An overview of resilience factors in food supply chains

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Abstract

Food supply chains face a number of unique vulnerabilities compared to other supply chains and there is concern that, as operating environment volatility increases, current "lean" supply chain management strategies may no longer be fit for purpose. There is a need to manage food supply chains in such a way that a return to the original state, or preferably an improved state, after being disturbed is possible. However, whilst the literature reveals a relatively large amount of work on resilience in supply chain management, there is poor consensus over how to define and implement a system of resilience, particularly one which takes into account food specific vulnerabilities. In response, this paper explores the current complexity of food supply chains, highlighting key dependencies, failure modes and key performance indicators. It then examines the interdependencies between capabilities and vulnerabilities in allowing balanced resilience and presents a framework to bring together and aid understanding of these factors across food supply chains.

Keywords: Resilience, Food Supply Chains, Sustainability, Global Food Security

1. Introduction

In the UK, shops and restaurants serve a vast array of foods from around the world, with supermarket policy often such that shelves never appear empty (1). Combined with high affordability of food, relative to incomes, and an ever growing disconnection between society and food production, it is no wonder that food is often seen as an infinite commodity. The idea that food supply chains (FSCs) could be interrupted is alien to your average citizen with

arguably the last really serious disturbances being rationing in the Second World War. Yet Britain is a relatively small land mass with a large population. It would be impractical and undesirable to be completely self-sufficient and for this reason Britain is inextricably linked to global production, demand and supply and with this comes vulnerability (2).

It is increasingly accepted that supply chains in all forms face increasing volatility across a range of business parameters from energy cost, to raw materials, and currency exchange rates (3-5). FSCs not only share these general risks, but also face their own unique vulnerabilities due to the limited shelf life of food, existing variability in quality and availability of raw materials, long production throughput times, and the fact that many raw ingredients are susceptible to deterioration in quality as they travel along the supply chain, resulting in heavy reliance on chilled transportation (4,6).

These vulnerabilities are only likely to become more pronounced in 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 through drought, flooding, and increased occurrence of pests, diseases and weeds (7). Changing climate may also disrupt the extent of key fisheries as key species migrate or are adversely affected by changing climate. Moving beyond the production stage, as population size and affluence increases, not only does demand for food increase, but diets transition towards becoming increasingly meat, dairy based as well as being more heavily processed.

In the past, the priority of Supply Chain Management (SCM) strategies has been, and continues to be, cost minimization and service optimization favouring flexible “just in time (JIT)” approaches and elimination of non-value adding activities. Yet it is argued that current SCM strategies, designed in a business operating environment of relative stability over the previous 30 years, are no longer fit for purpose given increasing volatility. The lack of inventory, inherent in such lean systems, limits the flexibility many such systems possess to deal with disturbances (8). It is increasingly clear that the emphasis today needs to be upon resilience- the ability of a food chain to quickly bounce back to its original or even an improved state following a disturbance (9).

Evidence suggests that the complexity of modern supply chains is poorly understood and that this may limit awareness of risk (9). In response, this work begins with a review of key components and dependencies of modern FSCs in order to assess whether existing definitions are fit for purpose. It then proceeds to explore the different definitions of resilience in food supply chains based on a review of the literature. It is felt that this is pertinent, given that resilience has many contributing factors, many different meanings to different stakeholders, and poor consensus of definition in the literature (10-11). Previous work in the literature has broadly focussed on the areas of Corporate Governance (10), Business Continuity Management (11), and National Emergency Planning (12). However, little of this work has focussed on FSCs in specific. This paper draws together key themes in the literature, and ultimately presents a framework which is designed to be utilised by all stakeholders across the food supply chain. It allows actors to map their individual supply chain dependencies, categorise unique vulnerabilities, capabilities and thus specific risk, and from this to create balanced resilience. It is envisaged that this framework will encourage ubiquitous resilience planning in industry, as well as improving supply chain visibility and aiding actors external to the food supply chain in better understanding its capabilities in the event of disruption.

2. Understanding Food Supply Chains

In order to define resilience in supply chains, it is important to define supply chains themselves. Keeping the UK as an example, FSCs can be said to broadly consist of initial primary producers, followed by manufacturers, wholesalers, retailers/caterers and finally the consumer. At each stage of the chain, value is added to the product to take into account processing, packaging, delivery and waste disposal. As such, as a general rule of thumb, the initial raw material often only reflects 15% of the finished product price (13). This provides the typical image of linear, value adding, food supply chains travelling directly from producer to customer (14-15). Indeed, there is evidence that many managers within the food supply chain still cling to this belief (9,16). This definition is incorrect because it ignores the fact that FSCs are often international and highly complex in scope, pulling in a number of other economic, environmental, social political and legal components. In doing so, this cloaks vulnerabilities, increases risk, and ultimately reduces resilience. Lambert et al. correctly distinguish between primary (direct

operational role in producing a given product) and secondary (resources, utilities, knowledge or assets, for example, dependencies such as fuel infrastructure, financial services or certain import dependencies such as exotic finished products) actors (17). As such, many advocate the replacement of "chain" with "network" to represent the fact that there will normally be multiple suppliers (including suppliers of suppliers) as well as multiple customers (and their respective customers) to be included in the total system. This is represented in *Figure one* below.

