of connectedness and control over structure and function”			X
		Manyena (2006)	“Resilience could be viewed as the intrinsic capacity of a system, community or society predisposed to a shock or stress to adapt and survive by changing its non-essential attributes and rebuilding itself”			X
		Davoudi et al. (2012)	“Resilience is not conceived of as a return to normality, but rather as the ability of complex socio-ecological systems to change, adapt, and, crucially, transform in response to stresses and strains”			X
		Rose (2011)	“The ability of a system to maintain function when shocked and to hasten the speed of recovery from a shock”	X		
		McDaniels et al. (2008)	“A complex system’s capacity to absorb shocks while maintaining function. Enhanced by both risk mitigation activities undertaken before the disaster and response activities following the event”	X		
	Ecological Systems	Derissen et al. (2011)	“The magnitude of disturbance that can be absorbed before the system changes its structure by changing the variables and processes that control behaviour”		X	
		Fiksel (2003)	“Resilience can be defined as the capacity of a system to tolerate disturbances whilst retaining its structure and function”		X	
		Tukamuhabwa et al. (2015)	“The adaptive capability of a supply chain to prepare for and/or respond to disruptions, to make a timely and cost effective recovery, and therefore progress to a post-disruption state of operations – ideally, a better state than prior to the disruption”			X
		Lebel et al. (2006)	“Resilience is a measure of the amount of change a system can undergo and still retain the same controls on structure and function or remain in the same domain of attraction”		X	
		Redman (2014)	“Resilience is the capacity of a system to experience shocks while retaining function, structure, feedback capabilities, and therefore identity”		X	
		Folke (2006)	“The capacity of the system ‘to absorb disturbance and re-organise while undergoing change so as to still retain essentially the same function, structure, identity, and feedbacks’’			X

	Supply Chain Management	Colicchia et al. (2010)	"The ability of a system to quickly react to the undesired events when they happen"	X		

(continued)

Food Specificity?	Context	Author	Definition	Engineering	Ecological	Adaptive
		Carvalho et al. (2012a, 2012b)	"Resilience refers to the ability of the supply chain to cope with unexpected disturbances. It is concerned with the system ability to return to its original state or to a new one, more desirable, after experiencing a disturbance, and avoiding the occurrence of failure modes"		X	
		Todo et al. (2015)	"Defined as speedy recovery through the repair and reconstruction of capital stock"	X		
		Kamalahmadi and Parast (2016)	"We define Firm/Enterprise Resilience as "the dynamic capability of an enterprise, which is highly dependent on its individuals, groups, and subsystems, to face immediate and unexpected changes in the environment with proactive attitude and thought, and adapt and respond to these changes by developing flexible and innovative solutions"			X
		Pereira et al. (2014)	"Supply chain resilience is defined here as the capability of supply chains to respond quickly to unexpected events so as to restore operations to the previous performance level or even to a new and better one"		X	
		Pettit et al.(2008)	"The capacity for an enterprise to survive, adapt and grow in the face of turbulent change"			X
		Elleuch et al. (2016a, 2016b)	"In this context, resilience is defined as the ability of a system to return to its original state or a more favourable condition, after being disturbed"		X	
		Wang et al. (2016)	"A resilient system is a system with an objective to survive and maintain function even during the course of disruptions, provided with a capability to predict and assess the damage of possible disruptions, and enhanced by the strong awareness of its ever-changing environment and knowledge of the past events, thereby utilizing resilient strategies for defence against the disruptions"			X
		Brandon-Jones et al. (2014)	"We define supply chain resilience as the ability of a supply chain to return to normal operating performance, within an acceptable period of time, after being disturbed"	X		
		Peck (2005)	"The ability of a system to return to its original [or desired] state after being disturbed"		X	
		Ambulkar et al. (2015)	"Firm's resilience to supply chain disruptions is defined as the capability of the firm to be alert to, adapt to, and quickly respond to changes brought by a supply chain disruption"			X
		Jüttner and Maklan. (2011)	"Supply chain resilience addresses the supply chain's ability to cope with the consequences of unavoidable risk events in order to return to its original operations or move to a new, more desirable state after being disturbed"		X	
		Christopher and Peck (2004)	"The ability of a system to return to its original state or move to a new, more desirable state after		X	

		being disturbed”			
Organisational	Asbjornslett et al. (1999)	“Resilience may be defined as a system’s ability to return to a new stable situation after an accidental event”		X	
	Fahimnia and Jabbarzadeh (2016)	“The capacity of a SC to absorb disturbances and retain its basic function and structure in the face of disruptions”	X		
	Kim et al. (2015)	“We define supply network resilience as a network-level attribute to withstand disruptions that may be triggered at the node or arc level”	X		
	Annarelli and Nonino (2016)	“Organizational resilience is the organization’s capability to face disruptions and unexpected events in advance thanks to the strategic awareness and a linked operational management to internal and external shocks. The resilience is static, when founded on preparedness and preventive measures to minimize threats probability and to reduce any impact that may occur, and dynamic, when founded on the ability of managing disruptions and unexpected events to shorten unfavourable aftermaths and maximize the organization’s speed of recovery to the original or to a new more desirable state”		X	
	Aigbogun et al. (2014)	“Resilience confers on the supply chain the ability to return to original or perhaps better supply chain performance under emergency risk environment”		X	
Engineering/ Physical System	Caschili et al. (2015)	“We can use the concept of resilience in order to describe the capacity of a hierarchical economic system (composed of several sub systems), to recover after being subject to a variety of challenges (shocks, disruptions, attacks, etc.) which move the system from its equilibrium”		X	
	Cimellaro et al. (2010)	‘‘Intrinsic capacity of a system, community or society predisposed to a shock or stress to adapt and survive by changing its non-essential attributes and rebuilding itself’’			X
	Spiegler et al. (2012)	‘‘The ability of a system to return to its original state or move to a new, more desirable state after being disturbed’’		X	
	Soni et al. (2014)	“Supply chains must be multidimensional and multidisciplinary, designed to incorporate event readiness, provide an efficient and effective response and be capable of recovering to their original state or improved state after a disruption; this is the meaning of supply chain resilience”		X	
	Berle et al. (2011)	“In this paper, resilience is defined as the ability of the supply chain to handle a disruption without significant impact on the ability to serve the supply chain mission”	X		
Total Definitions: 48			Sum: 11	Sum: 18	Sum:19

As Q1.1 concerns identifying suitable definitions of resilience for AFSCs, literature definitions were compared on whether they were from articles considering AFSCs in specific, or from different perspectives on resilience.

Thirteen of the articles offering definitions considered AFSCs in specific (although this specificity was not always obvious in the definition provided) and 35 were more general in focus.

The broader research contexts of the review articles were also compared to identify if certain research fields prioritise a specific type of definition. Engineering definitions were distinguished by their focus solely on resisting and recovering rapidly from external disturbances with minimal impact on system deliverables.

Ecological definitions, on the other hand, focussed on the amount of change a system can endure and recover from, possibly involving moving to a new equilibrium, while maintaining core functions.

It was identified that overall there was a slight preference for the adaptive definition of resilience. This is particularly true in works that were AFSC specific in focus, many of which hailed from a social systems perspective. Such works frequently considered resilience at community and societal scales and prioritised a system's ability to continue providing food, rather than economic viability of individual businesses within the chain.

Adaptive definitions made no mention of states of equilibrium but instead focussed on adaptive change to volatile external operating environments. As such, in addition to mention of ability to "resist" and "recover", the ability to "adapt" or "reorganise", whether in response to, or in anticipation of a disruption was common in such definitions (Wu et al., 2013; King, 2008; Cimellaro et al., 2010).

Here, end consumers and the different AFSCs that feed them are considered within the sphere of the wider natural world, where change is constant and control over that change by any given actor is small. For example, as complex social ecological systems, AFSCs are dependent on a number of ecosystem services to produce food, and significant social economic factors to manufacture and transport food. Each of these is exposed to vulnerabilities, for example, in the form of policy interventions, consumer demand and environmental management.

A breakdown in any one of these areas can lead to harvests failing, transport links breaking and consumer demands and tastes changing (Milman and Short, 2008; Yang and Xu, 2015). Therefore logically, to be resilient in such a world is to prioritise constant adaptation and reorganisation. As such, the complexity of vulnerability sources is much broader than an individual organisation might consider from a risk management perspective, and this would explain the observed preference for the adaptive definition. Key features of adaptive food definitions included the ability to maintain "function" as well as the ability of systems to adapt rather than to return to existing states of equilibrium. Tendall et al. (2015) advance the field by linking "function" with the United Nations Food and Agricultural Organisation definition of food security which concerns the four pillars of availability, access, utilisation and stability of food to end consumers (Fao, 2012; Tendall et al., 2015).

In comparison, non-AFSC-specific works saw greater contribution from organisational management and engineering/physical systems approaches. In these contexts, resilience consideration often takes place within an enclosed system, for example, a factory, and vulnerabilities tend to be more controllable and predictable (for example, machine faults, staff illness, etc.), thus encouraging pursuit of a single optimal management strategy (Vlajic et al., 2013; Berle et al., 2011). This can be seen as analogous to a "state of equilibrium" and would explain the preference in such works for an ecological definition of resilience where the focus is on a particular organisation's competitive advantage, specifically, minimising the time and cost of a disruption and exploiting competitor weaknesses (Pereira et al., 2014; Kim et al., 2015; Todo et al., 2015).

Articles in the area of SCM, regardless of whether they are AFSC focussed or not, have shown a growing shift away from engineering definitions of resilience towards adaptive definitions in recent years. There is evidence that this transition is linked to increasing awareness of the importance of constantly changing operating environments, in particular, the evolving challenges and opportunities of outsourcing to lowcost countries (Tang and Musa, 2011).

