Examining supply chain agility using Social Network Analysis

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Ngoc N.H. Le

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Abstract

In the current literature of supply chain agility (SCA), the extant agility models are not only rare but are also usually developed from the viewpoint of a firm rather than from a network perspective. While social network analysis (SNA) has proven its power and capacity in the social sciences, it has been rarely applied to supply chain management (SCM) phenomena. As such, this is a primary motivation for this study to take shape. The main focus of the research is refined to build on the Scion project on Rural Value Chains. It seeks to explore the appropriateness of SNA to assess SCA and to simultaneously make a relative agility comparison between supply chains by SNA. The empirical data are collected by structured interviews in a rural area of New Zealand and then analysed as a network case by varying SNA metrics, tools, and techniques.

This thesis sheds light on how SNA is appropriate to tap into the areas that are barely recognised by the extant approaches. The findings show that SNA is well able to consider interactions and linkages in complex networks, and it also enables the integrated lens of network and complex adaptive system (CAS) to examine network agility in a comprehensive and systematic manner. SNA lends itself well to phenomena that directly relates to, or results from, network topology, connectivity, and interconnectedness, such as network visibility, speed of responses, and the ability to have multiple connection options. However, if used exclusively, SNA is less appropriate to examine attributes that either have qualitative elements or which are associated with firm operations. This thesis has added to the literature the applicability of SNA to evaluate SCA and to model SCs. For policy makers, it offers a clearer understanding of the local network for regional development plans. For business owners, it proposes an alternative approach of evaluating SCA, SC relationships, and SC members, so as to build up effective SCM strategies.

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CAS	Complex adaptive systems
SC	Supply chain
SCA	Supply chain agility
SCM	Supply chain management
SNA	Social network analysis
RNC	Resilience to Nature's Challenges

Chapter 1: Introduction

Agility is one of three core qualities constituting effective and efficient supply chains (Lee, 2004). Volatile and uncertain environments, coupled with inter-relationships among organisations and industries, give rise to its importance for both survival and competitiveness (Feizabadi, Maloni, & Gligor, 2019; Seville, Van Opstal, & Vargo, 2015). How to achieve, improve, and enhance supply chain agility (SCA) is not only a topic of interest to researchers, but a pressing question for practitioners. Accordingly, building an appropriate agility model and assessing agility levels are equally essential before any proposed improvement plans are implemented. However, both agility models and agility assessment approaches have received little attention. Meanwhile, much of the literature centres around exploring the concept, developing measurements, and examining the effects of SCA on firm performance (AlKahtani, Rehman, Al-Zabidi, & Choudhary, 2019; Sharma, Sahay, Shankar, & Sarma, 2017).

SCA encompasses a variety of capabilities, for example, flexibility, responsiveness, and visibility, with a common emphasis on speed (Christopher, 2000; Fayezi, Zutshi, & O'Loughlin, 2017). From the lens of complex adaptive system (CAS), such capabilities are neither determined merely by an aggregation of organisations' efforts nor controlled deliberately by a single entity (Choi, Dooley, & Rungtusanatham, 2001; Pathak, Day, Nair, Sawaya, & Kristal, 2007; Surana, Kumara, Greaves, & Raghavan, 2005). Furthermore, from the network perspective, interconnectedness is inherent to any supply networks regardless of the awareness of organisations (Newman, Barabási, & Watts, 2006). Supply chain management (SCM) phenomena, therefore, should be investigated considering such complexities and non-linear relationships (Wichmann & Kaufmann, 2016). However, such capabilities are often studied from a firm's view (Sharma et al., 2017). A few studies may take a supply chain (SC) view but give little consideration to the relationship dynamics and interconnectedness of one SC with other SCs (Fayezi et al., 2017). Currently, there is a paucity of relationship-oriented research on SCA.

Theoretically, integrating both network and CAS lenses can enrich SC research, particularly aspects related to structure and dynamics (Bellamy & Basole, 2013). Social network analysis (SNA) has proven to be a powerful methodology and a valuable lens that can shed light on networks in either statistical or exploratory research of different disciplines (Quatman & Chelladurai, 2008). With the integrated lens of network and CAS, SNA can unveil hidden structures and mechanisms, which then allows examinations into varying SCM phenomena in a comprehensive and systematic manner (Bellamy & Basole, 2013; Kim, Chen, & Linderman, 2015). Despite this huge potential, the application of SNA to the SCM domain is, compared to other social science disciplines, a fledgling area (Bellamy & Basole, 2013; Wichmann & Kaufmann, 2016).

Within New Zealand, rural businesses play an important role in national primary sectors wherein the agriculture industry contributes around 5% to GDP annually (*OECD Economic Surveys NEW ZEALAND 2019*, 2019). Despite a richness of relationships embedded in rural areas, these settings are not well explored, in terms of SCM in general, and in particular, SC relationships. Furthermore, rural organisations are more vulnerable to random disturbances than their urban counterparts, due to their locations and heavy reliance on such primary economic activities as agriculture and fisheries (Regional economic activity report 2015, 2015). It is crucial to understand and develop resilience for rural SCs yet there is still a lack of empirical research in this field (Cradock-Henry, Buelow, & Fountain, 2018). The Rural Value Chains project led by Scion and funded by Resilience to Nature's Challenges (RNC)[1] is a recent project aiming to fill this gap. As one of eleven challenges under the National Science Challenges scheme, RNC was launched in 2015 with the ultimate goal of enhancing New Zealand's resilience to natural disasters. This particular study of Scion aims to develop a methodology for evaluating rural value chain resilience in the context of natural hazards.

This project seeks to bring together concepts of SCA, a CAS lens, a network perspective, and SNA application in an individual study that stems from and builds on the larger Scion project. This study factors in both the dynamic and interconnected nature of relationships among SC members to examine the SCA of a network case. It sets out to explore the applicability of an SNA approach for evaluating SCA. Over the course of the analysis, another driving force of this research is investigating how relative agility differs among underlying SCs of a network across a range of indicators by using SNA tools and techniques.

1.1. Research approach overview

This thesis favours constructivism and interpretivism in its approach. It employs a quantitative methodology, even though such a philosophical stance may appear to be more closely associated with inductive research. The method of choice is appropriate considering the nature of SNA and the priority of the research. By nature, as an analytical method, SNA aligns well with relationship measurement and connection visualisation. A quantitative approach optimises opportunities to

[1] http://resiliencechallenge.nz/about/

relatively compare agility between SCs and to replicate the application of SNA to other SCM phenomena or in other areas.

This thesis is designed in line with the larger project undertaken by Scion. It is conducted in a formal and descriptive manner within a given time frame to analyse a network case. Structured interviews are conducted with rural business owners and/or managers at their convenience and in locations that suit them. The interviews centre around how such individuals perceive organisational importance and their state of preparedness if disruptions strike. In addition to this, the interviews also prompt participants to evaluate their SC relationships.

The focus of data analysis is on network data as they are the most critical part of this research. The analysis is performed at three levels: network level, group level, and node level. Due to limited resources, this thesis only uses some common SNA metrics, tools, and techniques to evaluate network agility level in an area that is only a small segment of rural New Zealand. While there are different types of connections that exist, this thesis primarily focuses on relations based on information flows, given the increasingly emergent notion of virtual SCs. The network boundary is determined by the availability of potential contacts and the feasibility of approaching such respondents. Furthermore, only three main agility dimensions with typical attributes are examined as other agility elements discussed in the literature are beyond the scope of this project. To ensure the reliability and validity of the results yielded, this thesis applies several methods, for example, triangulation, respondent validation, and well-documented research process. Supervisory feedback also served to ensure the fairness and objectivity of the results.

1.2. The importance of this research

This research is important in three main ways. First, for researchers, this thesis adds to the currently scarce body of literature on SCA assessment approaches and methods. Throughout the analysis, the study aims to demonstrate how SNA as an approach is potentially applicable to evaluate and compare SCA. This then contributes to the wider literature of the SCM domain. In particular, this thesis illustrates how a specific SCM phenomenon can be studied from an integrated lens at all levels of analysis via a range of SNA tools and techniques. Second, the findings are expected to benefit practitioners by shedding light on how SCA should be evaluated in supply networks wherein complexity and interconnectedness are intertwined. Furthermore, the findings may suggest how critical relationships and critical partners can be identified and classified by an SNA approach rather than by conventional methods. Additionally, SC members can identify opportunities and constraints from their positions in the network and they can also learn from other SCs for network agility practices. Third, this study adds to the ongoing Scion project in relation to agility evaluation methods and an integrated lens since SCA and SC resilience are closely related. When taken in conjunction with the Scion project, this thesis may be also valuable at the macro level by serving as reference sources for those seeking to extend the application of SNA to assess value chain capabilities in other rural regions of New Zealand.

1.3. Thesis outline

The introductory section sets the scene for the chapters to follow. Chapter 2 provides a theoretical foundation on which this thesis leans by exploring the concept of SCA and extant approaches to assess this capability. It also outlines the research of SNA application, particularly to SCM phenomena. Chapter 3 aims to position this thesis by identifying and selecting an appropriate methodology to address the research questions, and to meet criteria of ethics and quality assessment. Chapter 4 provides an overview of a rural network case and the industry context so that the interpretation of results in the subsequent chapter are comprehensible, relevant, and valid. Chapter 5 presents the results of an in-depth network data analysis in the form of a relative agility comparison between prominent supply chains underlying the research network. Both these chapters pave the way for a discussion on the findings and a critique of this thesis in Chapter 6 wherein potential areas for further research are also outlined. Chapter 7 concludes this thesis with a summary of key findings and highlights of research implications.

Chapter 2: Literature review

Chapter 2 presents a literature review of supply chain agility (SCA) and social network analysis (SNA) to augment the readers' understanding on which the backdrop of this thesis leans. The literature is reviewed in three relevant streams: SCA, a complex adaptive system (CAS) lens, and SNA approach. The review starts by tracing the development of SCA. The similarities and differences of key elements constituting this concept are drawn from the highly cited research. The strengths and limitations of the current approaches, methods, and tools are then identified by a closer examination into the literature of SCA assessment. Subsequently, the fundamentals of a CAS are outlined, followed by an investigation of key studies advocating the adoption of a CAS lens in the supply chain (SC) research. The review is then extended to the research of SNA including the theoretical studies and particularly the research on this approach's application to investigating SCM phenomena. Throughout the literature review, the research questions come out, aiming to fill the gaps in the existing studies of SCA. The literature is also synthesised, leading to a proposed framework for studying SCA by an SNA approach. This chapter ends with a summary of central ideas in the literature which will be further discussed together with the analysis results in the next chapters.

2.1. Supply chain agility

2.1.1. Background, definitions, and characteristics

The concept of agility was introduced by Iacocca Institute of Lehigh University in 1991 as a necessary condition for competitiveness. Their focus was on a production system that can adapt to and quickly adjust processes according to constant changes in the business environment (Abdelilah, El Korchi, & Amine Balambo, 2018; Rimienė, 2011). This concept attracted the attention of the manufacturing sector in the early 1990s and then evolved as an organisational approach (Rimienė, 2011). Agility was first explored in the supply chain context by Dove (1996). However, it was the work of Christopher (2000) that made supply chain agility (SCA) popular and has driven the development of this concept since then.

Despite various studies, there is still a lack of consensus on SCA definitions (Sharma et al., 2017). This may be explained by two reasons. SCA is a multidimensional concept adopted from varying disciplines (Gligor, Holcomb, & Stank, 2013). It can be described, characterised, and assessed by different approaches and lenses. Furthermore, the evolution of SC phenomena may result in overlapping boundaries among concepts. Specifically, SC flexibility and responsiveness can be either properties of SCA or separate system capabilities, depending on the viewpoints and contexts (Abdelilah et al., 2018; Fayezi et al., 2017; Singh & Acharya, 2013). SCA shares some commonalities with SC resilience, and hence, it is sometimes regarded as relative resilience (Adobor & McMullen, 2018; Ali, Mahfouz, & Arisha, 2017).