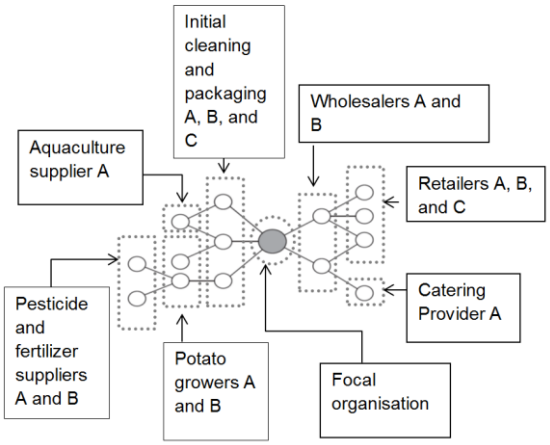

***Figure one**: Supply chain network complexity based on image by Christopher (2005).(18)*

This is reflected in definitions within the literature, particularly the widely cited work of Christopher (2005), "the network of organisations that are involved, through upstream and downstream relationships, in the different processes and activities that produce value in the form of products and services in the hands of the ultimate customer"(19). However, this view still only captures the financial plane of FSCs. Many advocate a triple bottom line view of FSCs which, in addition to finance, also includes social and environmental components. This is primarily from an increasing twenty first century appreciation of the need for sustainability, given increasing awareness of climate change, and social disparity (18,20). Ultimately, this view examines the "qualitative" outcomes of FSCs (18) (see *Figure two*).

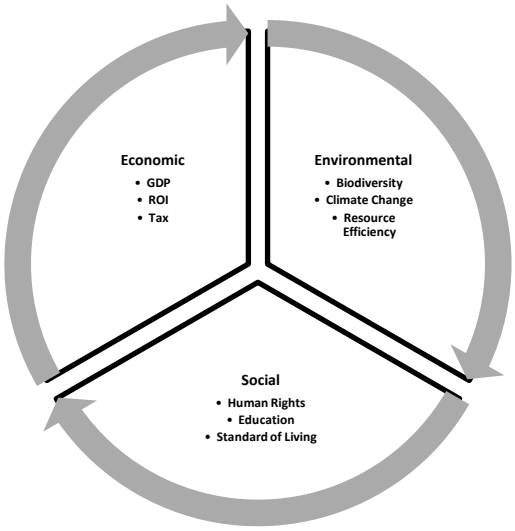

Figure Two. *Triple Bottom Line outcomes.*

However, the authors would argue that these different planes are more than sustainability targets. FSCs are unique amongst all supply chains in that they are dependent on healthy ecosystems for continued production, they are heavily affected by policy regarding land use and inputs, and they are a bridge to societal health, culture and connection with the natural world (21). Therefore, in addition to being requirements of sustainability, these different planes actually form a unique set of dependencies of FSCs, without which, the supply chain would not function. Therefore it is proposed the integration of these dependencies with existing secondary actors into six unique FSC dependencies which should be mapped alongside primary actors in order to gain the broadest awareness of supply chain surroundings. This view is represented in *Figure three*.