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Moving forward, a number of definitions in Table IV refer to one or more of the following abilities: to "Resist", to "Recover" and/or "Adapt"(Soni et al., 2014; Fahimnia and Jabbarzadeh, 2016; Leat and Revoredo-Giha, 2013; Annarelli and Nonino, 2016). Ponomarov and Holcomb (2009) categorised these into the distinct phases of readiness, response and recovery. Readiness refers to an organisation's ability to anticipate disruption and either prepare for it or avoid it. Response refers to either innate or pre-planned elements that mitigate the impact of a disruption, as it happens. Recovery refers to the ability of an organisation to repair losses caused by a disruption and return to meeting core priorities. Hohenstein et al. (2015) add the fourth phase of "Growth" which concerns learning from and adapting core priorities post disruption so that competitiveness actually improves compared to pre-disruption levels. However, it has been noted that many articles overwhelmingly see disruption in light of the reactive and recovery phases only (Higgins et al., 2010; Hohenstein et al.,2015).

Therefore, to summarise findings in relation to review Q1.1, it has been identified that resilience of AFSCs is frequently equated with the ability not only to resist disruption but also particularly to maintain the core function of supplying food to end consumers. The priority of resilience in AFSCs can therefore be described as the food security of end consumers. AFSCs are also incredibly complex systems involving myriad bio-geophysical, social, economic and political drivers and feedbacks that must be managed holistically to enhance resilience. Therefore, any definition of AFSC resilience must include the ability to adapt in line with changing operating environments as well as to prioritise availability, access, suitability and stability of food supply. To do so, it must consider more than the traditional phases of resisting and recovering from disruption and also include anticipation and post-disruption learning. Therefore, the authors of this paper propose the following definition of AFSC resilience:

The collective ability of Agri-food supply chain stakeholders to ensure acceptable, sufficient and stable food supplies, at the required times and locations, via accurate anticipation of disruptions and the use of strategies which delay impact, aid rapid recovery and allow cumulative learning post disruption.

This definition builds on existing adaptive definitions of food related resilience by incorporating the priority of food security rather than individual organisational competitiveness. By nature, it implies that resilience strategies must consider how resilience strategies implemented by one actor impact overall SCRES. Furthermore, by incorporating the fourth food security pillar of stability, the synergistic relationship between resilience and sustainability is highlighted. A key component of this definition is the word "mechanisms" and to explore what this practically entails; this review now moves on to Q1.2 to identify AFSC relevant resilience "elements" and "strategies".

3.3 Addressing Q1.2

There have been a number of works which propose strategies for manipulating an actor's resilience, many of which fall within the SCM discipline. Such strategies frequently rely on the assumption that resilience can be controlled by a portfolio of variously named "antecedents", "attributes", "capabilities", "elements" and "enhancers" which are management tools to counteract specific vulnerabilities (Hohenstein et al., 2015; Pettit et al., 2010; Pereira et al., 2014; Kamalahmadi and Parast, 2016). For consistency, and in line with Christopher and Peck (2004), Hohenstein et al. (2015) and Kamalahmadi and Parast (2016), the term "elements" is used from now onwards.

In total, 61 articles proposed one or more key elements for resilience. From these, this review identified 40 unique resilience elements. This breadth of resilience elements has, to the author's knowledge, not been attempted previously in the literature. These elements varied significantly in terms of "scope". This refers to whether resilience elements were applicable in response to disruptions within an individual organisation (for example, machinery faults) or within a

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supply chain (for example, loss of a specific supplier), in which case, elements addressed ways in which the supply chain could collectively adapt. The list of identified elements and their respective scope and publication sources are given in Table V. It should be noted that some elements appear in both the intra-organisational and intra-supply chain columns albeit with different contexts.

For example, redundancy at an organisational level refers to spare capacity and inventory, but at a supply chain level describes alternative transport routes between stages or backup infrastructure. When ranked according to the number of papers mentioning a specific element, flexibility, risk aware culture, redundancy and early warning detection systems were the most commonly cited elements at an organisational level. At a supply chain level, collaboration, flexibility, agility, visibility and adaptability were, respectively, the most commonly cited elements.

Despite there being a number of highly cited resilience elements, the overwhelming majority of elements identified appeared in less than 10 per cent of papers reviewed. This suggests that there is poor consensus on what elements are the most important for resilience. For example, Fiksel (2003) proposes four elements: diversity, efficiency, adaptability and cohesion. Pettit et al. (2010) on the other hand identifies 14 different elements. Without empirical validation, it is difficult to be sure that just because a resilience element is cited more frequently, that it is more significant for resilience than a less commonly cited capability. In particular, many of the less commonly cited elements are from research fields that are less active in the area of resilience, such as ecological and social systems. Such elements concern interactions and relations between organisations, communities and the natural environment as well as their ability to adapt, which are of major significance to "adaptive resilience" in AFSCs. Therefore, there is a need to capture the relationship between such elements and the more commonly cited elements.

Table V: Survey of resilience elements from the literature

Scope	Capability	Details	No. Papers	(%)	Sources
Intra-Organisational (IO)	IO 1. Flexibility	Ability of an organisation to adapt with minimum time and effort. Concerns the ability to switch suppliers, substitute ingredients, outsource processes, share materials and staff between sites, the ability of staff to fulfil multiple roles (IO15) and the levels of control over market position (IO16)	9	14.75	Tukamuhabwa et al. (2015), Kamalahmadi and Parast (2016), Pal et al. (2014), Stecke and Kumar (2009), Pettit et al. (2010), Tang (2006), Tomlin (2006), Zsidisim and Wagner (2010), Carvalho et al. (2012a, 2012b)
	IO 2. Risk Aware Culture	Describes the infrastructure a firm has in place to manage risk. For example this could include efficiency standards (IO4) such as six sigma, and the presence of Business Continuity (IO13) and Enterprise Risk Management Programmes	9	14.75	Christopher and Lee (2004), Blome and Schoenherr (2011), Jüttner and Maklan. (2011), Gölgeci and Ponomarov (2015), Ritchie and Brindley (2007), Peck (2005), Scholten et al. (2014), Thun and Hoenig (2011), Neureuther and Kenyon (2009)
	IO 3. Redundancy	Concerns the ability to alternate production capacity and to call upon surplus raw materials and finished inventory	8	13.11	Tukamuhabwa et al. (2015), Ponis and Koronis (2012), Manuj and Mentzer (2008), Stecke and Kumar (2009), Wieland and Wallenburg (2013), Aigbogun et al.

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				(2014), Carvalho et al. (2012b), McKinnon (2006)
IO 4. Early Warning Detection Systems	This concerns the use of foresight to extend preparation time. Specifically, it can include intelligence generation through big data and the internet of things	5	8.1	Suweis et al. (2015), Christopher and Peck (2004), Stecke and Kumar (2009), Gunasekaran et al. (2011), Pettit et al. (2010)
IO 5. Security	This refers to the security of both electronic information and the physical security of assets	4	6.5	Pettit et al. (2010), Stecke and Kumar (2009), Faisal and Banwet (2006), Elleuch et al. (2016a, 2016b)
IO 6. Efficiency	The way in which resources are used so as to avoid unnecessary waste and disruption. This could refer to the presence of efficiency standards such as six sigma	4	6.5	Fiksel (2003), Pettit et al. (2010), Aramyan et al. (2007), Elleuch et al. (2016a, 2016b)
IO 7. Contingency Plans	Pre-established crisis management teams and procedural guides for potential disruptions to enhance response speed and effectiveness. Most effective when combined with "IO4 Early Warning Detection Systems"	3	4.9	Zsidisin et al. (2010), Jüttner and Maklan (2011), Dani and Deep (2010)
IO 8. Inventory Management	Increased visibility of supplier operations and transport mediums to reduce the amount of redundancy required in a disruption. Closely related to "IS4 Visibility"	3	4.9	Kleindorfer et al. (2005), Wu et al. (2013), Stecke and Kumar (2009)
IO 9. Financial Strength	Availability of easily accessible financial assets. Linked to "IO1 Flexibility"	3	4.9	Pettit et al. (2010), Pereira et al. (2014), Dani and Deep (2010)
IO 10. Leadership Commitment	This concerns the quality of leadership and how it interacts with the rest of an organisation. It might concern the ability to prioritise, inspire and to learn from others/past disruptions. Important in establishing effective risk management culture	3	4.9	Durach et al. (2015), Kamalahmadi and Parast (2016), Dani and Deep (2010)
I0 11. Relationships	The way in which different teams and departments interact. Important aspects include communication methods and the routes of information flow	3	4.9	Smith et al. (2016), Durach et al. (2015), Christopher and Lee (2004)
IO 12. Human Resource Management	This concerns the ways in which human assets are trained, retained and allowed to develop. Examples include skillsets generated (particularly ability to fulfil multiple roles) and the use of staff in identifying risk	2	3.2	Durach et al. (2015), Stecke and Kumar (2009)
IO 13. Business Continuity	Contingency planning for the protection of "mission critical assets". Key component of "IS10 Robustness"	2	3.2	Peck (2005), Suweis et al. (2015)
IO 14. Innovation	Presence of shared beliefs, openness to learning and joint decision-making	2	3.2	Kamalahmadi and Parast (2016), Gölgeci and Ponomarov (2015)