This research does not aim to make a theoretical comparison of available definitions. Rather, it studies some selective definitions and approaches to achieve the research objectives. A comprehensive review of studies conceptualising SCA can be found in the works of Sharma et al. (2017) and Fayezi et al. (2017). A full account of distinctions made between agility and resilience can be found in the works of Charles, Lauras, and Van Wassenhove (2010); Gligor, Gligor, Holcomb, and Bozkurt (2019); and Lotfi and Saghiri (2018). Key elements discussed in the ten selected studies are summarised in the following table.

Table 1- Summary of key elements in 10 selected studies of conceptualising supply chain agility (SCA)

Author	**Unit of analysis**		**Drivers**		**Goals**		**Characteristics/Attributes**								
	Supply chain	Firm	External changes	Internal changes	Competitiveness	Survival	Market sensitivity/ Alertness	Virtual supply chain	Responsiveness	Flexibility	Integration	Speed	Dynamics of structures	Reconfiguration	Others
Naylor, Naim, and Berry (1999)	x		x		x		x	x						x	Robustness
Christopher (2000)		x	x		x	x	x	x	x	x	x	x			
Ismail and Sharifi (2006)	x		x		x					x		x	x	x	
Baramichai, Zimmers, and Marangos (2007)	x		x		x			x	x		x		x	x	Event management
Li, Chung, Goldsby, and Holsapple (2008)	x		x	x	x		x		x	x				x	
Braunscheidel and Suresh (2009)		x	x			x		x	x	x	x	x			Adaptability
Charles et al. (2010)		x	x		x				x	x		x			Effectiveness
Chen and Chiang (2011)		x	x		x		x		x		x	x			
Gligor et al. (2013)		x	x		x		x	x		x		x			Decisiveness
Fayezi et al. (2017)	x		x	x	*Not stated*		x		x		x	x			

From Table 1, SCA is regarded as a capability with two units of focus: the supply chain (SC) and the firm. The former emphasises the integration of business partners for the shared goal of competitiveness (Sharma et al., 2017). The proponents of this stream advocate the strengths of both intra and inter-firm relationships in achieving overall agility for SCs as a whole and for the member enterprises (Baramichai et al., 2007; Fayezi et al., 2017; Ismail & Sharifi, 2006; Li et al., 2008; Naylor et al., 1999). The latter refers to enhancing the organisational level of agility and then extending this capability to its wider SCs (Fayezi et al., 2017). While the supporters of this focus acknowledge the wider SC context, they tend to describe this concept from a firm's viewpoint. For example, Christopher (2000) attributed the extension of agility to a network of organisations. However, he defined agility as an organisational capability to manage its SC relationships for greater agility purposes. Likewise, network agility in the work of Chen and Chiang (2011) derives from a firm's ability.

The need for agility ranges from meeting customers' demands to helping SCs cope with uncertainty that most often arises from the demand side and the business environment (Lin, Chiu, & Chu, 2006). Agile SCs usually aim to enhance the competitiveness of the firm as well as the extended supply chains. The survival aspect is least explicitly stated in these selected studies. Rather, it is implied from "the key to survival in these changed conditions" (p. 37) in the work of Christopher (2000). Likewise, it is inferred from the approach of Braunscheidel and Suresh (2009) who view firm agility as a valuable means for supply chain risk management.

An agile SC is seen to be constituted by a wide range of capabilities[2] (Fayezi et al., 2017; Sharma et al., 2017). Responsiveness and speed are the most emphasised features since the essence of agility is to respond to unexpected and, usually, sudden changes in time-based competition (Christopher, 2000). Responsiveness has two aspects: reactive and proactive (Gligor et al., 2013; Sharma et al., 2017). Reactive responsiveness refers to the SC's responses to recognisable changes (Sharma et al., 2017). It can be associated with event management (Baramichai et al. (2007), adaptability (Braunscheidel and Suresh (2009), and a combination of decisiveness and swiftness (Gligor et al. (2013). Proactive responsiveness gives rise to anticipation and readiness, which are usually described as an ability to detect changes, opportunities, and threats (Gligor et al., 2013; Li et al., 2008) or an ability to sense the market (Christopher, 2000; Fayezi et al., 2017).

2 The literature uses varying terms such as dimensions, components, characteristics, and attributes to describe agile supply chains. In this research, they interchangeably refer to sub-capabilities of agility. Some components are renamed and similar attributes are intuitively grouped together based on the contexts wherein these characteristics are explained.

Speed most often accompanies with responsiveness to form quick response capability, a key component of SCA (Adobor & McMullen, 2018; Ali et al., 2017; Gligor et al., 2019). However, it is not always the case. According to Li et al. (2008), timeliness matters more in determining the degree of SCA. Similarly, delivering value on time tends to be more emphasised in the works of other contributors such as Faisal, Banwet, and Shankar (2007); van Hoek, Harrison, and Christopher (2001).

Flexibility is widely agreed to be an inherent component of agility as the latter concept evolves from the former (Abdelilah et al., 2018; Gligor et al., 2019; Sharma et al., 2017). There is abundant literature discussing the different types of flexibility. Among these, the study of Stevenson and Spring (2007) is a key reference in building the research framework for this thesis. From the supply chain perspective, the authors propose that a supply chain (SC) is flexible when the existing SC structure can cope with different events and when it can easily be reshaped under such events. It also entails the ability of organisations to have collaborative relationships with other members of the SC.

Quick responses, alertness, and flexibility are shared characteristics between SCA and supply chain resilience (Gligor et al., 2019). They could not be achieved without the availability and the sharing of information in virtual supply chains (Baramichai et al., 2007; Braunscheidel & Suresh, 2009; Christopher, 2000; Gligor et al., 2013; Ismail & Sharifi, 2006; Naylor et al., 1999). Indeed, visibility is necessary for supply chain capabilities, including agility (Chen & Chiang, 2011; Christopher & Peck, 2004; Gligor et al., 2013). Equally important to these agility dimensions is the integration of information, process, and network. Different as they are, forms of integration enhance and encourage alignment, collaboration and the sharing of knowledge and competencies which in turn contribute to the overall agility of the supply chain (Fayezi & Zomorrodi, 2015; Gligor et al., 2013; Sinha, Swati, & Anand, 2015).

Some other attributes are presented in the definitions of SCA, such as reconfiguration, dynamics of structure, robustness, and effectiveness. These attributes appear to be inconsistently used in the literature, perhaps due to a limited clarity in their proposed meanings or because they overlapped with the sub-elements of the main characteristics. This thesis adopts the work of Christopher (2000), who has provided a comprehensive description of these attributes, and employs the approach of Fayezi et al. (2017) in adopting a supply chain-wide unit of focus.

2.1.2. Assessment approaches, methods and tools

So far, only AlKahtani et al. (2019) has provided a literature review on approaches to investigating supply chain agility (SCA). These authors presented a descriptive analysis of their selected studies and briefly explained some of the approaches as examples. Among the selected publications, a significant number of studies have focused on examining the outcomes of SCA, specifically, the impacts of SCA on firm performance. A similar amount of work can be seen in relation to agility measures and agility enhancement, wherein the researchers seek to quantify the agility attributes and propose ways of improving agility. Meanwhile, few researchers have examined agility models or explored methods and tools for evaluating agility. In light of this, this thesis conducted another round of filtering key studies for further examination. The above literature review is the starting point for the selection process explained in Appendix 1.

During the screening process, it emerged that research perspectives could be barely identified in the current literature of agility assessment. Some articles do not explicitly describe the methodology either. For example, while Sreenivasa, Devadasan, and Murugesh (2012) proposed a model for enhancing total agility level (METAL), they did not specify their methodology or approach. Their adoption of an agility assessment tool of 30 agile manufacturing criteria to quantify the agility value was inferred from the conceptual features and the conclusion. Furthermore, there is no clear cut distinction between approaches, methodology, tools, and techniques in the extant papers. These terms were used interchangeably, but often in an inconsistent way.

The studies were selected if they focused on agility assessment methods and tools. Some studies were excluded even though their titles contained key words like “assessment”, “evaluation”, “methodology”, and “approach”. Although they initially appeared promising, upon closer examination, their main research objectives, focus, and direction tended to fit with other agility research avenues rather than with evaluation approaches and methods. Two such examples are the works of Baramichai et al. (2007) and Balaji, Subashree, and Velmurugan (2015). With a focus on SCA improvement, the former proposed a framework for agility creation. A quality function diagram (QFD)-based tool, a transformation matrix, and an implementation methodology were developed to support that model application to evaluating business situations against existing capabilities and performances. The latter article proposed that total agile design systems (TADS) is more of a solution to improve SCA through the adoption of technological advancements. Indeed, the agility levels are measured by an agility index and an agility qualification tool before and after implementing TADS. This may somewhat explain why this tool was not compared to the existing agility evaluation approaches and methods.

The selection process resulted in five studies providing an index, a model, or a system to assess the agility level of supply chains, as summarised in Table 2. These studies are theoretical, using either real case studies to test their models or illustrative cases to explain the applicability of suggested approaches. The assessment is most often made by a focal firm for its own supply chains. An exceptional case is Xu and Liu (2015), who propose an agility evaluation method for a network of firms, including the focal firm. The approaches, methods, and tools in the five studies differ from each other in terms of theoretical motivation and algorithms. However, they go some degree toward addressing the subjectivity and multidimensionality of supply chain concepts, including supply chain agility (Hernández & Pedroza-Gutiérrez, 2019).

Table 2 - Summary of selective studies of agility assessment approaches, methods, and tools

Authors	Approaches	Methods	Unit of evaluation	Research outcome(s)
Lin et al. (2006)	Fuzzy logic and multi-criteria decision making	Arithmetic mean, Euclidean distance, and fuzzy-ranking	Focal firm	A fuzzy agility index as an indicator of agility level and a means of identifying major barriers to agility improvement
Seyed Hosseini, Jassbi, Pilevari, and Didehkhani (2010)	Adaptive neuro fuzzy inference system (ANFIS)	Deductive, fuzzy inference systems, and artificial neural networks (ANN)	Focal firm	An adaptive neuro fuzzy inference system (ANFIS) using capabilities and enablers to evaluate agility level in a supply chain
Faisal et al. (2007)	Graph theory	Digraph and matrix representation	Focal firm	An agility index to evaluate and rank supply chains on agility dimensions
Charles et al. (2010)	Symbolic modelling	Case study	Focal firm	A maturity model to assess the agility of supply chains
Xu and Liu (2015)	Complex network	Analytical hierarchy process (AHP), fuzzy comprehensive evaluation (FCE), network structure parameters	Supply chain network	An agility evaluation system that factors in the impact of network structure and different organisation types

Fuzzy set theory has long been applied in management sciences (Lin et al., 2006). It has advantages such as comprehensibility, flexibility, affordability, and is easy to explain, compared to some conventional approaches for decision-making research (Tamir, Rishe, & Kandel, 2015).

This methodology allows for modelling uncertainty and the ambiguity of human thought by transforming linguistic terms into variables (Wu & Barnes, 2014). It is often employed in the literature of operations and supply chain management (SCM) because of its ability to represent qualitative concepts and measures (Zanjirchi, Rezaeian Abrishami, & Jalilian, 2019). Fuzzy-logic approach was first applied to the SCA evaluation by Lin et al. (2006) to address the vagueness and subjectivity of individual judgement in previous studies of SCA. The overall agility evaluation of a supply chain can be obtained by treating evaluative attributes as mathematical objects and assigning them numerical values. The study of Lin et al. (2006) was seminal, evidenced by the substantial amount of work that subsequently followed the fuzzy logic methodology, albeit with slightly different methods, tools, and techniques. Some examples include the studies of Jain, Benyoucef, and Deshmukh (2008); Kumar and Ramakrishna (2011); Samantra, Datta, Mishra, and Mahapatra (2013).