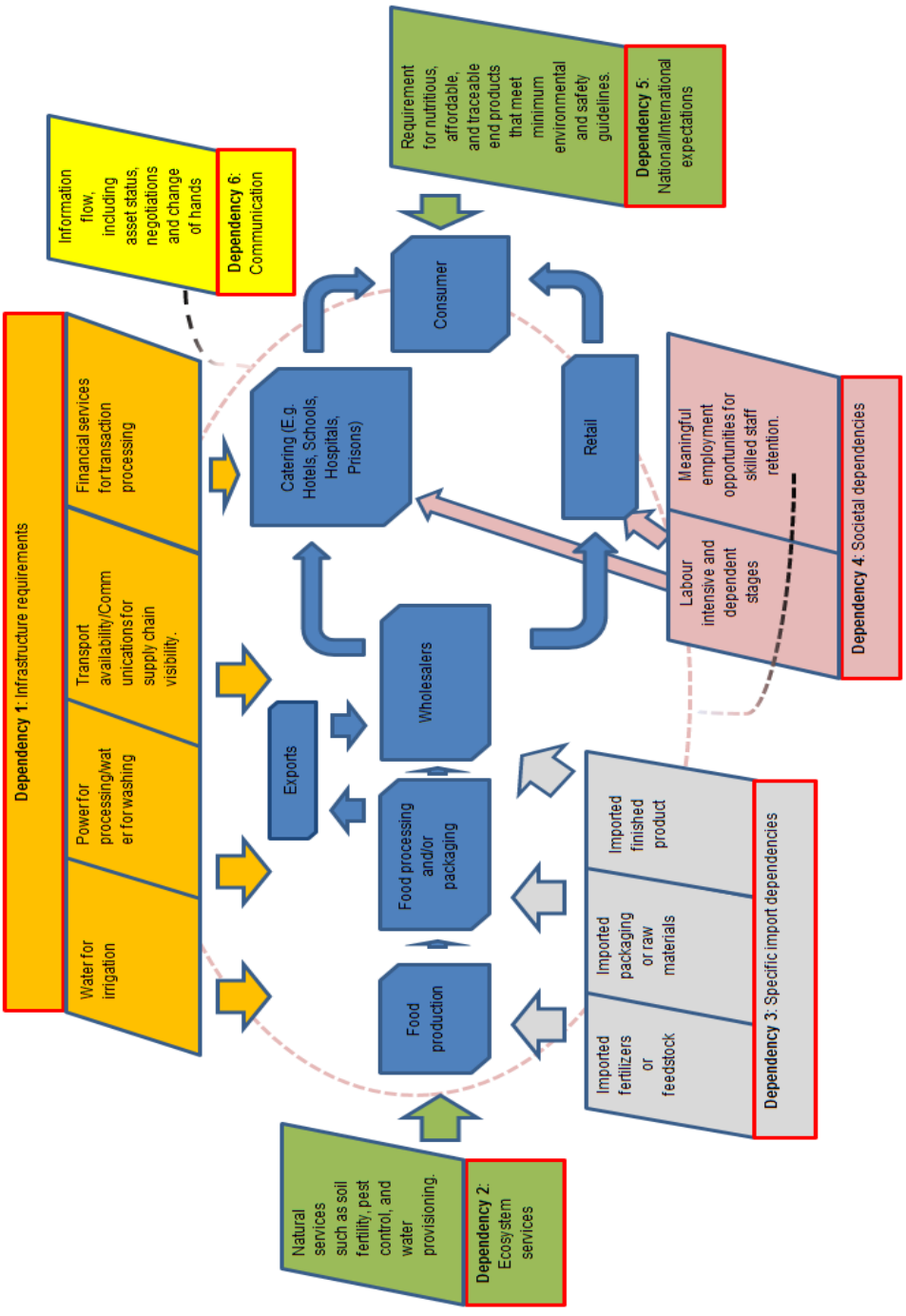

***Figure Three**: A simplified food supply chain highlighting key actors as well as dependencies on infrastructure and imports.*

3. Defining resilience in Food Supply Chains

The term resilience is used across a variety of fields from ecology (22), to psychology (individual and organisational) (23-24) and supply chain management itself (5). In all contexts, resilience is identified as the ability of a system to return to its original state or preferably an improved state after being disturbed (16,25,26). Asbjørnslett (2009) makes a key distinction between resilience and robustness, in that whilst a robust system can withstand disturbances, a resilient system is adaptable enough to find a new optimum stable state (27). The authors believe that this is a key distinction in FSCs because the overwhelming priority has to be to ensure that food reliably reaches end consumers, no matter the scale of the disturbance. The fact that input materials are of variable quality and often limited by shelf life surely supports the need for adaptability.

Disturbances are unexpected events of sufficient magnitude to push specific processes, organisations, or even whole supply chains into a failure mode (8,28,29). They are often not the result of a single event, regardless of magnitude, but rather the domino effect of that event, for example, production line delays leading to inventory reduction, missed deliveries, and reputation loss. Failure modes have been categorised by Svensson et al. (2000) (30) into volume (absence of materials downstream) and quality (material deficiencies downstream) disruptions. Vlajic et al. add to this the category of time (delays or idle times)(31). Carvalho et al. proposed that all failure modes could ultimately be grouped as raw material shortages, labour/capacity shortages, scrap/rework, and completed but undelivered work (32). These findings have been categorised in *Table one* overleaf along with our own descriptions.

Failure Mode	Description
Raw material shortage	Any disruption to deliveries from primary supplier. This could be crop failure, transport delays, or unacceptable variations in quality.
Labour/capacity shortage	This could be a shortage of skilled labour to respond to surges in demand. It could also be a loss of capacity on the production line or in storage. In all cases, the ability of the organisation to process raw material and pass downstream is diminished.
Scrap/Rework	This refers to food that is processed but cannot be passed downstream as it does not meet either, National or Private health and safety requirements, or, end consumer credence factor demands. Sometimes rework into lower margin products is possible (e.g. blemished fruit into jams).
Product completed but not delivered	Disruption to transport downstream. Can be particularly disastrous given short product shelf life and limited storage capacity for many actors.
Excessive deterioration of product quality prior to reaching end consumer	The result of any series of delays or unplanned environmental conditions which results in product quality deterioration to the point that it can no longer reach the end consumer.