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	IO 15. Knowledge Management	Staff skills and knowledge retention that effect their ability to change pace and type of role in a disruption. Sometimes cited as a component of "IO1 Flexibility"	2	3.2	Scholten et al. (2014), Pereira et al. (2014)
	IO 16. Market Position	Factors such as market share, product differentiation and customer communications which can be manipulated to aid recovery in the event of a disruption. An aspect of "IO1 Flexibility"	1	1.6	Pettit et al. (2010)
	IO 17. Adaptive Management	Active monitoring of decisions made in relation to past disruptions and their outcomes for incremental learning	1	1.6	Milestad and Darnhofer (2003)
Intra-Supply Chain (IS)	IS 1. Collaboration	Refers to two or more actors working together to generate advantages that could not be achieved individually. This could be in the form of: Shared forecasting, postponement and risk sharing. Cooperation and partnership. Aim of reducing uncertainties and complexity. Integration of systems	19	31.1	Jüttner et al. (2011), Pettit et al. (2010), Christopher and Peck. (2004), Carvalho et al. (2014), Scholten et al. (2014), Barratt et al. (2004), Zacharia et al. (2009), Smith et al. (2016), Hohenstein et al. (2015), Tukamuhabwa et al. (2015), Kamalahmadi and Parast (2016), Gunasekaran et al. (2011), Chen et al. (2012), Giannakis and Louis (2011), Johnson et al. (2013), Habermann et al. (2015), Lee. (2014), Dani and Deep (2010), Elleuch et al. (2016a, 2016b)
	IS 2. Flexibility	Degree by which a supply chain can respond to changing operating environments and customer requests. Supply chain wide alternative options achieved through partnerships. Ability to move staff and equipment rapidly	18	29.5	Lam and Bai (2016), Natarajarathinam et al. (2009), Pettit et al. (2013), Tendall et al. (2015), EstradaFlores et al. (2009), Stecke and Kumar (2009), Ivanov et al. (2015), Jüttner et al. (2011), Durach et al. (2015), Suweis et al. (2015), Soni et al. (2014), Skipper et al. (2009), Smith et al. (2016), Swafford et al. (2006), Stevenson and Spring (2007), Gligor and Holcomb. (2012), Aramyan et al. (2007)

(continued)

Scope	Capability	Details	No. Papers	(%)	Sources
	IS 3. Agility	The ability to respond quickly to unpredictable changes in supply and demand by changing configuration at tactical level. Examples include logistics capabilities and manufacturing flexibility	17	27.8	Christopher and Peck (2004), Wieland and Wallenburg (2013), Durach et al. (2015), Braunscheidel and Suresh (2009), Swafford et al. (2006), Durach et al. (2015), Tendall et al. (2015), Sharifi and Zhang (1999), Hohenstein et al. (2015), Tukamuhabwa et al. (2015),

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				Kamalahmadi and Parast (2016), Gligor and Holcomb (2012), Pereira et al. (2014), Scholten et al. (2014), Aramyan et al. (2007), Johnson (2013), Dubey et al (2014), Sharifi and Zhang (1999)
IS 4. Visibility	The ability to see structures, processes and products from one end of the supply chain to the other. Includes factors that aid availability of information such as channels for the sharing of risk information and IT infrastructure as well as frameworks guiding how this information is delivered to the right people at the right time	15	24.5	Christopher and Lee (2004), Pettit et al. (2013) Brandon-Jones et al. (2014), Carvalho et al. (2014, Soni (2014), Gunasekaran (2004), Smith et al. (2016), Durach et al. (2015), Faisal and Banwet (2006), Kamalahmadi and Parast (2016), Pereira et al. (2014), Stecke and Kumar (2009), Gunasekaran et al. (2011), Aigbogun et al. (2014), Johnson et al. (2013)
IS 5. Adaptability	The ability of a system to adapt incrementally or to completely transform in response to a changing operating environment	9	14.75	Fiksel (2003), King (2008), Tukamuhabwa et al. (2015), Pettit.(2010), Sinclair et al. (2014), EstradaFlores et al. (2009), Milestad and Darnhofer (2003), Lebel et al. (2006) Tendall et al. (2015)
IS 6. Node Criticality	Exists when a single entity within a supply chain is depended upon by a disproportionately large number of other entities, for example, a key port facility. Can significantly influence "IS2 Flexibility"	6	9.8	Durach et al. (2015), Kamalahmadi and Parast (2016), Stecke and Kumar (2009), Aigbogun et al. (2014), Ratick et al. (2008), Fraser et al. (2005)
IS 7. Information flow	Refers to the efficiency and effectiveness of information flow. Key determinant of "IS1 Collaboration"	6	9.8	Smith et al. (2016), Kamalahmadi and Parast (2016), Christopher and Peck (2004), Soni et al. (2014), Pereira et al. (2014), Faisal and Banwet (2006)
IS 8. Velocity	Speed at which products reach end consumer. Specific examples include efficiency, reduction of lead times and synchronisation of schedules. Element of "IS3 Agility"	6	9.8	Carvalho et al. (2014), Jüttner et al. (2011), Christopher and Peck (2004), Kamalahmadi and Parast (2016), Pereira et al. (2014), Johnson et al. (2013)
IS 9. Redundancy	Concerns the system wide design of emergency backup and storage facilities, surplus pathways between nodes and the extent to which elements are replaceable	6	9.8	Spiegler et al. (2012), Ivanov et al. (2015), Milestad and Darnhofer (2003), Bode et al. (2011), Ratick et al. (2008), Fiksel (2003)
IS 10. Robustness	Concerns the ability of a system to withstand a given amount of stress without loss of function	6	9.8	McDaniels et al. (2008), Bruneau et al. (2003), Tendall et al. (2015), Ivanov et al. (2015), Rodriguez-Nikl (2015), Wieland and Wallenburg (2013)
IS 11. Self-organisation	Concerns the autonomy, ability and will of a system to internally organise itself as opposed to being completely at the whim of external forces	4	6.5	Milestad and Darnhofer (2003), Estrada-Flores et al. (2009), Lebel et al. (2006), Pettit et al. (2010)
IS 12. Rapidity	Capacity to meet priorities and achieve goals in a timely manner to contain losses and avoid future disruption	4	6.5	Rodriguez-Nikl (2015), McDaniels et al. (2008), Tendall et al. (2015), Bruneau et al. (2003)

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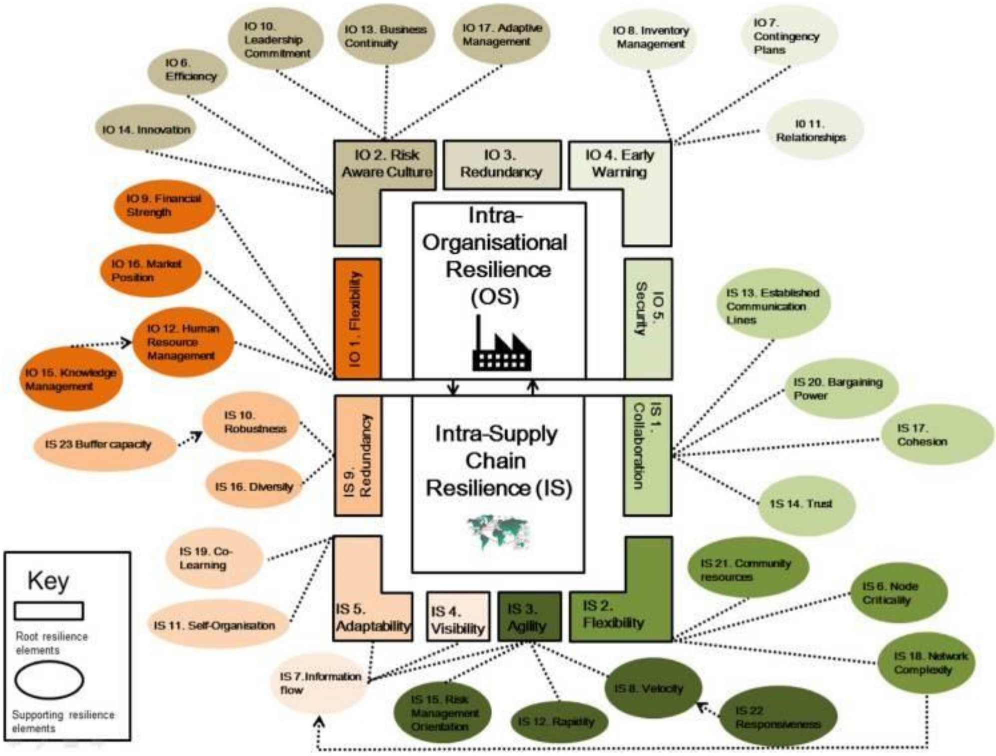
IS 13. Established Communication Lines	Pre-planned communication infrastructure and protocols that aid response speed and effectiveness in a disruption situation	4	6.5	Suweis et al. (2015), Hohenstein et al. (2015), Stecke and Kumar (2009), Dani and Deep (2010)
1S 14. Trust	Refers to the presence of enough trust between system actors that problems can be discussed openly. Key determinant of "IS1 Collaboration"	3	4.9	Kamalahmadi and Parast (2016), Pereira et al. (2014), Faisal and Banwet (2006)
IS 15. Risk Management Orientation	Presence of risk management strategies throughout operations of all supply chain partners. Can significantly reduce recovery time and cost post disruption	2	3.2	Durach et al. (2015), Jüttner et al. (2011)
IS 16. Diversity	Refers to variety in inputs, suppliers, staff and customers and important in the generation of system wide redundancy	2	3.2	Fiksel (2003), Carvalho et al. (2012a, 2012b),
IS 17. Cohesion	The existence of unifying factors between supply chain organisations, such as mutual end consumers, that can drive collaboration	2	3.2	Fiksel (2003), Carvalho et al. (2012a, 2012b),
IS 18. Network Complexity	Refers to the number of nodes and length between them in a supply chain. Can effect rerouting options and communication times in a disruption	2	3.2	Durach et al. (2015), Pettit et al. (2010)
IS 19. Co-Learning	This refers to the systems in place to aid supply chain wide joint learning from both near misses and actual disruptions	2	3.2	King (2008), Lebel et al. (2006)
IS 20. Bargaining Power	The presence of factors such as significant vertical integration that can influence the ability of other entities to act in a resilient manor	1	1.6	Durach et al. (2015)
IS 21. Community resources	The range of ecological, economic, social, physical, institutional and cultural resources a community can draw upon when faced with disruption	1	1.6	Smith et al. (2016)
IS 22. Responsiveness	Supply chain responsiveness to customers, for example, the ability to drive down lead times	1	1.6	Aramyan et al. (2007)
IS 23. Buffer capacity	Concerns the amount of change a system can undergo while retaining core functions. Major similarities with "IS10 Robustness"	1	1.6	Milestad and Darnhofer (2003)

The authors of this review identified that of the 40 resilience elements, some were broad in scope and some were much narrower, referring to specific aspects of the broader elements. These are referred to as "Core" and "Supporting" elements, respectively. For example, at a supply chain level, the authors of this review propose that flexibility is a "Core" resilience element, concerning supply chain wide alternative options of responding to a disruption. The resilience elements of "I016 Knowledge Management" and "IO16 Market Position" for example, while enabling resilience in their own right, are often cited as aspects of "IO1 Flexibility" (Carvalho et al., 2012a, 2012b; Pettit et al., 2010; Tomlin, 2006). Therefore, while IO15 and IO16 are not duplicates of IO1, they can be seen as "Supporting" resilience elements. This novel method of categorising resilience elements of relevance to AFSCs is shown in Figure 6. Categorising resilience elements in this way is useful for application to AFSCs because elements that represent communities and ecosystem services can be more easily recognised as supporters of more commonly cited elements. The proposed "Core" elements at an organisational level are now described in more detail.