The fuzzy logic approach is not without limitations. One of its drawbacks is the lack of a learning mechanism to automatically update rules if any changes occur (Özkan & İnal, 2014). This shortcoming is usually overcome by a combination of fuzzy logic with other approaches, methods, and tools. Seyed Hosseini et al. (2010) combine tools of fuzzy inference systems (FIS) and artificial neural networks (ANN) to leverage the strengths of both approaches. They propose an adaptive neuro fuzzy inference system (ANFIS) as an effective means to evaluate agility levels since this system considers both capabilities and enablers of SCA. Likewise, Xu and Liu (2015) add an analytical hierarchy process (AHP) to fuzzy comprehensive evaluation (FCE). The advantages of AHP are barely discussed in the literature of SCA, a gap which this study does not intend to address. However, it can be inferred from Xu and Liu (2015)'s suggested procedure of agility evaluation that AHP can contribute to an appropriate evaluation system by a hierarchical structuring of weighting criteria for agility indicators.

In the literature of supply chain performance measurement and evaluation, most of quantitative models focus on assessing SC efficiency. This leaves other SC capabilities like flexibility, leanness, and agility little explored (Lima-Junior & Carpinetti, 2017). These models are often used to evaluate a single SC or several SCs with similar structures rather than SCs of diverse industries (Ramezankhani, Torabi, & Vahidi, 2018). The research of Charles et al. (2010) on agility definition and assessment partly fill the above gaps. The authors assert that an appropriate evaluation model should support not only performance measurement but also benchmarking and mutual learning among SCs of different structures. Such a model needs to evaluate agility capabilities logically and consistently. Therefore, they adopt a symbolic modelling approach by which metrics of agility capabilities are linked by equations. When considering the differences between humanitarian and commercial SCs, they suggest a maturity model that allows the consistent evaluation and aggregation of relevant agility metrics. There is little information in the relevant literature to appraise the strengths and drawbacks of their approach. Therefore, this may be a potential research avenue yet not what this thesis aims towards.

The literature of supply chain performance measurement and evaluation is dominated by the focal firm's perspective (Lima-Junior & Carpinetti, 2017). The common evaluation scope is a firm and its direct customers and suppliers. Meanwhile, Xu and Liu (2015) are among few researchers advocating a supply chain network view for evaluating SC performance in general and for SCA in particular. They suggest an agility evaluation system that factors in network structure impacts, business types, degrees of importance, and an agility indicator weighting scheme. In this system, the overall agility of the SC is evaluated by varying indicators with a network view. They argue for a combination of network structure parameters, AHP, and FCE methods to ensure the comprehensiveness and wholeness of the system. It can be inferred from their study that the complex network theory approach is just a step in a whole evaluation procedure because only three node centrality measures are considered. However, their study somewhat demonstrates the potential applicability of this approach to assess SC capabilities.

A common feature observed in the above studies, and even in the wider literature, lies in the separate treatment of agility attributes. An overall agility level is most often aggregated by the results of individual attributes. The relative interdependencies among different agility capabilities, for example, between process integration and market sensitivity, are largely ignored. For that reason, Faisal et al. (2007) advocate the application of graph theory, specifically digraph and matrix methods to examine the dynamics of capabilities and sub-capabilities of agile SCs. As a logical and systematic approach, graph theory allows visual analysis, depicts interactions among variables, and enables analysis at different levels (Wagner & Neshat, 2010). Until now, the study of Faisal et al. (2007) is the only one considering the contribution of interconnectedness among agility attributes to the overall agility quantification. This adds to the literature of assessment and relative comparisons of agility between different SCs.

All the approaches of the selected studies can help organisations to identify agility dimensions and areas for improvement. However, they do not consider the interconnectedness and richness of SC relationships, including focal firms, their partners, and other entities of different SCs. The dynamics of network or wider SCs, wherein those organisations operate, are largely overlooked. Therefore, they have a limited ability to identify important relationships either to an overall agility level or to a specific attribute. This means the current dominating perspective from which SCs are linear systems has limitations. A more appropriate lens to capture such complexity and adaptivity of SCs is increasingly advocated in the literature of SCM (Surana et al., 2005). This will be further presented in the next section.

2.2. Supply chains as complex adaptive systems

2.2.1. Definitions and characteristics of a complex adaptive system

A complex adaptive system (CAS) is commonly defined as a system in which the agents interact with each other and with the environment in a dynamic, emerging, evolving, and self-organising way (Choi et al., 2001; Levin, 2003). Anderson (1999) characterises a CAS by four properties: interactions of entities by a schema, self-organisation, co-evolution with the environment, and recursion. Similarly, although with a more general view, Levin (2003) emphasises the diversity, individuality, and localised interactions of agents in a highly autonomous process that allows for replication or enhancement. Based on the above descriptions, it becomes discernible that agency is the key determinant of a CAS (Choi et al., 2001). A complex system is not a CAS if it lacks the ability to adapt to changes (Choi et al., 2001; Levin, 2003).

Three core pillars - internal mechanisms, environment, and co-evolution – play as the lynchpin for a CAS to operate and evolve (Choi et al., 2001). These pillars interact and interrelate with each other over time and across scales of space and complexity. Within a CAS, agents connect to and interact with the others by a set of shared norms, procedures, and beliefs. No single agent can govern or control the system. Instead, concurrent and parallel actions of various agents determine behaviour patterns and lead to the emergence of new structures in a CAS. Meanwhile, how agents are connected determines the level of complexity which then influence the degrees of freedom of each agent. CASs operate in dynamic and rugged environments of constant and inter-dependent changes. Although such an environment is external to a CAS, they have a mutual relationship. The environment causes changes to the system which reacts and then brings another set of changes to the environment. The system manages to maintain its balancing point to some extent against the changes in the environment. During this co-evolution, the changes affect the system and the environment in a non-linear way, due to the complexity of interactions and the interconnectedness of relationships. However, the characteristic pattern of a CAS remains unchanged. Consequently, the future of that system is still somewhat predictable (Choi et al., 2001).

2.2.2. A complex adaptive system view in supply chain management

Choi et al. (2001) were pioneers in extending the complex adaptive system (CAS) theory to supply chain management (SCM). They assert that the key properties of a supply network are analogous to those of CASs. Specifically, a supply network contains individual organisations that have exchange relationships with others through shared norms, working practices, and incentives. Each organisation cannot control the whole network, although any changes by an individual organisation may lead to system changes. This network operates in and co-evolves with a dynamic environment in a non-linear way, but with observable common patterns of behaviours. Therefore, supply networks can be appropriately viewed as CASs and should be managed following the principles of CASs. SCM strategies should gear towards an appropriate level of control and emergence instead of deliberate control of the entire SC.

The view that supply chains are complex adaptive systems has gained the academia' support. Surana et al. (2005) reinforce the need of adopting a CAS view not only to understand SC phenomena properly and systematically but also to manage SCs effectively. They advocate applying theoretical advances in the CAS literature to the modelling and analysis of supply chains, for example, nonlinear models for task assignments and dynamical models of resource allocation. The suggested models and techniques, albeit theoretically promising, require future empirical studies to test the feasibility and practicality. Similarly, Pathak et al. (2007) posit that a CAS view holds the promise of enriching the existing SCM literature theoretically and practically, although it may pose several challenges to the theory development. They extend the seminal work of Choi et al. (2001) by proposing a complex adaptive system network (CASN) concept. A CASN includes organisations of adaptivity, a topology of interconnectedness among supply chains, a system that self-organises and emerges, and an external environment that evolves together with these components. This definition is the starting point for further studies of SCM to feasibly adopt the lens and appropriately leverage the conceptualisation of CAS.

The adoption of a CAS view in examining SCA and the associated capabilities appears to be in its infancy, based on a thorough search of relevant literature. Changrui, Shouju, Yueting, Yi, and Chunhua (2002) advocate studying agile SCs from the viewpoint of CAS. They assert that fundamental principles of agile SCs reflect main characteristics and operating mechanism of

CASs. For instance, effective coordination needs an aggregation and interaction among the entities, leading to a balance between emergence and control of behaviours to respond to market changes. Furthermore, information sharing is equally critical for a CAS to evolve and for SCs to be agile. Therefore, a CAS modelling method is arguably appropriate to model agile SCs. They propose a conceptual model and a simulation model in which the complexity and the adaptation aspects of an agile SC are somewhat depicted respectively. Their proceeding lays some foundations yet has some limitations. The collaboration and operations mechanisms in such agile SCs are not yet evidenced. Additionally, their work might have been more convincing and influential if agility attributes had been considered in the models. To date, no studies verify the above models or advance a CAS viewpoint to investigate SCA systematically and formally. While a CAS view alone is not much pursued, as an integrated lens of CAS and network, a social network approach tends to draw increasing attention in the wider literature of SCM. Further details will be given in the following section.

2.3. Social network analysis

2.3.1. Overview of social network analysis

A social network is commonly defined as a set of nodes connected by more than one relations and relevant to a social context (Marin & Wellman, 2014). Nodes vary from individuals, departments, organisations, to countries and even journals. In any social network, nodes connect with each other by at least one of four broad categories of relations; similarities, social relations, interactions, and flows (Borgatti & Li, 2009). These relations, also known as ties, can co-exist, resulting in the network complexity. The study of such interconnectedness among social actors triggered the emergence of a social network perspective (Hanneman & Riddle, 2005). According to Quatman and Chelladurai (2008), this stance is unique as it intertwines research philosophies, methodologies, techniques, and practices. Therefore, the analysis techniques in such social studies often have both quantitative and qualitative elements.

Social network analysis (SNA) refers to both an approach and an analytical tool in examining the structure and qualities of relationships (Wichmann & Kaufmann, 2016). SNA has been widely utilised in social science disciplines from sociology and anthropology to economics (Marin & Wellman, 2014). As an approach, SNA is distinct from other conventional research methods in the social sciences in two main ways. First, SNA emphasises relational ties – linkages – between actors rather than the attributes of actors. Characteristics of social units result from relational processes, and hence, causation comes from the social structure to which individuals belong

(Hanneman & Riddle, 2005; Wasserman & Faust, 1994). Second, as the analyses focus on relational ties, the unit of analysis is not an individual, but an entity including nodes and the relationships among them (Easley & Kleinberg, 2010). The levels of analysis range from dyad (pair of actors), triad (relations of three actors), to larger systems. It is worth noticing that though dyads are a basic characteristic of SNA, it does not differentiate SNA from other approaches (Easley & Kleinberg, 2010). The uniqueness emerges when dyads link together into chains that directly and indirectly connect all actors with all others (Borgatti & Li, 2009).

As a set of tools and techniques, SNA allows comprehensive examination of networks at multiple levels (Hanneman & Riddle, 2005; Wasserman & Faust, 1994). Network structures can be explored by overall network characteristics and then uncovered by alternative approaches of searching community-like structures (Newman et al., 2006). The embeddedness of actors and their relations can be studied by using varying tools tailored for both whole-network and ego-network designs (Newman, 2018). The importance of actors can be investigated by different methods, such as centrality measurement, core-periphery, and roles and positions (Hanneman & Riddle, 2005). Furthermore, a certain method at any level even has a variety of viewpoints and/or techniques, for example, centrality measures and subgroup definitions. SNA also offers various simulation algorithms that are theoretically proven to be more efficient than conventional methods (Borgatti, 2006). The richness and constant development of SNA tools and techniques can meet varying purposes of network studies including network effects, network dynamics, and network assessment, just to name a few (Scott & Carrington, 2011).