Table one: FSC Failure modes (30-33)

The failure modes described above are measured as a major deviation from Key Performance Indicators (KPI) for a given organisations supply chain situation. It is important to note that these KPI's can vary for a given organisation in times of disturbance, and again depending on the scale of disturbance, compared to normal operating. *Table two* illustrates standard FSC specific KPI's identified in the literature.

FSC KPI Category	Indicator
(E) Efficiency (Resource utilisation)	1. Process Yield
	2. Inventory
	3. Return on Investment
	4. Profit
(F) Flexibility (Ability to meet unusual customer requirements)	1. Customer Satisfaction
	2. Volume Flexibility
	3. Delivery Flexibility
	4. Sales Level
(R) Responsiveness (Quickest possible response to demand)	1. Lead Time
	2. End Consumer Availability
	3. Shipping Errors
(Q) Quality	1. Health and Safety
	2. Shelf Life
	3. Sensory Properties
	4. Credence Factors
	5. Reliability
	6. Convenience

***Table two**: FSC KPIs (20)*

For an individual actor within a supply chain this could be a rare but catastrophic single event such as the Ch-Chi earthquake in Taiwan of 1995, or a seemingly less significant event, such as the 2000 fire at the Philips semiconductor plant in Albuquerque. Both had significant consequences for affected organisations in terms of performance, profit and reputation. It is also possible that effects will be transmitted along the supply chain, for instance, in the form of delays and changed material quality. In addition, this can also artificially alter demand along the supply chain, creating a bullwhip affect.

However, beyond affected organisations and their supply chain dependents, such disturbances are unlikely to cause real harm to end consumers. Indeed, disruption to end product market availability is often limited because other organisations can take advantage of the opportunity created (34). This is not the case with FSCs. There is increasing concern that because of the unique vulnerabilities faced by food supply chains (e.g. shelf life, variability of raw materials) a specific combination of disturbances could disrupt entire supply chains, with competitors unable to step in. Unlike many other commodities,

food is essential to human life and disruption for even a brief period can potentially seriously risk consumer wellbeing. A failure in any one or more areas of the provision of safe, nutritional, culturally acceptable food which is available on demand, in ample quantity at an affordable price and which is fully traceable, would be disastrous.

With so many potential failure points, clearly there is a need for increased resilience across FSCs, particularly given projected increases in operating environment volatility and vulnerability presented by lean operating systems. Many authors have analysed what components constitute resilience in a supply chain context. Many of these works ultimately divide resilience into two components: vulnerabilities and capabilities. Vulnerabilities are defined as innate factors that make an organisation susceptible to disruption and capabilities are defined as attributes serving as a control mechanism for organisations to anticipate and overcome disruptions (26). Resilience increases as capabilities grow and vulnerabilities diminish. This resilience can originate at an organisational level (e.g., the structure, resources and geographic location(s) of individual or combined supply chain actors) or at an individual level within an organisation (e.g. flexibility, motivation, perseverance and optimism) (35).

4. A Framework for resilience

This work has identified that, whilst food supply chains face a number of challenges and there is clear need to integrate resilience into day to day operations, resilience often means different things to different people. Clearly a more in depth understanding of one's physical supply chain surroundings against an awareness of relevant dependencies identified in *Figure three* is important. So too is an understanding of food specific KPIs and failure modes in order to assess current resilience as previously discussed. Crucially, it is a detailed understanding of capabilities and vulnerabilities that allows an organisation to truly assess resilience. As such, in *Figure four,* a framework is proposed grouping together these concepts in order to allow an organisation to understand their unique resilience components. The remainder of this paper will proceed to explore the concepts of vulnerabilities and capabilities in more detail.