Figure 6: Proposed categorisation of resilience elements identified in the literature



3.3.1 Proposed "core" intra-organisational resilience elements3.3.1.1 Intra-organisational 1: Flexibility.

At an organisational perspective, flexibility was cited in 14.75 per cent of articles reviewed. For most organisations, there will be two broad areas in which flexibility can be implemented; at sourcing and at production and distribution (Pettit et al., 2010). At sourcing, flexibility concerns ability to quickly change inputs (or mode of receiving inputs) through utilisation of common product platforms, product modularity, multiple pathways, supply contract flexibility and alternate suppliers (Tomlin, 2006). At production and distribution, flexibility entails the ability to quickly change outputs or the mode of delivery, for example, via multi-sourcing, delayed commitment/production, alternate distribution channels and fast re-routing of requirements (Carvalho et al., 2012a, 2012b). "Financial Strength" (IO9) concerns easily accessible liquid assets and so is a pre-requisite for many of the aforementioned flexibility options (Pal et al., 2014).

"Human Resource Management" (IO12) and "Knowledge Management" (IO15) concern aspects of how skills are developed, used and retained in an organisation so as to be able to rapidly adapt to changing job roles in a disruption (Zsidisin and Wagner, 2010). Both are important enablers of an organisation being able to switch sourcing inputs, production processes and distribution approaches. "Market Position" (IO16) concerns factors such as brand equity, customer loyalty, market share and product differentiation, which can influence response and recovery options; thus, "Market Position" can be seen as an enabler of flexibility. For example, in a disruption, a strong brand image combined with good customer communication can enable a supplier to promote substitute product lines, perhaps even securing future market share (Pettit et al., 2010).

3.3.1.2 Intra-organisational 2: Risk Aware Culture.

Risk aware culture was referred to in 14.75 per cent of papers reviewed and was used to broadly describe the infrastructure a firm has in place to manage risk. It goes beyond risk management in the sense of an assigned

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individual(s) simply identifying and mitigating risks on a case by case basis (Finch, 2004; Blome and Schoenherr, 2011; Jüttner and Maklan, 2011; Gölgeci and Ponomarov, 2015). Instead, it concerns the presence of a culture that encourages and enables organisation wide learning and adaptation from past disruptions and also leadership that espouses this (Christopher and Lee, 2004; Peck, 2005). It has been suggested that this may manifest in the form of high organisation wide efficiency, the presence of a business continuity plan and a high degree of joint decision making (Thun and Hoenig, 2011; Neureuther and Kenyon, 2009; Ritchie and Brindley, 2007). These principals were reflected in "Efficiency" (IO6), which concerns how resources are used so as to avoid unnecessary waste and disruption and "Leadership, "Business Continuity" (IO13), which concerns contingency plans for "mission critical" assets, "Innovation" (IO14), the presence of shared beliefs, openness to learning and joint decision-making both feed into the ability of an organisation to anticipate and respond to risk. Finally, "Adaptive Management" (IO17) which concerns the active monitoring of decisions made in relation to past disruptions and their outcomes enables incremental learning and adaptation to risk. Thus, all are supporting elements of IO2 Risk Aware Culture.

3.3.1.3 Intra-organisational 3: Redundancy.

Redundancy at the firm level was one of the most commonly cited resilience elements, appearing in 13.1 per cent of papers. Firm level redundancy concerns excess capacity to what is normally required. In this way, it buffers normal activities rather than providing options to do things differently as is the case with the element of "flexibility". One example could be spare inventory capacity, either in terms of ramping up production or in terms of excess storage space or transport capacity (McKinnon, 2006; Aigbogun et al., 2014). However, such approaches typically come at the cost of reduced efficiency and must be matched on an individual basis to specific identified risks (Ponis and Koronis, 2012; Manuj and Mentzer, 2008). It has been suggested that redundancy is best targeted at risk sources from beyond supply chain boundaries (such as natural disasters) and that elements such as "flexibility" are more effective for dealing with intra-supply chain disruptions (Wieland and Wallenburg. 2013).

3.3.1.4 Intra-organisational 4: Early Warning Detection Systems.

Early warning detection systems were referred to in 8 per cent of papers and concern a broad suite of attributes aimed at providing enhanced foresight of disruption so that an organisation can spend more time preparing and less time reacting to disruption. It includes not only monitoring abilities in the form of physical IT infrastructure but also the staff training and internal information flows that allow effective utilisation of information obtained, particularly with the rise of "Big Data" and The Internet of Things (IOT) (Christopher and Lee, 2004; Stecke and Kumar, 2009). As such, actions which an organisation can put in place internally to maximise warning of disruptions, such as "Inventory Management" (IO8), and to act on them, such as "Contingency Plans" (IO7), and "Relationships" (IO11) are key "Supporting" elements. Clearly, there are major overlaps between early warning detection systems which are considered to be intra-organisation and "visibility" which is often discussed in an interorganisational context.

3.3.1.5 Intra-organisational 5: Security.

Security concerns defence of assets (including knowledge, staff physical assets) against deliberate attack or intrusion. It is distinct from more general insurance and risk management and is increasingly pertinent in terms of food supply chains, given recent issues with traceability (Pettit et al., 2010; Bakshi and Kleindorfer, 2009; Elleuch et al., 2016a, 2016b).

3.3.2 Proposed "core" Intra-Supply Chain Resilience Elements

3.3.2.1 Intra-supply chain 1: Collaboration.

Collaboration was cited in 31 per cent of papers reviewed and refers to two or more actors working together to generate advantages that could not be achieved individually (Habermann et al., 2015; Zacharia et al., 2009; Lee, 2014; Scholten and Schilder, 2015). This can range from sharing of limited information to joint decision making, synchronisation of operations and more equal sharing of risk and assets, depending upon end consumer need and the level of trust between partners (Barratt, 2004; Giannakis and Louis, 2011). A number of "Supporting" elements are important in enabling collaboration to occur effectively and these include "Established Communication Lines" (IS13) which can aid the speed and effectiveness of coordination postdisruption as well as "Trust" (IS14) which influences the willingness of entities to talk in the first place. "Cohesion" (IS17), is also closely related as it concerns unifying factors such as mutual end consumers that can drive collaboration. "Bargaining Power" (IS20) concerns factors such as high relative purchasing power that might drive adversarial rather than collaborative supply chain relations. All of these supporting elements are enables of a "collaborative" AFSC.

3.3.2.2 Intra-supply chain 2: Flexibility.

In a supply chain context, flexibility was cited in 29 per cent of papers. Here, it concerned the degree by which a supply chain can maintain function and respond effectively to changing operating environments and customer requests through partnerships (Lam and Bai, 2016; Richey et al. 2009). It concerns alternate options that partners or the wider operating environment can provide, for example, postponement options, alternate infrastructure, logistics or staff (Gligor and Holcomb, 2012; Stevenson and Spring, 2007). "Node Criticality" (IS6) which concerns relative numbers of single key suppliers or buyers in a supply chain is a key aspect as is "Node Complexity" (IS18) which considers the density of actors in a supply chain and the distances between them (Saenz et al., 2015; Stecke and Kumar, 2009). Interestingly, "Node Complexity" is also a key enabler of "Information Flow" (IS7) in addition to "Flexibility" (IS2), as it determines the efficiency and effectiveness with which information is transmitted within a supply chain (Pereira et al., 2014; Smith et al., 2016). In turn, "Information Flow" (IS7) is a key "Supporting" element of the "Core" elements of "Visibility" (IS4) and "Adaptability" (IS3) highlighting the fact that supporting elements can serve to achieve multiple "core" elements. A final supporter of AFSC flexibility is "Community Resources" (IS21) which considers the range of ecological, economic, social, physical, institutional and cultural resources a community can draw upon when faced with disruption

(Smith et al., 2016).

3.3.2.3 Intra-supply chain 3: Agility.

In total, 27.8 per cent of papers referred to agility as a supply chain-wide resilience element. Agility is closely related to flexibility, but whereas flexibility concerns alternative "options", agility relates to how these options are used and particularly the speed at which they can be implemented to recover lost functionality (Sharifi and Zhang, 1999; Dubey et al., 2014). Interestingly, while agility focuses on quick recovery, it does not always have to involve the most efficient response (Braunscheidel and Suresh, 2009; Swafford et al., 2006). As such, "Velocity" (IS8) which concerns the speed and efficiency with which products traverse a supply chain, and "Rapidity" (IS12), which concerns the ability of a supply chain to meet objectives in a timely manner both aid overall agility (Christopher and Lee, 2004; Tendall et al., 2015; Johnson et al., 2013). Additionally, supply chain "Risk Management Orientation" (IS15) which concerns supply chain wide presence of procedures to identify and develop contingency plans for disruptions can enhance recovery speed and effectiveness, thus contributing to agility. Equally, "Responsiveness" (IS22) which concerns a supply chain's ability to respond to consumer demands, particularly via lead time reduction efforts, also supports overall supply chain agility (Saenz et al., 2015; Aramyan et al., 2007).