2.3.2. Social network analysis in supply chain research

As discussed in the previous section, supply chains are viewed as complex adaptive systems (CASs), exhibiting behaviours that can be drawn from network theories (Choi et al., 2001). Theoretically, integrating both network and CAS lenses can enrich SC research, particularly aspects related to structure and dynamics (Bellamy & Basole, 2013). Hearnshaw and Wilson (2013) made an important contribution to the development of SC theory based on complex network theory considering SCs as CASs. The investigation of different network models together with complex and adaptive phenomena advances the understanding of SCs. The propositions set forth can be applied to explore characteristics of efficient SCs from both lenses. The work of Hearnshaw and Wilson is subsequently extended by Sonia, Muhammad, and Young (2015), who go beyond a focus on efficient SCs to develop resilience metrics and examine the applicability of various network models to resilient SCs through agent-based simulation.

SNA has proven to be a powerful methodology and a valuable lens that can shed light on networks in either hypothesis testing or exploratory research in different disciplines (Quatman & Chelladurai, 2008). As Bellamy and Basole (2013) note, SNA is useful in not only facilitating understandings of SC components, but is also able to uncover underlying connections, embeddedness, structure, and mechanisms in complex supply networks. Despite this potential, the application of SNA to the SCM domain is, compared to other disciplines in social science, still in its infancy (Bellamy & Basole, 2013; Wichmann & Kaufmann, 2016).

SNA was first introduced to the field of logistics by Carter, Enram, and Tate (2007), who outlined the potential of SNA application at intra-organisational and inter-organisational levels. Borgatti and Li (2009) tailored relevant SNA concepts and network mechanisms to supply chain contexts. Their work not only adds clarity to the application of SNA but also emphasises the importance of selecting appropriate theoretical perspectives to maximise the benefits of SNA approaches and tools. It is one of a few key studies on which further research of SNA in SCM has been built. The relevancy of SNA for inter-firm relationship management is reinforced by Galaskiewicz (2011) who also advocates network visualisations as a means to study network dynamics over time.

Much of SNA research has focused on exploring and investigating structural aspects of networks. Kim, Choi, Yan, and Dooley (2011) made headway towards demonstrating the applicability of SNA as a valuable way of analysing supply network structure. Their theoretical framework links various SNA metrics at node and network levels to supply network constructs and performance implications respectively. This then adds to SNA conceptual clarifications in supply network contexts, similar to the work of Borgatti and Li (2009), but with a deeper focus and by using real cases. In a similar vein, Kim et al. (2015) integrate both social network perspective and graph theory to formalise supply network disruption and to highlight the role of network structure on supply network resilience. Their findings around the effects of network structure on resilience, in conjunction with a resilience metric they propose, serve as a foundation on which later studies of supply chain resilience build.

Network topology tends to be widely examined in studies related to risk management and is barely explored in other SCM domains (Wichmann & Kaufmann, 2016). For this reason, Hernández and Pedroza-Gutiérrez (2019) extend the literature of network configuration influence to supply chain agility (SCA) with a food SC as a network case. Their proposed topological metrics for evaluating agility level could only capture one aspect of quick response and left other key agility dimensions unmeasured. However, their study sets out potential research directions that others can pursue, particularly for SCA evaluation from an SNA approach.

2.4. Gaps in the literature

The literature review identifies two main gaps in the research to date and suggests potential areas for future exploration.

2.4.1. Agility assessment approaches, methods, and tools

The literature of SCA is dominated by studies focusing on agility conceptualisation, measurement, improvement, and linkage between this capability and firm performance (AlKahtani et al., 2019). There is a paucity of research on approaches, methods, and tools for evaluating agility. Furthermore, SCA studies adopting a qualitative or inductive methodology outnumber those following a quantitative approach. This can be explained by the dominance of theory-based, conceptual, and exploratory research on agility phenomenon (Sharma et al., 2017).

From the viewpoint of firms, much of the literature on SCA tends to apply organisational contexts rather than considering relationship dynamics (Fayezi et al., 2017). Chen and Chiang (2011) considered SC relationships when studying the role of network agility in firm innovation. However, network agility was defined as a firm's ability to handle its own supply chain. Exceptional examples are the works of Xu and Liu (2015) and Hernández and Pedroza-Gutiérrez (2019). A lack of studies going beyond a focal business to a wider network view is still evident.

2.4.2. Application and applicability of SNA in supply chain management

The adoption of SNA either as a lens, a methodology, or a set of analytical tools is still nascent in the domain of supply chain management (Bellamy & Basole, 2013; Kim et al., 2011). Among network properties, network structure and topology seem to attract the most attention in the SC literature using SNA. This leaves a huge opportunity to explore other properties such as interconnectedness. Macro network views and micro actor views are the most popular approaches while analyses at group level remain scarce. In addition, a wide range of network tools, SNA metrics, and visualisation techniques has yet to be fully deployed or explicitly integrated, even in extant studies focusing on SC topologies and typologies (Basole, 2016; Kim et al., 2015; Wichmann & Kaufmann, 2016). SNA promises to be an appropriate lens for further investigation of diverse SC phenomena including, but not limited to, supply chain flexibility, complexity, and sustainability (Wichmann & Kaufmann, 2016). Empirical studies represent another potential gap to fill in terms of either assessing or demonstrating the applicability, reliability, and practicability of SNA in such SC phenomena.

2.5. Research objectives and questions

This study sets out to explore the applicability of SNA approach for evaluating SCA. Over the course of the analysis, another driving force of this research is investigating how relative agility differs among underlying SCs of a network across a range of indicators by using SNA tools and techniques. The achievement of these two objectives requires addressing the following lines of inquiry, which then can fill the current literature gaps identified in Section 2.4.

Question 1: How applicable is SNA as an approach for SCA evaluation?

1a) Which tools and techniques of SNA are appropriate to evaluate SCA?

1b) Which dimensions of SCA can be appropriately evaluated by SNA?

Question 2: How does agility vary between supply chains, based on a SNA approach?

2a) In what agility aspects do these supply chains differ?

2b) How significant are the gaps of agility?

2.6. Proposed research framework for studying supply chain agility using social network analysis

Based on the literature review and the research objectives, this thesis proposes a framework of two main parts for studying supply chain agility (SCA) using a social network analysis (SNA) approach. The first part is a conceptual model of SCA from SNA perspective. The second part sets forth propositions about the effects of network properties and characteristics on agility dimensions. These two parts are explained as follows.

2.6.1. A conceptual model of supply chain agility from a social network analysis perspective

This piece of research leans on the notion of a complex adaptive system network (CASN) of Pathak et al. (2007) and follows the seminal studies on SNA in SCM to model SCA as depicted in Figure 1. From a CASN lens, a supply network[3] evolves together with the environment characterised by dynamism, uncertainty, and risks (Day, 2014). Any changes in the environment can impact supply network which may then, in turn, impact the environment directly or indirectly (Pathak et al., 2007). This co-evolution might affect SCA that is driven by the environment (Fayezi et al., 2017; Gligor et al., 2013) and is arguably determined by network structures and

[3] Terms “supply chain(s)” and “supply network(s)” are used interchangeably in this thesis.

characteristics (Wichmann & Kaufmann, 2016). The impact of the co-evolution and the role of the environment on SCA, however, are beyond the scope of this research. From a network perspective, SCA is not formed merely by the aggregation of each organisation's capability (Sonia et al., 2015; Wichmann & Kaufmann, 2016). Rather, it is assumed to be determined by all the network elements that are interrelated.

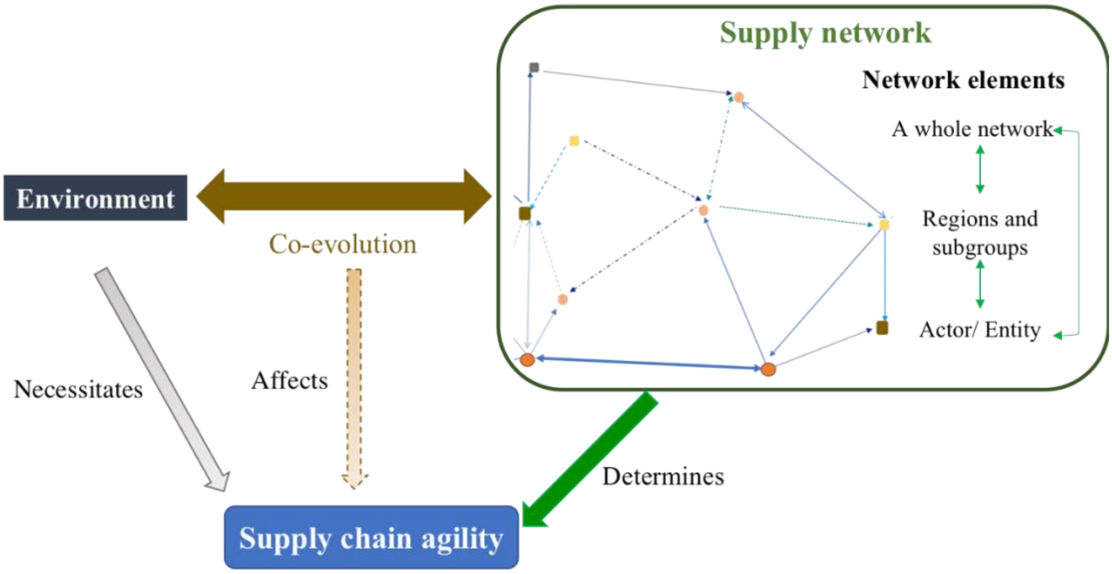

Figure 1 - Conceptual model of supply chain agility from a social network analysis perspective

2.6.2. Propositions of relationships between network properties and supply chain agility dimensions

Table 3 presents a set of propositions about relationships between network characteristics and agility attributes unbundled from network properties and agility dimensions, based on the literature review. The literature of SNA uses different terms such as variables, properties, components, characteristics, and attributes interchangeably. In this thesis, the term property means something inherently possessed by a network element whereas the terms characteristic and attribute serve to describe a specific feature of that property. Of the various SCA dimensions explored in the literature, this study chooses to focus on flexibility, responsiveness, and visibility, since they attract significant attention and involve different sub-capabilities.

Network visibility is constituted by three main elements that previous researchers, as cited in the work of (Basole & Bellamy, 2014), have identified. Accessibility refers to the ability to access information across a SC. It is widely agreed in the literature that this is a necessary condition even if it may assume different names, such as virtual supply chains (Christopher, 2000) or information integration (Lin et al., 2006). Transparency refers to how well the organisations are aware of their trading partners' supply chain activities whereas the extent and quality of exchanged information determine the degree of their structural insights into such activities.

In this study, responsiveness entails both reactive and proactive aspects. The former is determined by short-time response, synchronisation, and integration. Specifically, it includes the speed at which flows go through the network (Christopher & Peck, 2004), the capability of network members to synchronise their operations and process (Wilding, 2013), and process and network integration (Christopher, 2000). The latter refers to the ability to detect changes and capture novel ideas or opportunities. The notion of market sensitivity that (Christopher, 2000) advocates is borrowed but redefined to better reflect this attribute.

This thesis adapts the flexibility framework of Stevenson and Spring (2007) and a flexibility indicator in the context of complex supply networks, as proposed by Sonia et al. (2015). Accordingly, network flexibility is indicated by the number of connections among functional network members. It includes reconfiguration and relationship flexibility types. Reconfiguration equates to a network's adaptability to changes while relationship flexibility is defined as the ability to have multiple options for collaborative connections.