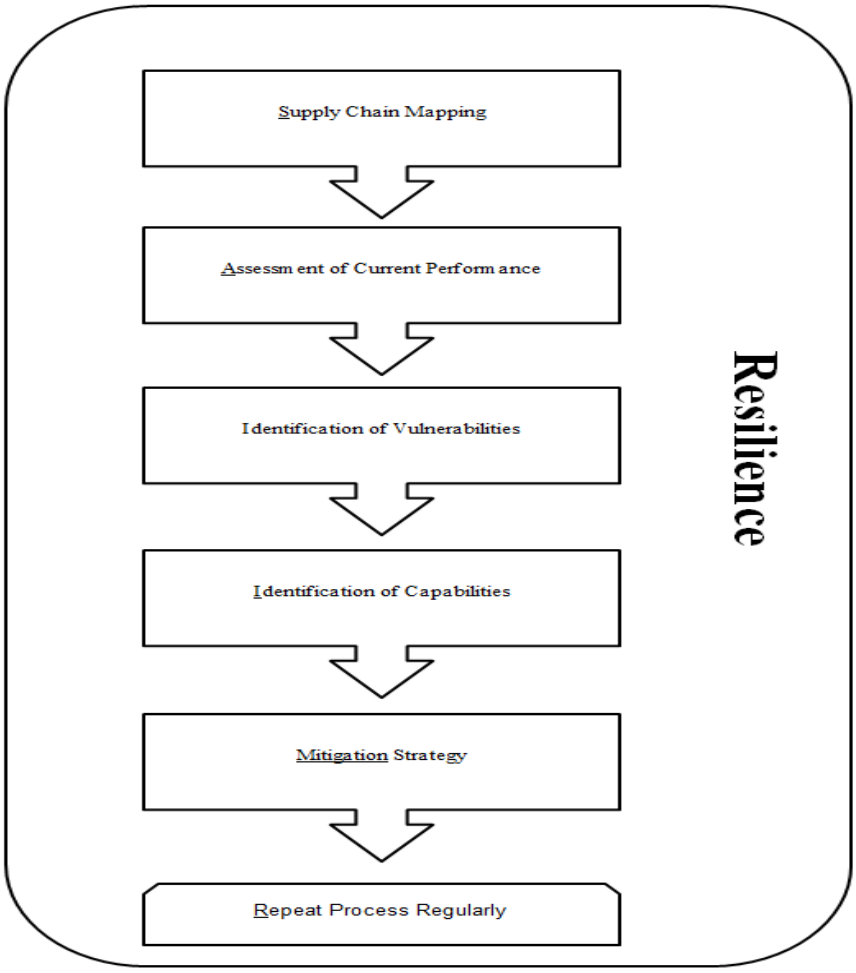

***Figure Four**: Proposed Framework for understanding bespoke resilience.*

5. Vulnerabilities

Consistent with the literature, we define vulnerability as follows: "*fundamental factors that make an enterprise susceptible to disruptions*" (30,34,36). There are numerous methodologies within the literature for classifying vulnerability but few of them are FSC specific. It is possible to identify two broad groups of supply chain vulnerability classification: internal (either within company or within immediate supply chain) and external (outside of supply chain) (8,16,30,37). Some external vulnerabilities are controllable to a degree, such as some societal or financial aspects, but others such as market forces and environmental aspects, are more often than not uncontrollable. In terms of internal vulnerabilities, at a company level (such as equipment, processes and organisation) these are mostly controllable.

External Vulnerabilities (Ext)					
Financial (Fin)	**Market (Mar)**	**Legal (Leg)**	**Infrastructural (Inf)**	**Societal (Soc)**	**Environmental (Env)**
1. Market price fluctuation 2. Currency fluctuation 3. Regional economic downturns	1. Market decline 2. Variability and seasonality in **availability** of raw materials 3. Variability in **Quality** of raw materials 4. Variability in demand	1. Changes in laws and regulations (e.g. animal welfare, agricultural subsidies, traffic regulations, quotas, and food safety).	1. Level of development in transport infrastructure and its capacity 2. Availability and access to water, power and fuel. 3. Level of primary production and processing technology	1. Workforce health (e.g. flu pandemic) 2. Terrorism 3. Political unrest 4. Criminal acts 5. Level of corruption 6. Industrial actions 7. General public response to activities 8. Changing customer attitudes	1. Natural disasters (both Geological and Meteorological) 2. Biological factors (e.g. livestock disease, pests) 3. Anthropogenic hazards (such as pollution, land contamination)

Internal	Internal Vulnerabilities (Internal or Supply Chain Specific)			
	Physical Resources (PR)	**Logistics Control (LC)**	**Information System (IS)**	**Intra Organisational Structure (IOS)**
Supply Chain Specific (SC)	1. Product related hazards 2. Heterogeneous raw material (prior to accounting for market and environmental factors) 3. Complexity of supply chain network 4. Over reliance on a single key business partner 5. Sophisticated equipment/Infrastructural restrictions	1. Strict requirements from key customers 2. Low reliability of chain partners 3. Lack of control in supply chain (e.g. for outsourced activities) 4. Lack of risk management in other companies	1. Lack of infrastructure to support information sharing 2. Lack of information visibility across the supply chain (e.g. poor traceability) 3. Varying ICT standards used in supply chain	1. Loose contracts 2. Outsourcing 3. Lack of collaboration, due to trust 4. Low level of training & experience in other companies employees
Organisation Specific (OS)	1. Reliability of equipment 2. Product characteristics 3. Inventory related issues (particularly shelf life and storage requirements) 4. Intermediate/final product quality 5. Intermediate/final product compliance with legislation (health and safety, waste, worker safety) 6. Capacity (both in terms of quantity and variety of products)	1. Low potential control actions 2. Subjective decision making 3. Inaccurate forecasting 4. Level of attention to risks and business continuity planning	1. Inadequate decision support systems 2. Slow data transfer and processing 3. Late detection of disturbances or lack of relevant data 4. Inaccurate/insufficient data at the broadest level 5. Inability to properly interpret data	1. Weak internal coordination & cooperation 2. Extent of Corporate Social Responsibility Programme. 3. No standardized working procedures 4. Lack of preparedness for disturbances 5. Low level of training and inexperienced workers

***Table Three**: FSC Vulnerabilities (8,26,31)*

At a supply chain level these are partially controllable (for example, raw material quality and supply and demand factors) but this depends on the level of supply chain integration and collaboration.