3.3.2.4 Intra-supply chain 4: Visibility.

Visibility is cited by 24 per cent of papers as being a key supply chain scale resilience element. It concerns the ability to see structures, products and processes from one end of the supply chain to the other (Pettit et al., 2013). Clearly therefore, there is major overlap with "Information Flow"

(IS7) which concerns effective and efficient flow of information from one end of the supply chain to the other (Soni et al., 2014; Faisal and Banwet, 2006). However, it is not only about information flow but also about directing the right knowledge to the right people at the right time (Christopher and Lee, 2004; Carvalho et al., 2014). Therefore, it is very much about information management. Such information can concern company processes and assets or, alternatively, the wider operating environment, for example, consumer trends and competitor technology. As such, visibility is synergistic with "Collaboration" (IS1) (Brandon-Jones et al., 2014; Gunasekaran et al., 2011; Aigbogun et al., 2014).

3.3.2.5 Intra-supply chain 5: Adaptability.

Adaptability is a measure of a system's ability to adapt incrementally or to completely transform in response to a changing operating environment (Sinclair et al., 2014; Tukamuhabwa et al., 2015). It is distinct from "Agility" (IS3) which concerns tactical level adaptations and instead focuses on system wide evolution in response to changing operating environments. To be able to do so, a supply chain's "adaptability" is also dependent on the presence of "Self-Organisation" (IS11) which refers to the autonomy, ability and will of a system to internally organise itself as opposed to being driven by external forces. (Milestad and Darnhofer, 2003; Lebel et al., 2006). Equally important is "Co-Learning" (IS19) which involves the procedures in place to aid system wide joint learning from both near misses and actual disruptions (King, 2008; Pettit et al., 2010).

3.3.2.6 Intra-supply chain 9: Redundancy.

Redundancy at a supply chain scale concerns system-wide design of emergency back-up and storage facilities, surplus pathways between nodes and the extent to which different supply chain nodes and components are replaceable (Bode et al., 2011; Ratick et al., 2008). It was cited by 9 per cent of papers reviewed as being a key supply chain wide resilience enabler. An important "Supporting" element is "Robustness" (IS10) which is a marker of a system's ability to absorb change without losing core functionality (Ivanov et al., 2015). In turn, the principles of "Robustness" seem to be almost identical to those of "Buffer Capacity" (IS23) (Milestad and Darnhofer, 2003; Spiegler et al., 2012). "Diversity" (IS16) has also been linked to redundancy in the context of different skill sets that can be used to reach the same outcome at a supply chain level (Fiksel, 2003).

Having identified relevant resilience elements from the literature, this section now completes Q1.2 by exploring the resilience strategies that help an organisation to identify what resilience elements to use in a given situation and time. It was observed that one of the more common approaches in the literature was to focus on resilience elements with the highest citation factor (Manuj and Mentzer, 2008; Christopher and Lee, 2004; Ratick et al., 2008). In very industry specific works, this approach is effective, however, as was identified in the introduction of this review, AFSCs must consider a broad range of risks stemming from social, environmental and economic drivers. This means that the right resilience element might not always be the most highly cited element. This is addressed in Figure 6 by the proposal of a range of "Core" and more focussed "Supporting" elements that are highly situation specific. However, this means that there is a need for a more thorough implementation strategy.

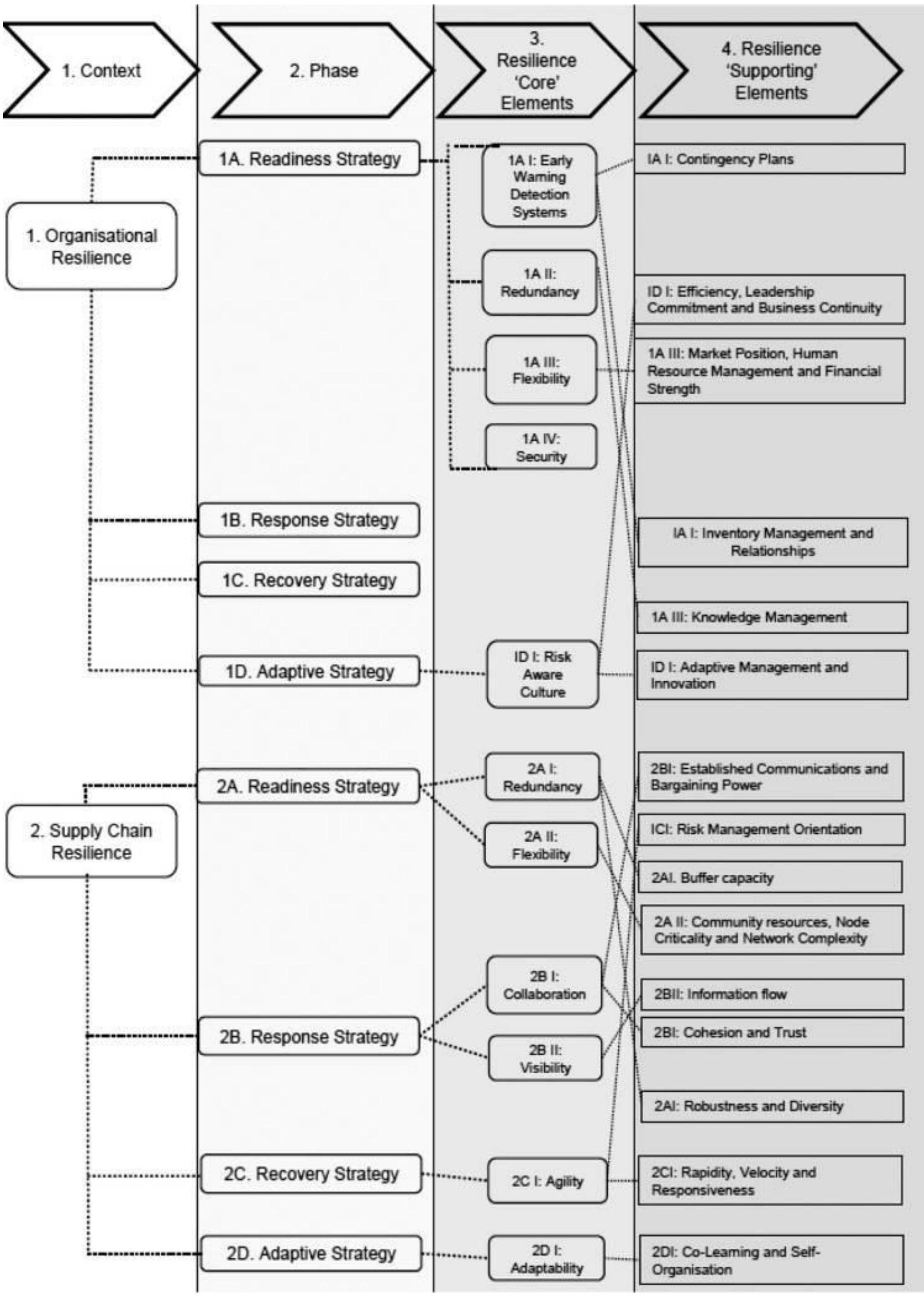
One solution is to use the "phases" of disruption which were identified in addressing Q1.1 as being major components of many resilience definitions in the literature. These phases are "Readiness" (the ability to anticipate potential disruptions), "Response" (the ability to mitigate the impact of a disruption as it happens) and "Recovery" (the ability to return to core function and repair losses rapidly) as identified by Ponomarov and Holcomb (2009). Added to these three is "Growth" (the ability to adapt for competitive advantage) as described by Hohenstein et al. (2015). Hohenstein et al. (2015) further develop the use of phases by attempting to match a small number of resilience elements to a "Proactive" Strategy (aligned to the "Readiness" phase) and "Reactive" Strategy (aligned to the "Response", "Recovery" and "Growth" Phases). While useful and novel, the proposed groupings consist of a narrow range of the elements compared to those identified by this review (Figure 6), and furthermore, these are heavily orientated towards organisational competitiveness, rather than how a complex system, such as an AFSC, can maintain function and adapt. The authors of this review therefore propose the categorisation of the resilience elements identified (Figure 6) by phase as presented in Figure 7. For consistency, the “Readiness”, “Response” and “Recovery” phases identified by Ponomarov and Holcomb (2009) have been retained.

In this context, elements categorised in the Readiness Phase concern elements that assist in monitoring changes to the operating environment and those which, while being useful in later phases, must be built in in advance. Elements in the Response Phase focus on mitigating the impact of disruption and helping to maintain functionality. Elements in the Recovery Phase are orientated towards minimising the time needed to restore any lost functionality and enabling adaptation at an operational level (such as accepting new ingredients or distribution routes). In this review, the “Growth” phase identified by Hohenstein et al. (2015) has been renamed as the “Adaptive” phase. This is because the context of the growth phases supports the notion of competitive advantage and incremental improvement of the pre-disruption state of equilibrium (Hohenstein et al.,2015).

However, exploration of the adaptive theory of resilience (addressed in Q1.1), suggests that the focus of this phase in an AFSC context should be the alignment of core values with an ever-changing operating environment. Therefore, adaptive phase elements concern the ability for long term, system wide, adaptation, perhaps significantly affecting core function, in response to changing operating environments.