Transmission and coordination are presumably two mechanisms underlying the network effects on SCA. Under the transmission mechanism, the ties between any two organisations are the pipes carrying information. An actors[4] having many ties is hypothesised to obtain more information (Borgatti & Li, 2009). Under the coordination mechanism, stronger ties are suggested to be associated with greater commonality and coordination between organisations, subgroups, and network regions[5] (Borgatti & Li, 2009). Supply chain collaboration as an enabler for SCA stems from the above mechanisms. This also aligns with much of the literature. In addition, as Towill (2005) notes, agile supply chains should be prepared for, and sufficiently robust to withstand, severe shocks and disruptions. This is echoed by Pettit, Fiksel, and Croxton (2010), who contend that agility capabilities should reduce vulnerabilities. Consequently, robustness is proposed as a foundation for network agility.

The propositions are made based on the researcher's initial estimates. A "+" means a positive relationship whereas a "-" means negative. "/" indicates possible neutrality and a blank cell

[4] In this thesis, actors/entities refer to organisations/businesses and these terms are used interchangeably.
[5] A region in SNA means an area of a certain network based on graph theory. It is not a geographical location.

implies the possibility of no impact, unspecified impact, or irrelevance. It is worth noting that this part should not be treated as a detailed analysis plan to test or examine the propositions. Rather, this serves as a guideline to select appropriate SNA metrics, tools and techniques to assess network agility in the next chapter.

Table 3 – Network properties and SCA dimensions propositions

Network			Visibility			Responsiveness				Flexibility		Robustness - Foundation	SC collaboration - Enabler
Elements	Properties	Characteristics/ Attributes	Accessibility	Transparency	Quality & scope of exchanged information	Speed	Synchronisation	Integration	Market sensitivity	Reconfiguration	Relationships		
A whole network	Network topology/ configuration	Network centralisation		-	-	-	+	+		-	-		
	Network cohesion	Connectedness	+	+			+	+		+	+	+	+
		Density	+	+			/	/	+	+	+	+	+
		Path length			-	-							
Regions and subgroups	Interactions	Similarities	+	+			+	+	/	+	+	+	+
	Linkages	Tie strength	+	+		+	+	+	+	+	+	+	+
		Connectivity	+				+	+		+	+	+	+
Actors/ Entities	Positions	Brokerage	+	+	/	/	+	+	+			/	/
		Clustering	+	+	/	/	+	+	/	+	+	/	/
	Roles	Centrality	+	+	+	+	+	+	+	+	+	/	+
		Power	+	+	+	+	+	+	+	+	+		+

2.7. Summary of key aspects of the literature

Supply chain agility (SCA) encompasses diverse dimensions and sub-capabilities for survival and competiveness (Gligor et al., 2019; Sharma et al., 2017). Agile supply chains (SCs) can quickly sense and flexibly respond to unexpected changes, based on the availability of, and accessibility to, information across the SCs (Christopher, 2000; Fayezi et al., 2017; van Hoek et al., 2001). Although the SC context is widely acknowledged, SCA is often defined and studied from the firm's viewpoint, in terms of its own SC rather than from the perspective of a network encompassing extended SCs (Fayezi et al., 2017). The research on SCA assessment approaches, methods, and tools is scarce while studies on agility measurement, enhancement, and relationships with other phenomena are numerous (AlKahtani et al., 2019). The extant research on agility evaluation approaches typically aims to address the vagueness of human perceptions and to provide quantifiable results (Hernández & Pedroza-Gutiérrez, 2019). However, little work has been undertaken with regard to considering relationship dynamics.

A complex adaptive system (CAS) lens has been increasingly advocated as applicable to study and manage supply networks (Choi et al., 2001; Surana et al., 2005). Key properties of supply networks are asserted to be analogous to those of CASs, including internal mechanisms of self-organisation and emergence, a dynamic environment, and a co-evolution between the system and the environment (Choi et al., 2001; Surana et al., 2005). Meanwhile, a network perspective allows the examination of interconnectedness between entities, which then adds to the application of complexity theory to SCM research. Theoretically, integrating both lenses can provide a comprehensive and systematic approach to study the structure and dynamics of supply networks (Bellamy & Basole, 2013).

As an approach and as a set of analytical tools, social network analysis (SNA) is demonstrated to be powerful and valuable for examinations of the structure and characteristics of relationships. SNA differs from the more conventional research methods in the social sciences in that it primarily focuses on relational ties and the unit of analysis instead of emphasising the attributes of actors and individuals (Easley & Kleinberg, 2010; Hanneman & Riddle, 2005; Wasserman & Faust, 1994). Multiple researchers have outlined the relevancy and potential of SNA in SCM research but the application of SNA to a real case in the SCM domain is still nascent (Wichmann & Kaufmann, 2016). The applicability of SNA to the SCM field is most often explored in studies on structural aspects of supply networks, particularly those focusing on network resilience, disruption, and robustness (Hernández & Pedroza-Gutiérrez, 2019; Kim et al., 2015; Kim et al., 2011; Nair & Vidal, 2011; Sonia et al., 2015). There are various promising avenues within SCM that await the adoption of an SNA methodology (Wichmann & Kaufmann, 2016).

During the literature review, the identified gaps motivate this study to pursue an SNA approach to study SCA. A reasonable framework and appropriate future directions for this research cannot be achieved without a basis of fundamental studies in the discipline of SCA, CAS, and SNA as summarised in Table 4. How this thesis is undertaken to build on these formative works will be presented in the next chapter.

Table 4 - Summary of key studies influencing this thesis

Authors	Main contributions
Christopher (2000)	Providing a seminal definition that covers main agility attributes
Fayezi et al. (2017)	Providing a comprehensive review of SCA
Faisal et al. (2007)	Advocating graph theory approach to evaluate SCA
Xu and Liu (2015)	Demonstrating the applicability of complex network theory to assess SCA
Choi et al. (2001)	Extending the complex adaptive system (CAS) theory to SCM
Pathak et al. (2007)	Advocating the potential of a CAS view to develop SC theory
Wasserman and Faust (1994)	Reviewing and discussing SNA methods and tools systematically
Borgatti and Li (2009)	Adding clarity to the application of SNA by tailoring relevant SNA concepts and network mechanisms to SC contexts
Kim et al. (2011)	Demonstrating the applicability of SNA to analyse supply network structure
Hearnshaw and Wilson (2013)	Investigating different network models and complex and adaptive phenomena based on complex network theory Exploring characteristics of efficient SCs
Sonia et al. (2015)	Examining the applicability of various network models to resilient SCs through agent-based simulation
Kim et al. (2015)	Formalising supply network disruption Highlighting the role of network structure on supply network resilience
Wichmann and Kaufmann (2016)	Providing a systematic literature review of SNA application in SCM
Hernández and Pedroza-Gutiérrez (2019)	Proposing network topology metrics for evaluating agility level

Chapter 3: Research methodology

Chapter 3 and its supporting appendices explain how this study is designed and conducted to achieve the research objectives stated in the previous chapter. Section 3.1 discusses how the researcher's philosophical beliefs guide the investigation and shape the research methodology which is then explained in Section 3.2. Section 3.3 outlines the research design, followed by a discussion on data collection and data analysis approaches in Sections 3.4 and 3.5 respectively. This chapter ends after the chosen research methdods are justified in view of quality criteria in Section 3.6.

3.1. Philosophical perspectives

3.1.1. Ontological perspectives

In general terms, ontology refers to the belief of an individual about the nature of social reality (Grix, 2002). It serves as the foundation for all research activities (Bryman & Bell, 2011). An ontological position seeks to answer core questions, including what exists, what it looks like, what constitutes social reality, and how society and the actors inside it interact with each other (Grix, 2002). There are two main ontological perspectives representing two opposing views of social reality: objectivism and constructivism.

I lean more towards constructivism, which supports the view that the social world is shaped by the individuals interacting within it (Bryman & Bell, 2011). Social actors not only operate in the social reality of that world, but also construct and develop that reality through their continuous interactions with it (Robson, 2002). In addition, I believe that the social world is made up of various inter-relationships and inter-dependencies. It is dynamic and subject to any changes caused by the social actors within it. Consequently, I see myself as a constructivist who advocates constant revisions of social reality rather than an objectivist who views the social world as static, tangible, measurable, and observable (Grix, 2002; Robson, 2002).

Ontological positions differ in the domain of supply chain management (SCM). From an objectivist stance, supply chains (SCs) have their own inherent characteristics as a natural consequence of SC design and practices. Such characteristics are independent of the intention and awareness of SC members (Srai & Gregory, 2008; Wagner & Neshat, 2010). For instance, supply chain vulnerability is inherently dictated by the SC structure, which may be affected if a disruptive event were to strike on either the demand or supply side (Kurniawan, Zailani, Iranmanesh, & Rajagopal, 2017; Stecke & Kumar, 2009; Wagner & Bode, 2006). Similarly, supply chain capabilities, for example, resilience and flexibility, are built-in without the intentional awareness and demonstration of firms (Adobor & McMullen, 2018; Stevenson & Spring, 2007). Furthermore, though SC capabilities are not always observable, they can be measured or quantified. This can be evidenced by the abundant literature on measurement in SCM, including supply chain agility (SCA).

While I partially agree with the above stance, I tend to share the same beliefs as constructivists in SCM research. SC capabilities, despite being built-in, can be intentionally developed and changed by organisations (Ali et al., 2017). The agility level of SCs can vary upon a change in the purchasing strategy (Baramichai et al., 2007), the inclusion of risk management practices (Wieland & Marcus Wallenburg, 2012), the adoption of TADS (Balaji et al., 2015), just to name a few. Furthermore, from the perspective of CAS, SCs interact with dynamic and complex environments. This leads to the need for constant adjustments in order to "stay fit and agile" over time (Choi et al., 2001, p. 359). Network structures are not fixed either even though they are seen as lasting patterns of relations among actors (Wasserman & Faust, 1994). This can be explained by network dynamics in changing contexts and with varying influential factors on different types of relations (Newman et al., 2006; Snijders, 2014). Additionally, from an SNA perspective, SC relationships are interconnected and interdependent, leading to non-linear relationships that are not always observable or measurable (Borgatti & Li, 2009; Galaskiewicz, 2011). Similarly, inter-dependencies exist not only among agility components but also among various sub-attributes of each component (Faisal et al., 2007; Stevenson & Spring, 2007).

3.1.2. Epistemological perspectives

The discussion of epistemology centres around the available knowledge in a field of study, its validity, and acceptable methods to obtain that knowledge (Grix, 2002). An epistemological position aims to answer whether social phenomena can be investigated by approaches and principles of natural sciences (Bryman & Bell, 2011). Because of a close relationship between ontology and epistemology, there are also two contrasting ideas: positivism and interpretivism (Grix, 2002).

While I partially agree that knowledge can be obtained from observable and measurable facts without involving the observer's values (Robson, 2002), I find myself in favour of interpretivism for three reasons. First, people and their institutions, the subject matter of social sciences, are distinct from objects of natural sciences. Social studies, therefore, require different research processes and methods (Grix, 2002). Second, human interactions are highly complex and non-linear. This causes difficulties and, sometimes, impracticalities in drawing causal relationships for a certain social phenomenon (Bryman & Bell, 2011). Third, it is not always possible to observe and measure social reality because there are various meanings attached to human behaviours. By viewing phenomena from the social actors' perspective, hidden factors can be uncovered (Robson, 2002). Therefore, interpretivism offers a better approach to a comprehensive understanding and appropriate interpretation of the social world.

Interpretivism is dominant in the literature of SCA, particularly in the conceptual and theoretical works. Studies that define agility and which distinguish this concept from other similar SC phenomena follow this perspective. Examples of such studies include Charles et al. (2010); Christopher (2000); Fayezi et al. (2017); Gligor et al. (2019); Li et al. (2008), to name but a few. While van Hoek et al. (2001) believe that agility can be measured, they also adopt an interpretivist position to uncover key dimensions and elements of SCA. Similarly, proposed agility assessment approaches and tools often draw on interpretivism to gain insights into agility dimensions and metrics, which are difficult to define and examine directly in conventional natural sciences (Faisal et al., 2007; Li, Goldsby, & Holsapple, 2009; Lin et al., 2006).