Vlajic et al. (2012) have classified a number of food related vulnerabilities from a literature review accordingly and these have been summarised in table 3, albeit with minor modifications based on our own FSC specific reading (26,38-40). External vulnerabilities have been broken down into Financial, Market, Legal, Infrastructural, Societal and Environmental which we feel best matches our supply chain model (figure four). We have also broken down internal vulnerabilities into four categories: Physical Resources (facilities, equipment, and product characteristics), Logistics Control (planning, control and co-ordination of processes), Information Systems (availability of information and decision support systems), and Intra Organisational Structure (roles and co-ordination of departments and individuals within an organisation). It is important to highlight that many of our categories inevitably overlap and cannot be taken in isolation. For example, many of the top external vulnerabilities, such as terrorism for example, are in this position, partly because some actors within FSCs are particularly vulnerable to direct attack, but because, they open up a range of secondary vulnerabilities such as nature of government/social response, infrastructure damage, and network congestion. These in turn, exacerbate existing internal vulnerabilities.

6. Capabilities

It has been proposed that a system is resilient when capabilities balance vulnerabilities (26). In this context, capabilities are defined as "attributes that enable an enterprise to anticipate and overcome disruptions". Numerous authors have examined capability factors from a supply chain management perspective. Perhaps one of the most comprehensive works is that of Pettit et al. (2008) which identified, via literature review, 14 unique focal organisation capability factors and a number of sub factors. This work has formed the basis of *Table 4* below, although this work has been adapted to take into account our own findings in the study of food specific supply chains. The aim is to provide a comprehensive list of capabilities relevant to actors within FSCs rather than an operating paradigm as such (41). Similarly, our capabilities are not organised in any order of priority as their significance will vary depending on an individual's unique vulnerabilities.

6.1 Concentration

Concentration refers to the physical distribution of all core supply chain components to a focal company. Generally, the more dispersed the facilities, the more resilient as the domino effect from a local disruption is likely to be

limited. However, the key theme to be considered from a resilience perspective is the presence of bottlenecks. For example, an organisation can have dispersed suppliers of raw material, but if all of these are dependent on a single transport hub, such as the channel ports in the UK, then vulnerability will still be high (42).

6.2 Adaptability

Adaptability is defined as the ability of an organisation to modify operations to provide optimum response to a disruption or opportunity. In FSCs adaptability can be broken down into flexibility in sourcing and flexibility in order fulfilment. Considering flexible sourcing, a key priority is multitude of sources (although these can be shallow in relationship (5)). This is important as it limits exposure to a number of food specific vulnerabilities from drought to disease as well as accidents and supplier closures common to other supply chains.

Flexibility in order fulfilment concerns ability to change output. A key component is the ability to change distribution channels which could be the ability to use rail rather than road, or as in the case of the US Air Force, involves purchasing spare capacity with airliners for emergency situations (26). This often involves practical challenges, such as the ability to re-package products and there are overlaps with redundancy (and the negative costs associated). However, some companies such as DHL have been able to expand their market position in times of crisis, such as the Eyjafjallajökull 2010 eruptions, by being able to rapidly switch from road to air distribution (43).

6.3 Redundancy

Redundancy concerns the availability of spare (not required for standard operations) capacity in raw material stores, production capacity, power generation, transport and IT systems. It is the classical strategy for responding to uncertainty. However, it does constitute a significant cost if not required as part of day to day operations. Additionally, food shelf life requirements sometimes limit its potential usefulness.