At an organisational level, four of the five “Core” resilience elements are readiness phase elements. Early warning detection by nature involves techniques of generating forewarning of possible disruptions ahead. Flexibility, redundancy and security must all be built in advance (Pettit et al., 2010; Manuj and Mentzer, 2008). None are free, and this necessitates careful matching to vulnerabilities identified by early warning detection. Risk aware culture, the final organisational “Core” resilience element, is an adaptive phase element due to its focus on systemic learning from past disruptions, and joint decision making to bolster future preparedness. Interestingly, “Supporting” elements are not necessarily used at the same stage as their matching “Core” element. For example, under the “Core” element of Early Warning Detection Systems, the “Supporting” element “Contingency Planning” is a readiness phase element; however, the “Supporting” elements of “Inventory Planning” and “Relationships” between teams and individuals, while established in preparation, are actually used at the response phase. At a supply chain level, distribution of “Core” elements by phase is much more even, with redundancy and flexibility appearing as readiness phase elements, collaboration and visibility as response phase elements, agility as a recovery phase element and adaptability as an adaptive phase element. Flexibility and redundancy concern advanced design of products, processes, infrastructure and transport routes in preparation for disruption (Sheffi and Rice, 2005; Stecke and Kumar, 2009). Collaboration and visibility concern relative ability to work with supply chain partners to mitigate disruption and maintain core function. While they are supplemented by readiness phase activities such as contingency planning and establishing IT infrastructure, the actions themselves are commonly cited as response elements (Jüttner and Maklan, 2011; Scholten et al., 2014). Agility is most commonly cited as a recovery element and is concerned with the ability to rapidly make good lost functionality through making tactical changes in response to the new operating environment (Wieland and Wallenburg, 2013; Braunscheidel and Suresh, 2009). Adaptability on the other hand is an adaptive phase element and concerns the relative freedom a supply chain has to fundamentally realign itself at a strategic level post disruption. This might be, for example, a system-wide overhaul of logistics, but to do so, there needs to be a culture of discussion and joint learning/decision-making across supply chain partners (Estrada-Flores et al., 2009).

Figure 7: Proposed strategy for using resilience elements based on phase of disruption



3.4 Addressing Q1.3

This paper has so far analysed the multi-disciplinary definitions, elements and strategies concerning resilience and identified aspects that are of importance to AFSCs. In addressing Q1.3, this paper will now synthesise the identified multidisciplinary aspects of resilience into a conceptual framework of AFSC resilience. As identified in addressing Q1.1, AFSCs are complex socioecological systems with interactions occurring across different scales, distances and periods, all of which must be assessed together to accurately model resilience. This review has identified a number of unique food system challenges, summarised as follows (Diabat et al., 2012; Higgins et al., 2010; Taylor and Fearne,2006):

1 A network of potentially thousands of participants, in stark contrast to the widely accepted view of a linear buyer–seller chain reaching from farm to consumer.

- It is important to appreciate that a vast range of supporting dependencies such as equipment suppliers, fuel infrastructure, financial services and logistics, among others, enable food to reach end consumers.

2 Strong social drivers, such as health, lifestyle, the need to protect the natural world, as well as economic goals.

3 Strong genetic, environmental and climatic variability.

- Food products are naturally variable in colour, shape and size even before the effect of the growing environment and particularly climate change are considered in terms of their effect on yield.

4 Low-value end products.

- Food is typically purchased frequently and represents a low proportion of household expenditure in relation to other consumer goods such as electronics (although it is accepted that proportion of household expenditure can vary significantly depending on location).

5 Declining margins.

- A range of factors, in addition to those described in challenge (d), including globalisation and the increasing dominance of large multiple food retailers, are driving ever lower margins in AFSCs.

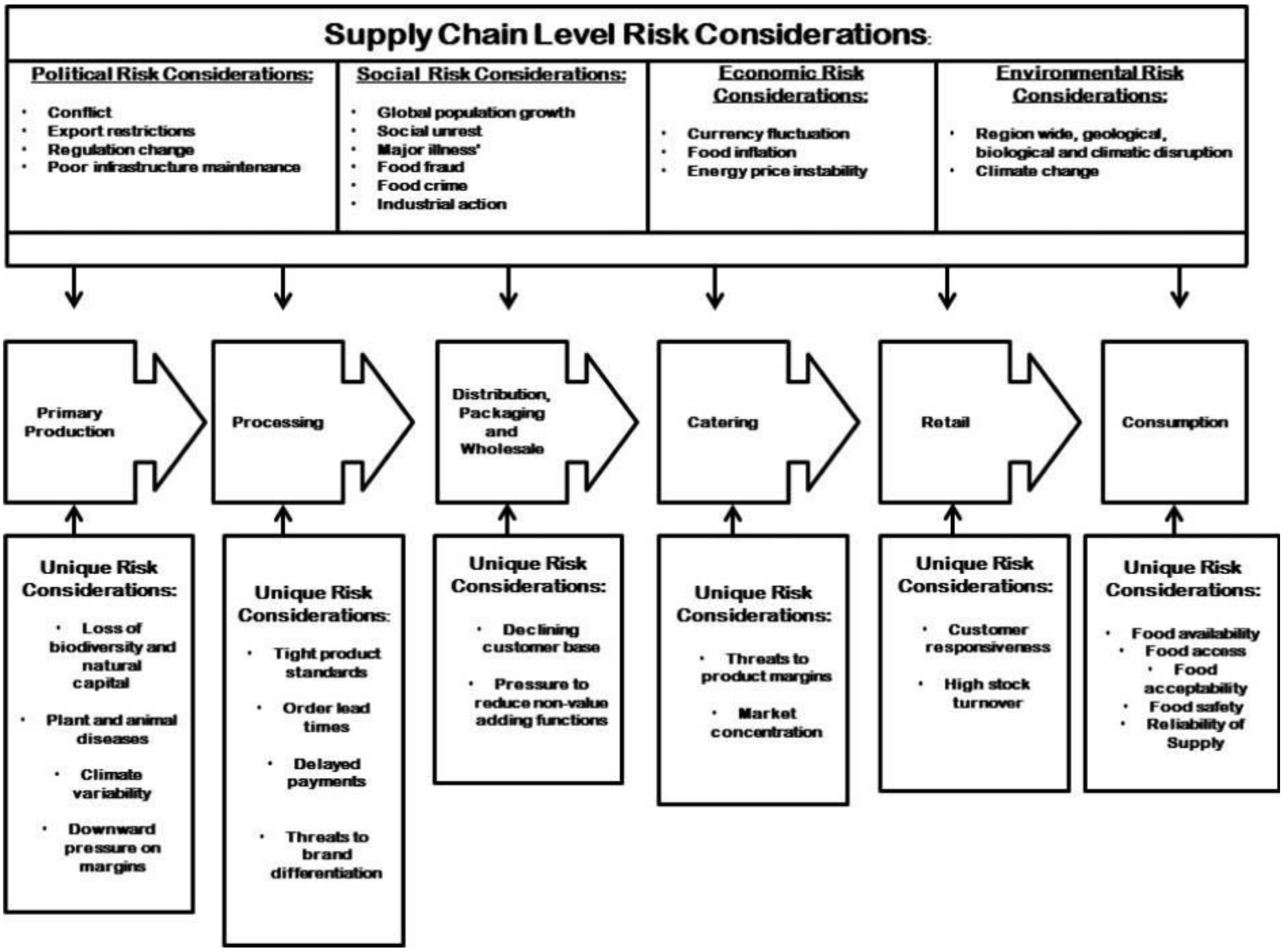
Figure 8 explores how these challenges manifest as unique risk sources for each of the traditional AFSC stages: primary production, processing, distribution, catering, retail and consumption (Elleuch et al., 2016a, 2016b). Primary producers face a range of natural stressors which put yield and quality at risk, such as disease and bad weather, as well as anthropogenic damage to natural capital such as pollination, soil fertility and water access. Historically, they have also faced major downstream pressure from buyers which has squeezed their margins, often driving smaller farmers, and thus production diversity, out of business. Food processors, who historically held much more supply chain power, are similarly facing downwards pressure from large retailers, favouring "lean" approaches which reduce nonvalue adding activities, thus reducing flexibility and redundancy (Van der Vorst and Beulens, 2002). Increasingly, viability is dependent on brand differentiation, a gap which retailers are fast closing with their own "private labels". Wholesalers are traditional stock holders in AFSCs and major risks stem from a reduction in customer base as smaller "cash and carry" buyers are being replaced by large supermarkets. Catering is commonly the biggest source of value in modern AFSCs. Key strengths include customer responsiveness and diversity, although there is some risk from market concentration.

Retailers themselves are often described as the gateways of modern AFSCs due to their market share and proximity to end consumers. Yet, the "Just in Time" models which enable them to offer high variety and value leaves them at risk of supply disruption. Their proximity to consumers also means that they can have less time to react to changing consumer demands. The resilience of each stage described so far is vital in ensuring food security, or in more specifically, that food is physically available (ready for consumption in principle), accessible (somewhere the consumer can access it), acceptable (in a form that is culturally acceptable), safe and reliable.

In addition to their own unique risks, all of the stages together are influenced by a number of overarching risk sources in the wider social, political, environmental and economic spheres (Colicchia et al., 2010; Vlajic et al., 2013). These risk sources can often be separated by significant distance and even periods from a given organisation or supply chain and their impacts are not linear (Vlajic et al., 2012). For example, recent extreme weather in key regions of Spain and Italy decreased production by as much as 60 per cent. Due to retailer sourcing policies across the continent, many initiated decades ago, where focus was placed on a relatively small number of large-scale intensive producers, often purely for economic reasons, large sections of Europe suffered severe vegetable shortages in the winter of 2016-2017. Due to the growing times of crops, and length of buyer contracts, such disruptions can take many months to resolve (Food Navigator, 2017). Thus, it is vital that distance, time and scale are considered together.