Generally, in social network research, interpretivists seek to explore and examine network practices, network orientations, network effects, and network dynamics in view of respective contexts (Hollstein, 2014). As the application of SNA to SCM is still in its infancy, there are few examples from which to draw. However, the perspective of interpretivism can be inferred from conceptual studies. For example, Kim et al. (2011) explore the structural characteristics of supply networks in the context of an automotive supply chain. A few years later, supply network disruptions and resilience are conceptualised through a similar approach by Kim et al. (2015).

I lean towards interpretivism to study SCA from an SNA lens. I acknowledge that the relative agility of different SCs can be evaluated by a range of network metrics. However, I am interested in exploring how network properties impact on SCA rather than drawing a direct causal relationship between network characteristics and each agility attribute. Furthermore, by nature, agility capabilities and network characteristics are intangible. The interdependencies among SC relationships, and among agility attributes are not observable neither. Accordingly, they require an understanding of the meanings attached to, and interpretation of, findings from the perspective of SC members.

In summary, this research will undertake constructivist and interpretivist perspectives. Much of this study involves quantifying and visualising SC relationships, which looks like an approach of the natural sciences. However, rather than merely evaluating SCA of different SCs, this study seeks to go further and explore the applicability of SNA to further studies of SCM. Therefore, it is indeed an exploratory piece of research wherein figures and numbers only serve to illustrate and interpret the application in a specific case.

3.2. Appraisal and selection of alternative research methodologies

3.2.1. Appraisal of alternative research methodologies

There are two main groups of research methods: quantitative and qualitative. These two groups share some similarities but differ from each other in various aspects (Bryman, 2016). Quantitative research is usually conducted by observations of events and their measurements (Bryman & Bell, 2011). This methodology is mainly applied in studies that test hypotheses from existing theory or which are seeking to determine causal relationships. Conversely, in qualitative studies, researchers are typically either immersed in a social setting or engaged in an open yet unstructured dialogue with social actors (Cobb & Hagemaster, 1987; Fossey, Harvey, McDermott, & Davidson, 2002). This is an inductive approach used to discover and construct meaning through which new theories emerge.

Quantitative research follows strict yet standard, and hence, replicable processes. Although researchers are observers during the research process, they can exert control over the variables in the research environment (Bryman & Bell, 2011). In contrast, qualitative research allows tailored procedures in which researchers are intensely engaged, but with limited control over the variables in the research environment (Ghauri & Grønhaug, 2010). Naturally, the former fits with objectivism and positivism while the latter is preferred by researchers taking a constructivist and interpretivist stance (Robson, 2002).

Quantitative research benefits researchers in four key areas: replication, generalisation, causality, and measurement (Ghauri & Grønhaug, 2010). These advantages are generally lacking in qualitative research. By using well-devised tools and clearly determined processes, replication is made possible to obtain future results with objectivity. The results from a studied sample can be generalised for a bigger group based on numerical findings, statistical analysis tools, and sampling principles. Causal relationships can be drawn from independent and dependent variables by statistical tools. Moreover, with indicators and checks for reliability and validity, this methodology allows for a precise measurement of concepts which can then help to advance the understanding of different concepts in the field of study (Bryman & Bell, 2011).

Researchers in favour of qualitative methods advocate three main advantages (Merriam & Tisdell, 2016; Taylor, Bogdan, & DeVault, 2016). First, from observations and intense engagement, researchers can reach a fuller and deeper understanding of the social actors studied and their respective behaviours in a specific context. Second, the flexibility and limited structure resulting from tailored procedures can lead researchers to findings that might have not been disclosed in a quantitative study. Third, flexible measurements and iterative research paths enable changes over time to be captured. The dynamic nature of the social world can be studied, instead of being understood from a static view, as is the case in quantitative research (Bryman, 2016). Qualitative studies, therefore, address some key limitations of quantitative research.

Mixed methods were introduced to provide more comprehensive findings by combining strengths of both quantitative and qualitative paradigms in the same study concurrently or sequentially (Doyle, Brady, & Byrne, 2016). For example, a preliminary qualitative study may identify some interesting findings, leading to opportunities for further quantitative examinations to gather more data and to perform a wider analysis. Therefore, the mixed methods approach is gaining increasing popularity. However, because quantitative and qualitative approaches derive from two contrasting philosophical positions, a conflict of perspectives can occur in the co-existence of these approaches (Bryman, 2016; Collis & Hussey, 2013; Doyle et al., 2016).

3.2.2. Selection of an appropriate research methodology

Qualitative approaches are dominant in the literature of SCA assessment (AlKahtani et al., 2019). Inductive reasoning tends to fit well with studies which either aim to develop theory, clarify concepts, or propose models and measurement to assess SCA. Because there is a lack of consensus around notions of SCA (Sharma et al., 2017), and there are few well-developed metrics for evaluating agility factors (Faisal et al., 2007; Giachetti, Martinez, Sáenz, & Chen, 2003), few quantitative studies have resulted. This thesis complements the extant literature by adopting a quantitative methodology in considering the following factors.

By nature, SNA as an analytical method aligns well with the measurement of relationships. A set of SNA tools and techniques allows a fuller examination of network impacts on SCA. This methodology can tap into the aspects that might be overlooked or minimally covered by a purely qualitative approach. Connection patterns and subgroup structures become discernible from network metrics and visuals rather than from the interpretation of meaning attached to business transactions. Likewise, key organisations to network agility are determined by their positions in the network instead of subjective self-assessment and perceptions.

Although the benefits of rich and deep information from participants is indisputable, the primary focus of this study is on inter-firm relationships, rather than clarifying concepts of SCA or developing better understandings of human behaviours in evaluations of relationships. In addition, while constructivist and interpretivist commitments are commonly associated with qualitative research, this is not always the case. Constructivist and interpretivist lenses can still be adopted in quantitative studies of social sciences (Bryman, 2016).

By employing a quantitative approach, the research objectives of this study can be achieved. Quantified and visualised SC relationships make it possible to relatively compare agility levels between supply chains. The research findings can be found to be reliable by testing for internal and external validity, and by using objective analytical tools and techniques, and rigorous testing methods. The standard process allows the replication of exploring and examining the applicability of SNA to study SCA and other SC phenomena. While a mixed methods approach may be a potential alternative to exploit the advantages of both quantitative and qualitative approaches, limited time and resources preclude this study from adopting this methodology.

3.3. Research process and research design

This thesis follows a research process illustrated in Figure 2. Evaluating and deciding appropriate research options are critical as they guide the direction of data collection and data analysis (Cooper & Schindler, 2008). Initial findings are constantly compared, contrasted, and reviewed against the literature for supporting ideas and arguments. This feedback loop results in final findings and conclusion that can add to the extant literature.

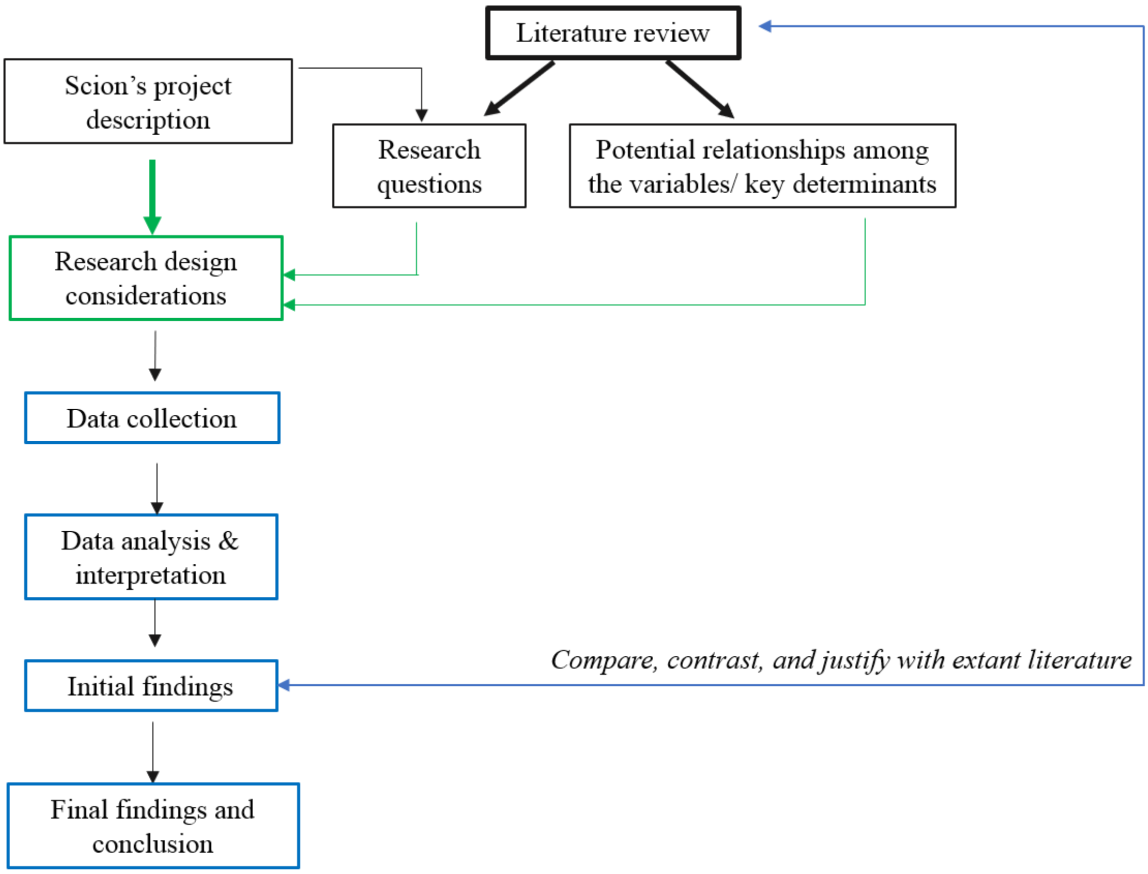

Figure 2 - Research process at high level

The research questions and the literature synthesis have informed the research options, most of which are mainly determined following the larger project of Scion and outlined in Table 5. This thesis is of descriptive purpose, since it tries to explore a variety of SNA tools and techniques and concurrently deploy a range of indicators to investigate relative agility across SCs of a network case[6]. This research is conducted in a specific rural area of New Zealand by formal procedures and personal forms of communication accordingly.

Table 5 shows that this study's variables cannot be controlled or altered by the researcher by any means. Likewise, the participants' daily routines basically remain unchanged. Both the SC relationships and SCA are dynamic and evolving, and hence, are best investigated over an extended period of time. However, there are limitations in the scope of a master's thesis, including time, budget, and access to potential participants. Therefore, this study is undertaken once rather than in iterations and can only provide a snapshot of that specific research period.

[6] It is worth noting that a case study in this thesis is neither a statistical case nor a full contextual analysis of quantitative and qualitative studies respectively. Rather, it is a network case, lying between these two extremes

Table 5 – The design of this study – adapted from Cooper and Schindler (2008) and Borgatti et al. (2013)

Category	**Selected option**	**Rationale**
Purpose of the study	Descriptive	A need to identify • appropriate tools and techniques to evaluate relevant agility attributes • *what, when, where, how much* relative agility of SCs differs and *which actor* influences the agility gaps
Topical scope	Case study	Emphasis on details of a network case (e.g. industry background, network characteristics, and linkages)
Question crystallisation	Formal	Involving procedures to answer the research questions
Method of data collection	Communication	The complexity of relationships and agility capabilities requires personal means
Research environment	Field setting	Conducted in specific and actual locations
Researcher's control of variables	Ex post facto	The reality of networks, SC relationships, and agility capabilities cannot be manipulated or influenced
Participants' perceptions	Routine	Basically, no or few deviations
Time dimension	Cross-sectional	Limited time, budget, and access to target respondents
Network design	Ego-network	Feasibility considering limited resources and possibility to set the network boundary

Given the limited resources of this project, it is not feasible to apply a whole network research design due to the large number of businesses in the region. Furthermore, the goal and the nature of the research questions in this thesis do not allow setting restrictions to the number of trading partners an organisation has. Therefore, this research follows the suggestion of Borgatti, Everett, and Johnson (2013) in using an ego-network research design. This design helps to simplify the issues of bounding the network. It is also advocated for improving data quality because it enables higher levels of confidentiality (Hanneman & Riddle, 2005; Scott, 2013). While the information on the global pattern of connections may be somewhat lost, what is gained is richer data of the network area local to focal entities – also known as egos in SNA terminology.