Theme	Description	Aspects
Concentration	Geographic Dispersion	1. Geographic distribution of facilities, markets, and assets
Adaptability	Flexibility in Sourcing	1. Multiple sources 2. Supplier contract flexibility 3. Modular product design (only applicable in highly processed foods) 4. Capacity to change to different varieties of raw material,
	Flexibility in order fulfilment	1. Alternate distribution channels 2. Products designed for late differentiation 3. Inventory Management systems 4. Availability of alternate production facilities.
	Research and Development	1. Novel product development 2. A strong R&D culture 3. More efficient infrastructure
Redundancy	Redundancy	1. Reserve production capacity 2. Reserve raw material stock 3. Reserve finished product 4. Backup power generation 5. Backup communications 6. Backup information systems
Efficiency	Resource Efficiency	1. Waste reduction (and where possible re-use) 2. Labour optimisation 3. Asset utilization
	Operational Efficiency	1. Lead time reduction 2. Bottleneck mitigation 3. Small batch-high frequency
	Organisational ethos	1. Accountability 2. Creative problem solving 3. Motivation/Perseverance
Awareness	Strategic visibility	1. Awareness of relevant geo-politics 2. Consumer trends 3. Science/technology 4. Markets 5. Competitors.
	Supply chain visibility	1. Business intelligence gathering 2. Raw material/product traceability 3. Information technology 4. Automated decision support.
	Internal visibility	1. Asset status awareness 2. Frequent quality/safety compliance checks 3. Information Technology. Automated decision support.
	Collaboration/ Cohesion	1. Inventory sharing 2. Product lifecycle management (returns) 3. Product development. 4. Joint decision making (demand forecasting, production scheduling, distribution and contingency planning)
Anticipation	Anticipation	1. Monitoring 2. Forecasting 3. Near-miss analysis (11,44) 4. Business continuity planning 5. Scenario planning 6. Readiness to take advantage of competitor disruptions.
Market status	Brand	1. Product differentiation 2. Brand reputation and value

	Customer relations	1. Presence of CSR 2. Customer Loyalty 3. Market share
Security	Physical	1. Layered defences 2. Personnel screening 3. Restricted access 4. Awareness via local/national Government liaison
	Electronic	1. Protection of digital information
Financial readiness	Ability to withstand unexpected costs or temporarily reduced revenue	1. Insurance 2. Financial reserves and liquidity 3. Portfolio diversification 4. Product price margin

Table 4: *FSC Capabilities (5,8,11,26,38,45-49)*

6.4 Efficiency

This involves a number of factors such as Resource Efficiency, Operational Efficiency, and Ethos which in addition to saving an organisation money on a day to day basis, offer a number of advantages during a time of crisis. For example, a cross-trained staff pool allows an organisation to better respond to disruptions ranging from flu pandemic, to trade union action, as well as opportunities to "surge" production to meet market opportunity (38). On the other hand, not only can a strong ethos provide the in house innovation to identify new markets, but in times of crisis, it can be the deciding factor in whether staff persevere and rise to the challenges presented (46).

6.5 Awareness

Many authors highlight the importance of visibility, information sharing and the need for increased collaboration in FSCs. Such work has been grouped under the label of awareness. This ranges from the strategic scale, in terms of relevant policy, legislation and consumer demands, through to an awareness of what your supply chain partners and competitors are doing, and a tactical understanding of your own operational status. This is not simply about accessing relevant data, but about having the ability to process this information into a relevant format and deliver it at the opportune time (26).

6.6 Anticipation

Anticipation is the ability of an organisation to discern and prepare for potential future scenarios. It involves aspects such as real time monitoring and

the use of historical data, models and judgement to forecast demand. It also involves analysis of near-miss events as it has been suggested that most major disruptions were preceded by near misses that almost exceeded normal operating parameters but just fell short (44). In order to move beyond a reactive stance to disruption, evidence suggests that Business Continuity Planning offers the most comprehensive form of emergency preparedness for a proactive response. However, it's perceived cost and complexity has limited widespread implementation (11). Finally, an awareness of

Competitors' products and how you could substitute your products for theirs in a disruption forms a more positive, but equally important, area of anticipation (26).

6.7 Market Awareness

Market awareness involves the strength of an organisations brand and their management of customer relations. At its simplest, strong brand reputation can compel consumers to either wait for restock or search elsewhere for your brand, rather than seeking out substitutes and this can aid recovery substantially (26). In terms of customer relations, a strong presence, particularly a corporate social relations strategy can encourage two way exchange of information with consumers as well as ensuring legal/policy/social compliance.

6.8 Security

Security involves the prevention of disruptions, supply chain security breaches, product adulteration, and damage to brand image. This does not necessarily have to be deliberate in intent- good physical restrictions to restricted areas and protection of vital data can prevent accidental damage too. However, security is heavily linked to awareness and particularly collaboration so that efforts can be coordinated with that of regional and national government (26).

6.9 Financial Readiness

Financial readiness is a measure of an organisations ability to absorb irregularities in income and outgoings. The availability of financial reserves, insurance to offset risk, as well as a diversified asset structure are all important. Evidence suggests that products with a higher profit margin are better able to recover from disruption (26).

7. Discussion

By being aware of individual unique capabilities and vulnerabilities (through using FSC specific taxonomies such as the prototypes in tables one and two) a specific organisation can modify capabilities accordingly to generate balanced resilience (see *Figure five*). In this state, vulnerabilities will either be removed entirely or offset to a manageable level by an organisations capability to adapt. Furthermore, day to day operations will be more efficient as a result of the constant process of tweaking capabilities to meet the changing supply chain situation.