Appendices

Figure 8: Unique AFSC risk sources from a whole supply chain perspective and that of individual actors within a given AFSC

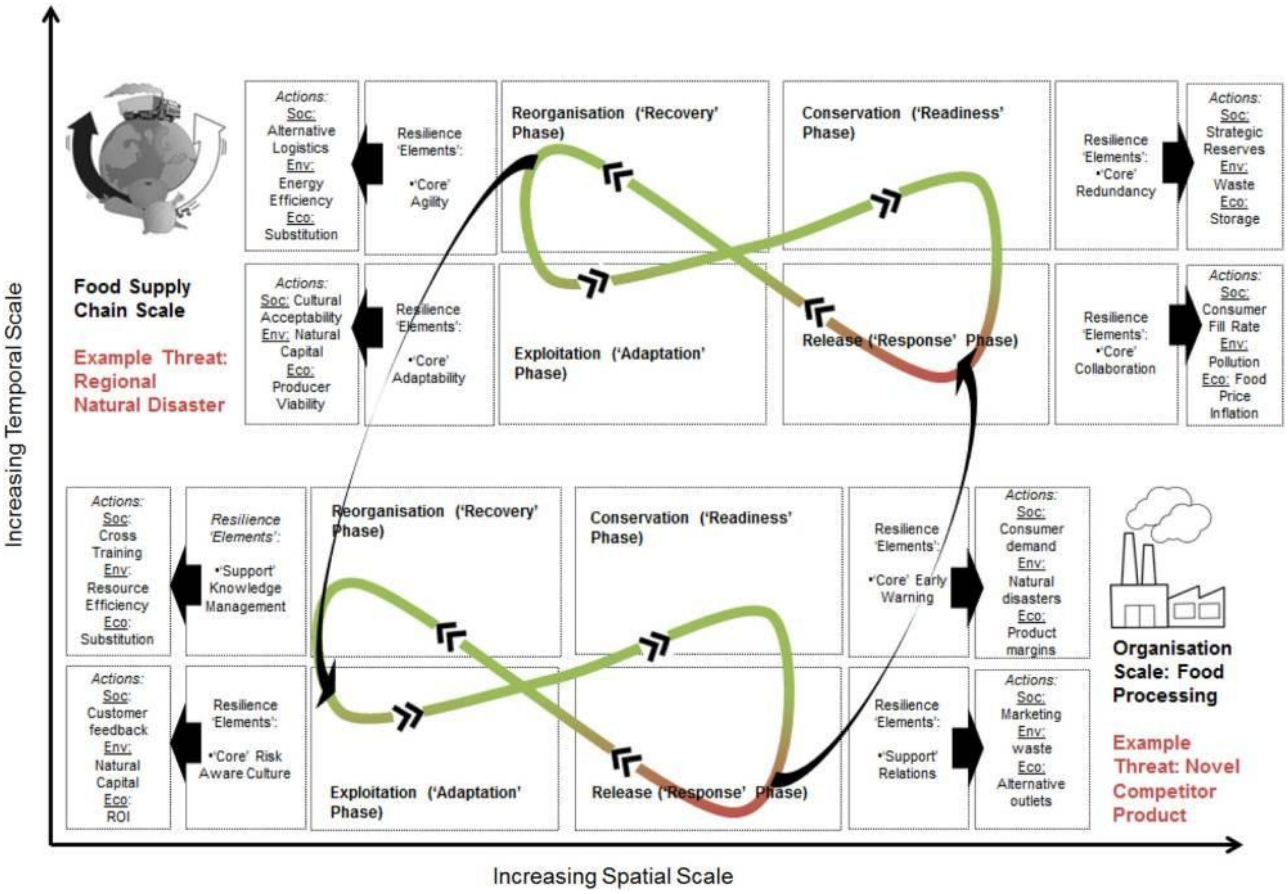


One approach to addressing this issue is to break down AFSCs into constituent stages and optimise them based on average operating conditions, perhaps by identifying resilience elements and strategies as has been attempted at a farm, processing, retail and community level in the literature (Milestad and Darnhofer, 2003; King, 2008; Leat and Revoredo-Giha, 2013; Macfadyen et al., 2015). However, optimising individual stages of a supply chain in this way does not necessarily allow them to adapt to novel situations, and it is possible that optimising one stage may be detrimental to upstream or downstream stages which is unacceptable if the end goal is a more reliable food system overall.

In response, the authors of this review propose that the adaptive definition of resilience is an important lens through which any understanding of AFSC resilience must be built. The adaptive definition prioritises the role of cross-scale system component interactions to the point that external volatility is presumed to be a permanent feature and as such, rather than being a one-off fix, resilience must be seen as a cyclical process of “conservation”, “release”, “reorganization” and “exploitation”. In particular, similarities between the drive towards concentration of assets and connectivity in today’s global AFSCs and the "conservation" phase suggest vulnerability to major disruptions.

In addressing Q1.2, this paper identified the importance of capturing multidisciplinary "Supporting" elements of resilience, which reflect the role of social and environmental components of AFSCs rather than the traditional economic buyer–seller relations described in many supply chain works. These resilience elements are vital in addressing the unique AFSC risk sources identified previously. This review has also identified the importance of phase-based strategies of identifying which "Core" and "Supporting" resilience elements should be used and when. Therefore, the framework of AFSC resilience proposed is a synergistic one, combining the ecological science understanding of adaptive systems and "panarchy", with resilience elements and strategies originating from SCM. A descriptive example of this framework can be found in Figure 9. The framework proposes that parallels can be drawn between the four stages of the adaptive cycle (conservative, release, reorganisation and exploitation) and the four phases of a disruption, respectively (readiness, response, recovery and adaptation). It is proposed that there is similarity between the readiness phase of a disruption and the conservation stage of the adaptive cycle due to both considering the relative preparedness of a system before a disruption. There are also similarities between the response phase of a disruption and the release stage of the adaptive cycle, as both focus on the effects of a disruption. Similarly, there are overlaps between the recovery phase of a disruption and the reorganisation

Figure 9: Example application of proposed AFSC framework synthesising the adaptive cycle of resilience with resilience elements and phases

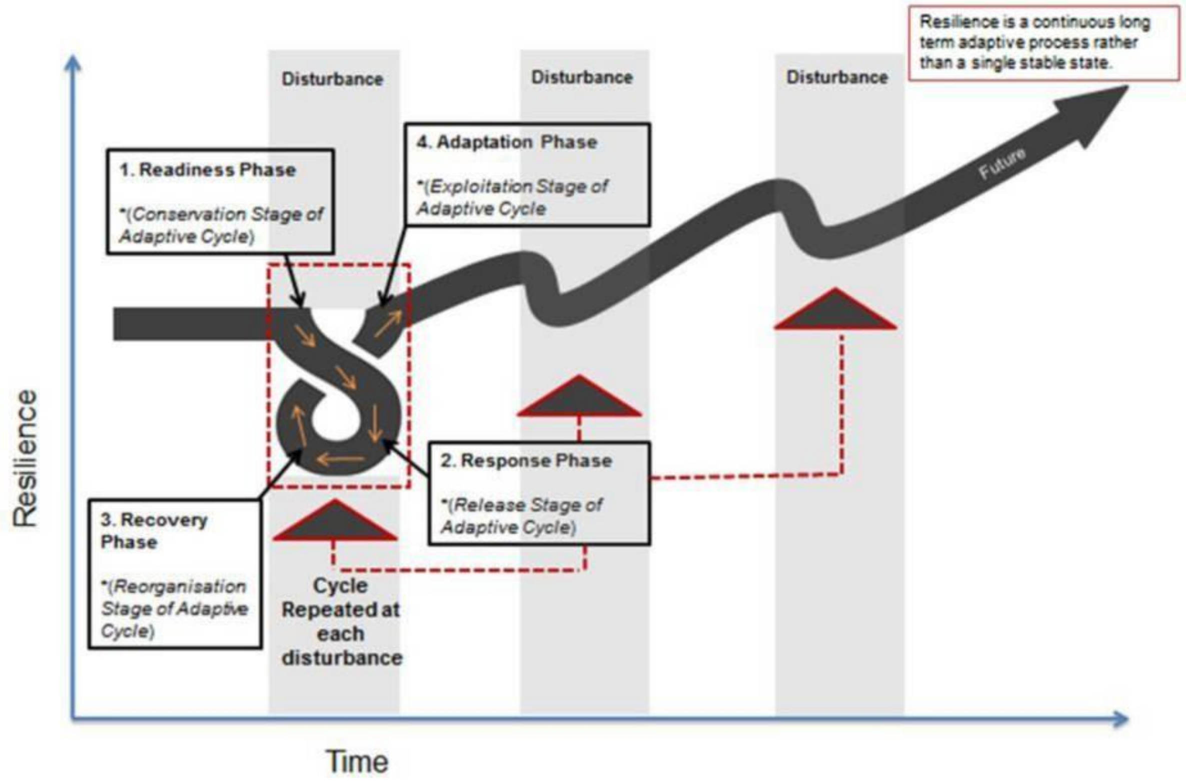


stage of the adaptive cycle as both concern regaining functionality. Finally, overlaps also exist between the adaptive phase of a disruption and the exploitation stage of the adaptive cycle, as both involve growth potential as a result of adaptation to previous disruptions. These relations are exemplified in Figure 9 from the perspectives of an organisation, in this case a food processor, and the overarching food supply chain. Each faces a unique example risk from those categorised in Figure 8; the food processor a novel food product launched by a competitor unexpectedly and the supply chain, a serious regional natural disaster. By dividing the disruption into phases, the food processor and the broader supply chain are able to assign bespoke mitigating resilience "elements" from those categorised in Figure 6. To better reflect characteristics of AFSCs, such as their importance to end consumer food security and diverse range of stakeholders, the actions for each resilience "element" are divided into social, environmental and economic indicators. This distinguishes them from previous works which have applied resilience elements for the purpose of organisational competitiveness. Not only do these three indicators represent the broad dependencies of food systems but they are also commonly used as the three pillars of sustainability; thus, the framework underpins the synergistic relationship between resilience and sustainability identified by others. Using the example of the supply chain, actions at the response phase where collaboration was identified as a suitable "Core" element include the need to work together as a supply chain to ensure food is available, safe and accessible to consumers. At an environmental level, the caveat is added that efforts to get food to consumers, perhaps by using alternative logistics, do not come at the cost of excessive pollution. Economically, it is vital that organisations do their best not to exploit competitive advantage and drive food price inflation for end consumers. This, of course, is highly idealised, and the reality is that actions by individual organisations, in this example the food processor, to an earlier threat such as product competition, may actually preclude them from working collaboratively at a supply chain level. This represents a major advantage of using the adaptive model because it can explore the cross-scale interactions that can take place over great geographical and temporal distances. A further key advantage of using the adaptive cycle as a basis for an AFSC framework is that it is cyclical in nature. In other words, there are no optimised "states of equilibrium" for an organisation to work towards, and this makes it inherently better suited to describing volatile operating environments, where disruptions are continuous, such as food systems, as illustrated in Figure 10. As such, the emphasis is on ingraining resilience across all activities, rather than as a one-off tool to address individual disruption risks, and in doing so, resilience becomes cumulative. In this way, a resilient food system is more of a safe-fail system rather than a fail-safe system (Anderies et al., 2013).