3.4. Data collection approach

3.4.1. Types of data needed

This thesis needs primary data for three reasons. First, primary data align with the research design of this study. Specifically, they are critical for the description of a network case, and for maintaining the originality of the social reality being investigated. Second, there is little material available to help answer the research questions. There is a paucity of studies focusing on SCA evaluation methods and tools, and on the application of SNA to SCM research. Third, primary data are particularly useful to SNA research. They allow plenty of freedom of choosing the types of relations and the features of entities for examination (Borgatti et al., 2013).

The primary data in this thesis derive from those of Scion's project[7], which include two categories: attributes of organisations, and relational data. The former centres around the businesses themselves, including financials and self-evaluation in disruptive scenarios. The latter is related to their main suppliers and customers. These SC relationships are evaluated by a range of criteria. While the latter is the most critical part of this research, the former is necessary to assist the further understanding of and explanation for results analysed from the latter.

This study uses secondary sources of data mainly to support decision-making in research design and data analysis. Before the data collection stage, academic papers helped to refine the research questions, the devising of proper tools, and the design of appropriate procedures (Ghauri & Grønhaug, 2010). Professional journals, general and industry statistics, government reports, and regional documents provided the researcher with a basic understanding of rural New Zealand. These sources of data also serve to validate the results and strengthen the analysis and interpretation undertaken in this thesis (Bryman, 2016).

3.4.2. Methods of data collection

Of all the common data collection methods associated with quantitative research, interviews were deemed the most appropriate for this study. Interviews allow a bottom-up data gathering approach and aligns with the research design of Scion's project. Furthermore, it is the method of choice to solicit network information in SNA research (Marsden, 2014). Documents and archival records were also reviewed to enhance the researcher's understanding of the topic and situations. This

[7] Refer to Appendix 2 for details of main variables in the Scion project's data

process of document analysis is a means of triangulation to verify information elicited from respondents during the data collection stage (Collis & Hussey, 2013).

Interviews are conducted in a structured and face-to-face manner for two main reasons. A fixed order of words and a consistent vocabulary in the questions posed provide a stable base for analysis (Collis & Hussey, 2013), and particularly, for relative comparisons of agility between different SCs. Indeed, face-to-face communication is upheld by the literature as an efficient means of building rapport with respondents. This then helps to maximise elicitation, increasing the opportunity to yield network data as fully and richly as possible. Non-response on the part of interviewees can be reduced accordingly (Borgatti et al., 2013).

The structured interviews use a questionnaire designed to capture both non-network and network data in a simple and time-saving way for respondents. Most of the questions are open-ended. This format is particularly suitable to solicit network data because the list of potentially relevant trading partners of organisations is unknown (Borgatti et al., 2013). Each interviewee is asked to list his or her main suppliers and customers who all together contribute to at least 80% of supply value and at least 80% of sales respectively. The strength of these SC relationships is assessed by a rating approach with a relative scale. The Likert scales are also applied to ask organisations for their self-assessment about the plausible outcomes of closure and degrees of readiness to respond to disruptive events. A full questionnaire and step-by-step instructions for respondents to list their SC members are in Appendices 3 and 4 respectively.

Throughout the data collection, strict confidentiality and respects for stakeholders are treated as essential ethical components. This study adheres to the principles provided by Massey University's Code of Conduct and those agreed by Scion for social science studies. A range of ethical considerations to assure the compliance can be found in Appendix 5.

3.4.3. Sample selection and sampling

This thesis follows the sample selection and sampling procedures of Scion's project. The subject of this research is registered businesses in a specific rural area of New Zealand. Owners or managers could represent their organisations in participating in the interviews. To be qualified respondents, respondents needed to clearly understand the structures and procedures of relations with their trading partners so that they could relatively evaluate their SC relationships. The domain of investigation is predominantly rural with the economy relying on primary industries and small communities. This area also has a relatively higher vulnerability to natural hazards than other areas in New Zealand. Consequently, the businesses there tend to operate in a more volatile environment than their counterparts.

A combination of purposive sampling and snowball sampling is the principal technique because target respondents are often hidden and hard to find by conventional methods (Bryman, 2016). Furthermore, snowball sampling is particularly useful to approximate the network boundary (Borgatti et al., 2013). The project team leaned on personal contacts to reach out to key personnel at the associations, corporates, and cooperatives, who could then introduce the researchers to other personnel in organisations in similar or relevant industries. This study also identified a list of potential business contacts from the New Zealand business directory and local groups of enterprises. Additionally, the study also used the contacts that have been referred by the interviewees as their trading partners in the corresponding supply chains.

3.5. Data analysis approach

This thesis has two main categories of data: organisational attributes (non-network data), and relations (network data). The former provides background information and an overview of the network case. The latter offers information about the ties that construct the network. Like a statistical study, the analysis of the former involves descriptive statistics for numerical results. Meanwhile, the latter is analysed by a social network analysis approach. The whole process of data analysis is in accordance with human ethics as described in Appendix 5.

This section outlines the analysis approach for network data as it is the most critical part of the research. Figure 3 shows that the analysis encompasses all three levels. It focuses on information flows since the key aspects of SCA, such as visibility and responsiveness, are closely associated with information. UCINET 6 package is used to perform the analysis due to the high applicability and the strength of the built-in sub-programmes (Scott & Carrington, 2011). Specifically, UCINET software allows the examination of network agility through a range of network metrics, tools, and techniques associated with three levels of analysis. NetDraw helps with network visualisation while KeyPlayer offers a new simulation approach.

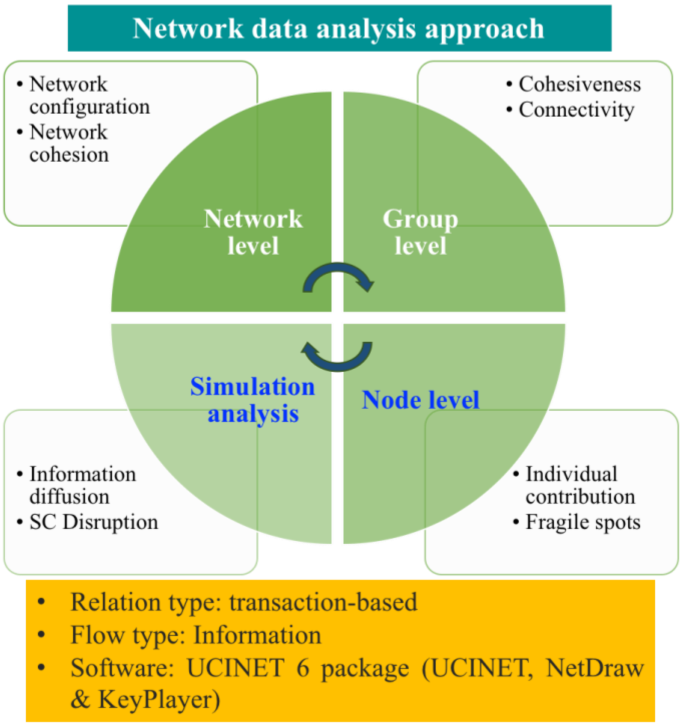

Figure 3 - The approach of network data analysis in this thesis

The above figure indicates the sequence of analysis which starts by assessing the overall agility at the network level. The network structure is then uncovered to see the agility distribution in network regions and subgroups at the group level. Before simulations are run to study information diffusion and disruption scenarios, differences among organisations are closely examined at the node level. All levels of analysis lean on the symmetrised network data for two main reasons. The information exchange is usually mutual and can be initiated from either suppliers or customers, thus, the network is of non-directional characteristics. Furthermore, plenty of analytical tools and techniques of most SNA software packages including UCINET can only work well with undirected relations.

The network-level analysis takes into consideration the available connections of interviewed organisations and their trading partners. This provides a macro view of a whole network characterised by configuration and cohesion (Borgatti et al., 2013). Network configuration usually refers to the overall pattern of connections determined by centralisation levels in a network (Kim et al., 2015). Meanwhile, network cohesion often consists of a family of concepts to reflect the knitted-ness of ties (Borgatti et al., 2013; Hanneman & Riddle, 2005). A set of metrics and indices selected to examine the network characteristics after considering their relevance to aspects of SCA are briefly explained in Appendix 6.

At the group level, a bottom-up approach is taken to identify cohesive subgroups and regions wherein the entities are closely connected, and hence, tend to be more agile. The roles of actors, their connectivity, and cooperation among them can be identified too. This research adopts the criteria of cohesive groups in the work of Wasserman and Faust (1994) which focus on the properties of pairwise ties. There are two classes of such criteria: the concentration of ties within a group and the relative strength or frequency of ties within a group compared to external ties. Further details are in Appendix 6.

At the node level, individuals[8] (organisations in this research), through their positions in the network, presumably impact the network agility level in two ways. On the one hand, some individuals can contribute to agility dimensions such as visibility and responsiveness, directly or indirectly. Such actors are usually popular, potentially influential, or are in a favourable position to be a conduit of information flows. On the other hand, some other individuals may pose a risk to network fragility or create bottlenecks for communication across network regions. The agility of the network may be hindered accordingly. Individual contribution is evaluated mainly through centrality measures, whereas fragile spots are studied by fragility analysis. Details of such measures and analyses are in Appendix 6.

The above approaches can shed light on which areas warrant attention, especially when it comes to evaluating the network's current capability. However, several questions emerge. For example, what if only 1% or even just 0.5% of the network could know that piece of information and they were the only starting points to transmit the message? On which centrality measures should such a seeding group be chosen? Likewise, how badly damaged would the connectedness of the network be if disruptions strike certain organisations rather than fragile spots? The simulation analysis seeks for key actors and network mechanisms in such scenarios by two main approaches which will be further explained in Appendix 6 and demonstrated in Chapter 5.

3.6. Critical review of the chosen research methodology

The quality of this research is evaluated based on reliability and validity criteria. The framework applied to this thesis is summarised in Table 6. It is adapted from the work of Neuman (2014) and is particularly influenced by the work of Borgatti et al. (2013), who emphasise how threats

[8] The term "individuals" can mean a specific entity or a set of key players, depending on the measures and the algorithms chosen.

to data reliability and validity could be minimised by the chosen research methodology and other preventive approaches.