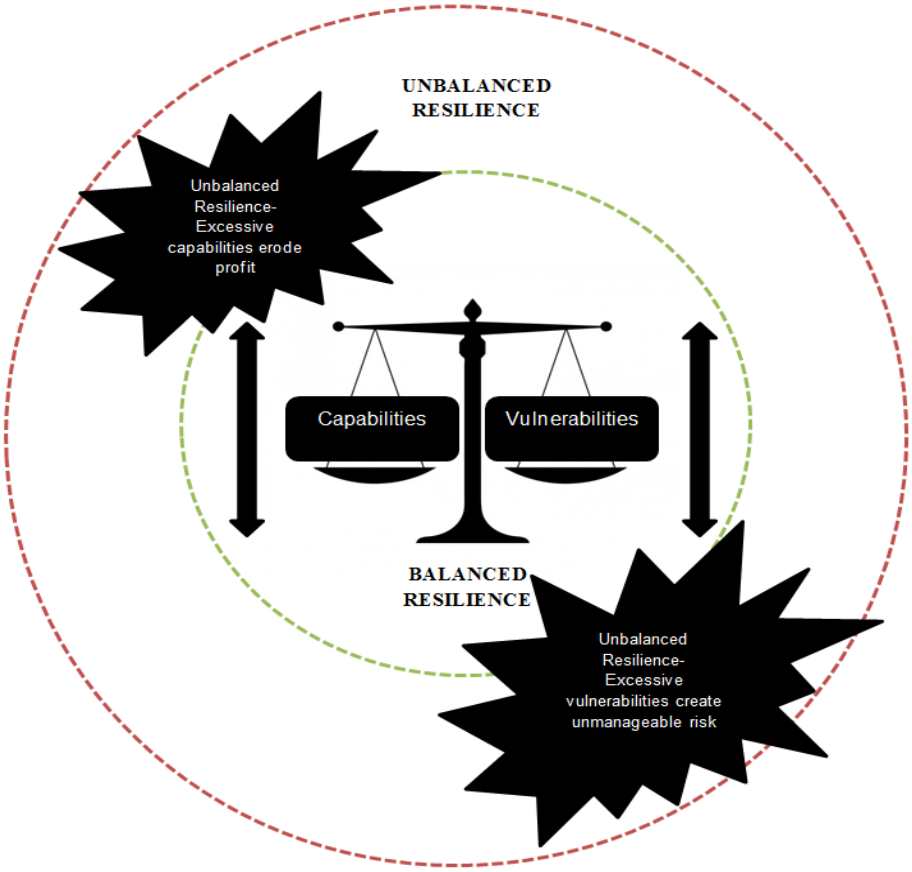

***Figure Five**: the balance of vulnerabilities vs capabilities.*

On the other hand, it is easy to result in an unbalanced situation. For example, excessive capabilities compared to vulnerabilities can erode profits. Likewise,

in the fast moving FSC situation, if resilience identification is not carried out at regular intervals, it is possible to return to a state where capabilities become dated. This will result in a return to a general high risk state with high probability of high consequence events occurring.

This method of calculating resilience has several advantages over traditional calculation of resilience which is often based on historical occurrences and profit as the overriding KPI. As detailed mapping of physical as well as dependency based vulnerabilities (and through this, identification of bespoke KPIs and failure modes) is required to identify organisation vulnerabilities and capabilities, it allows identification of previously cloaked vulnerabilities (see *Figure four*). It also avoids the assumption that events will occur in a similar pattern, and unfold in the same manner, as the past which is dangerous in the increasingly unpredictable operating environment which FSCs face (50).

It is proposed that development of this framework will provide a useful tool to supplement traditional risk management strategies. Additionally, because the full breath of FSC dependencies identified in *Figure four* will be captured through a continuously growing taxonomy of capabilities and vulnerabilities, in theory, the proposed resilience framework will result not just in resilient FSCs, but sustainable FSCs too.

8. Conclusions

The premise of this work lies in the incredible complexity of contemporary food supply chains, projected increases in operating environment volatility, and perceived weaknesses stemming from lean management systems. In this work the importance of mapping supply chains to better understand the complex network of dependents and thus increase risk visibility has been identified. Understanding of resilience specific to FSCs in the literature and identified a number of FSC specific KPIs and Failure Modes has also been explored in depth. Ultimately, this paper brings together these factors, along with the themes of capabilities and vulnerabilities, in the form of a framework to aid understanding and implementation of the concept of resilience within food supply chains. Whilst the concept is at an early stage, it is felt that charts of vulnerability and capability factors (see tables one and two) represent possibly the most comprehensive of their type in terms of FSCs. Similarly the proposed methodology for calculating resilience offers significant advantages

over traditional risk management practices in terms of scope of vulnerabilities identified and reduced reliance on historical trends. Clearly, the next step is for validation of the capability and vulnerability taxonomies through industrial interviews, surveys and focus groups.

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