4. Implications for Supply Chain Theory and Practice

In light of a number of recent high-profile disruptions to AFSCs such as the 2007-2008 food price spikes, the winter 2016-2017 European vegetable disruptions and projected future volatility, this review was designed to explore how the increasingly popular topic of resilience can be applied to AFSCs. In meeting this objective, definitions, elements and strategies of resilience were investigated, analysed based on their suitability for AFSCs and synthesised into a novel framework of AFSC resilience which considers AFSCs as complex systems rather than constituent organisational competitiveness, as has been the focus in the past. This presents a number of implications at a practical level in terms of management and policy. Findings suggest that it is important to consider a wide range of resilience elements which go beyond the most commonly cited "Core" elements and to consider "Supporting" elements. Such "Supporting" elements often consider the broader relationships, knowledge management and capacities for learning and adapting which are vital in achieving "Core" elements such as flexibility and redundancy.

Figure 10: The cumulative nature of resilience



These "Supporting" elements are also vital in understanding AFSC resilience from an "adaptive cycle" perspective, as they enable the links between organisational resilience strategies and broader supply chain wide resilience to be better understood. Ignoring such "Supporting elements" and the cross-scale interactions between different geographical and temporal points in a supply chain will restrict a given organisation's resilience to outside volatility (Caschili et al., 2015). Appreciating such links is important for ensuring that food systems are robust enough to guarantee food availability, access and acceptability which are three of the four main areas of food security, which in turn, is arguably the ultimate goal of food systems. In achieving the fourth goal, reliability, the broader sustainability impacts of chosen resilience elements must be considered, and this is enabled by using social and environmental, in addition to more traditional economic, indicators. Linked to this is the need to design resilience strategies around the different phases of disruption in which a resilience element must be implemented. This is vital because resilience elements often have a cost and, unless carefully matched to a specific vulnerability, can be highly resource inefficient and harmful to long-term sustainability (Tang, 2006).

From a theory perspective, this review has identified what appears to be a growing consensus that the adaptive definition is best suited to describing supply chain and particularly AFSC resilience (Table IV). Furthermore, the focus of works across multiple disciplines appears to have moved on from definitions towards proposing resilience "elements" and "strategies". However, to be useful in an adaptive context, it is imperative that such resilience "elements" and "strategies" consider not only an immediate organisation, or even its supply chain partners, but also broader social and environmental supply chain dependencies and their cross-scale interactions. In response to this challenge, this review comprehensively categorises 40 resilience elements from multiple research fields into "Core" and "Supporting" elements, enabling the valuation of less commonly cited elements which enable the ability to adapt and consider different spatial and temporal scales. Yet, the framework proposed is conceptual in nature, and to help advance AFSC resilience theory, there is a need for empirical validation of the elements that help actors at the different stages of an AFSC (Figure 8) to be resilient. There is also need for further development of the social, economic and environmental indicators proposed in Figure 9 which help organisations to "action" a given element whilst underpinning their resilience strategy in good sustainability practice. This is part of a broader need for future works to develop strategies for implementing resilience "elements" that aid wider supply chain delivery of food security, rather than strengthening individual organisations within that supply chain.

5. Conclusions

Resilience of national and global food systems is an increasingly important topic in light of growing volatility induced by challenges as diverse as climate change, population growth and resource constraints. Despite a growing interest in the concept of resilience from a number of research fields, a number of factors including the focus on food security as a priority, rather than economic competitiveness, as well as unique attributes of food as a biological resource, mean that these works are not readily adoptable by AFSCs. In response, this review systematically reviewed 137 relevant works to address Q1. To support this objective, the findings were analysed in the form of three review sub-questions.

In answering Q1.1, 48 papers offered definitions, all of which were based on one of either the engineering definition (single optimum state of equilibrium), the ecological definition (multiple possible states of equilibrium) or the adaptive definition (no states of equilibrium, but rather a constant process of evolutionary learning in response to constant changes stemming from external systems). Analysis of publication dates suggest that the adaptive definition is increasingly accepted as the most appropriate way of describing complex systems such as supply chains, particularly AFSCs. A number of definitions referred to the abilities of readiness, response and recovery as being key resilience enablers and adaptive definitions often added a fourth capacity which was to "adapt" after disruptions, thus ensuring that resilience is relative to operating environments and not static idealised conditions. Yet, in many works, the priority of resilience is often organisational competitiveness. The findings suggest that for AFSCs the goal should be food security and therefore the following definition of AFSC resilience is proposed: The collective ability of AFSC stakeholders to ensure acceptable, sufficient and stable food supplies, at the required times and locations, via accurate anticipation of disruptions and the use of strategies which delay impact, aid rapid recovery and allow cumulative learning post-disruption.

In answering the first part of Q1.2, 40 unique resilience elements were identified from 61 papers. A small number of elements received the majority of citations, and this was often how resilience "strategies" were formed in the literature (Hohenstein et al.,2015). Many of the less commonly cited elements explore interactions and relations between organisations, communities and the natural environment, as well as their ability to adapt, and this has important implications for how individual company actions can interact across spatial and temporal scales with broader AFSC resilience. In response, the unique categorisation of resilience elements into "Core" and "Supporting" elements is proposed to capture this values. This approach also allows the alignment of each to a relevant "phase" of disruption (readiness, response, recovery and adaptation) and in doing so, forms a more comprehensive resilience implementation "strategy".

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In addressing Q1.3, relevant findings concerning resilience definitions, elements and strategies from the previous two review sub-questions were synthesised to propose a hybrid adaptive cycle-resilience element framework that was underpinned by a number of stage specific risks and characteristics of AFSCs. In this framework, it is proposed that resilience elements and their phases of use can be associated with the key principles of the adaptive cycle, namely, conservation, release, recovery and exploitation. In linking the two, the cyclical nature of disruptions is highlighted, reinforcing the cumulative nature of resilience efforts. Furthermore, because the adaptive cycle is designed with systems in mind, it captures the links between resilience elements used at an organisational level and their impacts on the corresponding adaptive phase in the wider supply chain. Not only is such a hybrid approach unique in its own right, but the application of AFSC stage-specific risk sources and indicators that consider social and environmental impacts, as well as the more traditional economic performance measures, when considering which resilience elements to use, better align this framework with food security and long-term sustainability rather than economic competitiveness.

6. Limitations and future work

This review has provided a timely and rigorous systematic review of a range of multidisciplinary works relevant to resilience in an AFSC context. Its novelty lies primarily in the synthesis of relevant concepts from a range of disciplines to form a more holistic view of AFSC resilience than would have been possible from reading any piece of the review material in isolation. However, it is at base a conceptual piece of work, which is restricted to information published in the peer reviewed literature. As such, while the authors feel that the practical implications of this work are potentially significant due to their ability to help align resilience at an organisational level with wider societal food security, empirical validation of the resilience elements and strategies described is a key next step. Furthermore, the framework described in Figure 9 is orientated towards developed world supply chain structures and specific risks in this context. However, resilience is equally pressing in developing world supply chains, particularly given the greater prevalence of subsistence agriculture in such regions and the fact that it is in the developing world that a great proportion of global population growth and urbanisation is projected to occur (United Nations, Department of Economic and Social Affairs, Population Division, 2015; Gorton et al., 2014). Here, it is likely that risks will stem from primary production challenges and post-harvest storage issues. This may therefore challenge the suitability of the mitigating resilience elements proposed in this paper. As such, adapting the framework for a developing world setting is something the authors aim to investigate in future work.

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Appendices

Appendix 4: Conference Paper

An Overview of Resilience Factors in Food Supply Chains

This paper has been published in the proceedings for the European Society of Ecological Economics and was presented by Jamie Stone at the 11th International Conference of the European Society for Ecological Economics at the University of Leeds, UK.

For reasons regarding conciseness, it is not included in full, but can be freely accessed from the Loughborough University Online Institutional Repository here: https://dspace.lboro.ac.uk/dspace-jspui/handle/2134/19826

Appendix 5: Book Chapter

Forging New Frontiers in Sustainable Food Manufacturing

This article has been accepted for publication in the book *Smart Innovation, Systems and Technologies* and presented as a keynote paper by Prof Shahin Rahimifard at the 4th International Conference on Sustainable Design and Manufacturing on 26-28th April 2017 in Bologna, Italy.

This paper cannot be included in this appendix due to copyright reasons. The publisher website can be found at this link: http://www.springer.com/series/8767.