Table 6 - Framework of quality evaluation for this thesis

Criteria	Description/ Explanation	How the criteria were met
Reliability		
▪ **Internal**	Dependability	Avoidance of typical errors in the design and data collection
▪ **External**	Replicability	Well-documented research process
	Objectivity	Minimised risk of biased analysis Respondent validation
Validity		
▪ **Internal**	No errors internal to the research design	Well-considered practices of research implementation
	Credible results	Respondent validation Triangulation
▪ **External**	Generalisability/ Transferability	Description of a network case Well-documented research process

3.6.1. Reliability

The above framework shows that, in this study, reliability refers to dependable and objective results derived from consistent and replicable processes. Dependability can be achieved by avoiding or minimising the risk of common errors in the research design and data collection phase, especially when network data is concerned (Borgatti et al., 2013). The current format of open-ended questions may cause an insufficient amount of information being elicited from respondents about their supply chain (SC) partners. Potentially, there is a high possibility of nodes and ties being excluded and/or included subjectively and mistakenly, which in turn affects data analysis, particularly at both network and node level. Such a risk cannot be completely mitigated but can be minimised by giving detailed instructions to interviewees to list as many trading partners as possible if this information was neither sensitive nor confidential. There was little chance of retrospective errors in this research because respondents were asked to report SC relationships that comprised long-term patterns of interactions rather than those that were temporarily discrete. A rigorous validation process was also applied to avoid errors during data management, processing, and interpretation. Specifically, data entry underwent at least three rounds of cross-checking; one round by the project team of Scion, and two rounds by the researcher. The UCINET 6 package was regularly updated to avoid software bugs and data formatting errors. Furthermore, feedback was sought from the researcher's supervisors at every stage of the research process, from her decisions to omit or include organisations and their relations, through to data fusion, aggregation, and interpretation.

A study similar to this one could be feasibly produced since all the procedures, practices, and decisions were documented in detail in the interests of result verification and further replication. The replicability of this study is underpinned by various efforts to achieve objectivity. For example, the researcher's interpretation of the network analysis results were reviewed by her supervisors to minimise any risk of bias. In addition to this, a respondent validation technique was applied three times during the project. At the end of interviews, responses were briefly recapped to give interviewees an opportunity to provide feedback, to confirm what was said, and to request for adjustments to be made. During data analysis, respondents received a brief report on the current strengths and risks in their value chains based on initial results. Once the project ended, a summary of aggregated research results was shared with them. The sharing of results serves not only to reciprocate the contributions of participants but also functions as a means to validate the initial results and to confirm the appropriateness of the study's analysis and interpretation.

3.6.2. Validity

This thesis aimed to achieve valid findings through the overall research design rather than relying solely on measurement validity. This study was implemented following a rigorous consideration of practices. The methods of choice for data collection served to limit as much as possible the prospect of missing data caused by non-response. According to Borgatti et al. (2013), non-response is a major threat to the validity of SNA studies as it affects the structural and analytical outcomes at any level of analysis. The choice to conduct structured interviews in a face-to-face and one-on-one manner was made with a view to building rapport with interviewees. The success of this method is evidenced by the relatively rich data that emerged -- not only of SC relationships, but also the sharing of additional information by interviewees. Before the project was carried out, two pilots had been conducted to ensure that the official questionnaire was appropriate and not too onerous. Detailed instructions for mapping supply chains, coupled with a mix of open-ended questions and Likert scales, gave interviewees a range of question formats for which to provide full answers.

Credible results were achieved from a combination of respondent validation and triangulation techniques. The former, as explained above, could increase both the reliability and validity of the study’s findings. The latter mainly involved with using multiple tools, measures, and levels of analysis for a given subject or issue. For example, the importance of organisations to network agility was not only measured by centrality measures at the node level, but also evaluated against co-membership at the group level, and were compared to the simulation results as well. In addition, the researcher also analysed documents and archival records to verify responses, especially attribute-related information.

The current respondent-driven sampling method did not allow the results of network agility state to be generalised for a wider region. However, the literature indicates that this in itself does not affect the robustness of the measures used, and hence, does not compromise the validity of the study (Borgatti et al., 2013; Costenbader & Valente, 2003). Moreover, the scope of this project is a network case that could not be analysed in a statistical sense. The description of this case in the next chapter, coupled with a well-documented research process, provides a clear picture for readers to evaluate. Therefore, this study has some degree of transferability, particularly in relation to the applicability of SNA to other SCM contexts.

3.7. Chapter summary

The purpose of this chapter is to select an appropriate methodology to achieve research objectives. Influenced by the researcher’s beliefs on the nature of social reality and knowledge obtainment, a constructivist and interpretivist perspective is pursued as the philosophical stance to explore the applicability of SNA in evaluating and comparing SCA of SCs. A quantitative methodology is undertaken after considering the nature of SNA approach and priority of the research. The methods of data collection and data analysis are carefully considered to meet criteria of reliability, validity, and human ethics. The application of SNA to evaluating SCA is explored and illustrated within a context. The next chapter is important as it portrays the setting to understand the empirical data and to draw the meaning of varying SNA metrics, tools, and techniques in relation to agility aspects.

Chapter 4: Research context

Chapter 4 introduces the research context with two main parts: an overview of a case study and industry context. The first part draws on primary data from structured interviews to outline business demography and to describe a research network whose subsets can be extracted afterwards. The second part uses secondary data from publised literature to present key features of the main industries in the research network before highlighting their relevant similarities and differences for subsequent comparison purposes. This chapter functions as the setting for the in-depth contextualised analysis and interpretation of the SNA application to evaluate relative agility across SCs in Chapter 5.

4.1. Overview of a case study

4.1.1. Business demography

The database contains both primary and secondary supply chain information gathered from 50 business representatives in the targeted rural area over a ten month period, from May 2018 to February 2019. Based on the main products and services, the interviewed organisations were classified into three main industries: agriculture, tourism and hospitality, and general services, as illustrated in Figure 4.

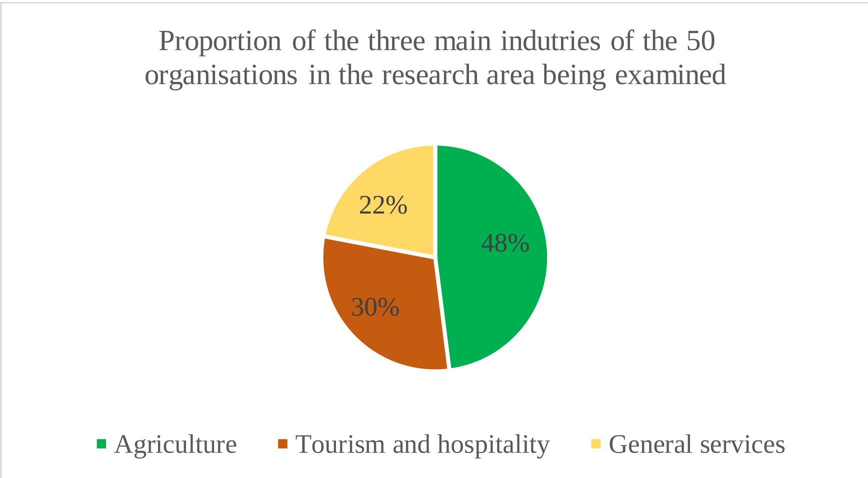

Figure 4 – Proportion of the three main industries of the 50 organisations in the research area being examined

The biggest sector is agriculture, which ranges from farms to agriculture-related businesses. The sector of tourism and hospitality consists of accommodation, catering, food services, art and recreational services. General services include finance, construction, and transportation, to name but a few. While these services can cater for any industry's needs, in this case, they are mainly for agriculture, and tourism and hospitality. Likewise, the suppliers and customers, despite differences in their business nature, mainly served and operated in these two sectors. Therefore, the two prominent supply chains that underpin this rural network case are agriculture, and tourism and hospitality.

In terms of business size, Figure 5 shows that two thirds of these interviewed organisations are small in size with fewer than 20 employees.[9] They are usually family farms, farming services, and self-employed service providers in the rural area being studied by this project. Their customers are largely local, coming from the targeted region. The three companies marked as "global" have not only nationwide operations but also international trading partners. They serve a wide range of customers, mainly in agriculture supply chains.

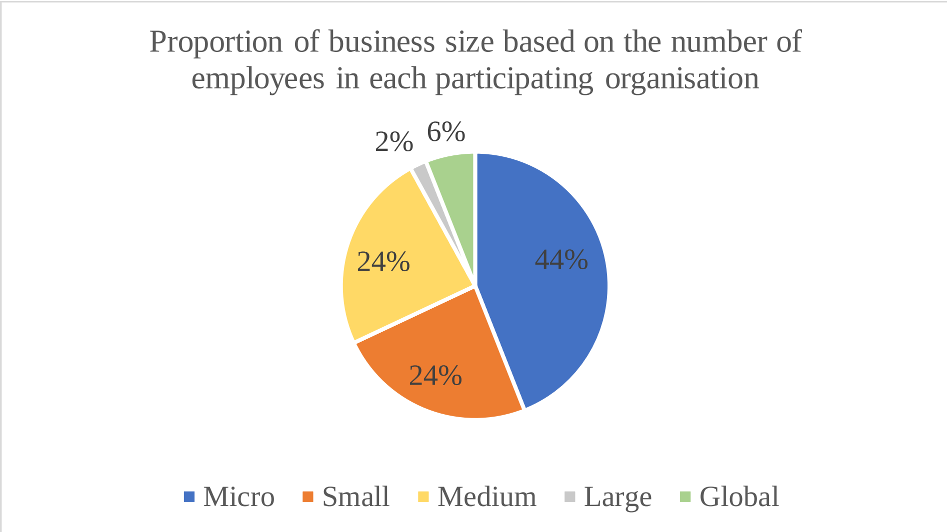

Figure 5 – Proportion of business size based on the number of employees in each participating organisation

Across the 50 organisations examined, there is an enormous gap in terms of turnover[10], with the smallest being less than NZD 14,000/ year, and the biggest being more than NZD 2.6 billion/ year. There is only a small number of enterprises that could earn more than NZD 100 million/ year whereas nearly 60% of the businesses managed to have a revenue of between NZD 300,000 and NZD 3 million annually. The most common range of annual revenue of these focal businesses was NZD 200,000 – 1,000,000.

9 Refer to Appendix 7 for details of how employment numbers were categorised in this thesis.
10 The annual revenue was calculated from main outputs that contributed at least 80% to the incoming flow of money to the businesses.

4.1.2. The research network

The research network constitutes 50 ego-networks wherein 'egos' refer to interviewees and 'alters' mean their main suppliers and customers. Initially, the 50 egos referred to around 650 organisations and individuals as their alters. However, in the interests of clarity, the study subsequently excluded generic or unspecified names, such as local tourists, regional farmers, and groups of gardeners. Some alters were subsequently merged when it became apparent that the same company was being referred to, even if it initially appeared to be separate entities when interviewees used different abbreviations or mentioned alternative locations. Therefore, the number of alters decreased to 406. A network was finally constructed from these ego-networks including a total of 456 entities[11] and 724 directed economic exchange relationships among these organisations. "Directed" means that each transaction has a direction from a sender to a receiver in terms of materials, products, and services flows.

The ego-networks of a small community in the area being researched can arguably reflect the general pattern of SC relationships of a larger network. It was observed during data processing that there was considerable overlapping across some alters of egos, and that some egos were also the alters of some others. This kind of interconnectedness, coupled with the richness of data, makes it appropriate to consider the aggregation of these ego-networks as a whole network. Therefore, the research network can be analysed by SNA tools and techniques of a whole-network approach, for example, metrics of network characteristics, and subgroup analysis.

Based on graph theory, Figure 6 visualises the research netwok that is split into dense areas and loosely connected zones due to uneven distribution of overall connections. The green, brown, and yellow nodes represent the interviewed businesses of agriculture, tourism and hospitality, and general services industries respectively. The remaining nodes represent the suppliers and customers mentioned by the interviewees. A line or an edge between any two nodes means there is a transactional relation between these organisations or actors[12]. An arc indicates the direction of materials, products, and services, from the point of origin to the destination.

[11] In the interests of consistency, this thesis uses the terms 'entities' and 'actors' interchangeably to refer businesses, their suppliers and/or customers, regardless of whether they are an organisation or an individual person.

[12] In a typical network diagram, nodes or points represent actors, and lines or edges between nodes represent ties, relationships, relations, and connections between these actors. In this study, these terms are used interchangeably.

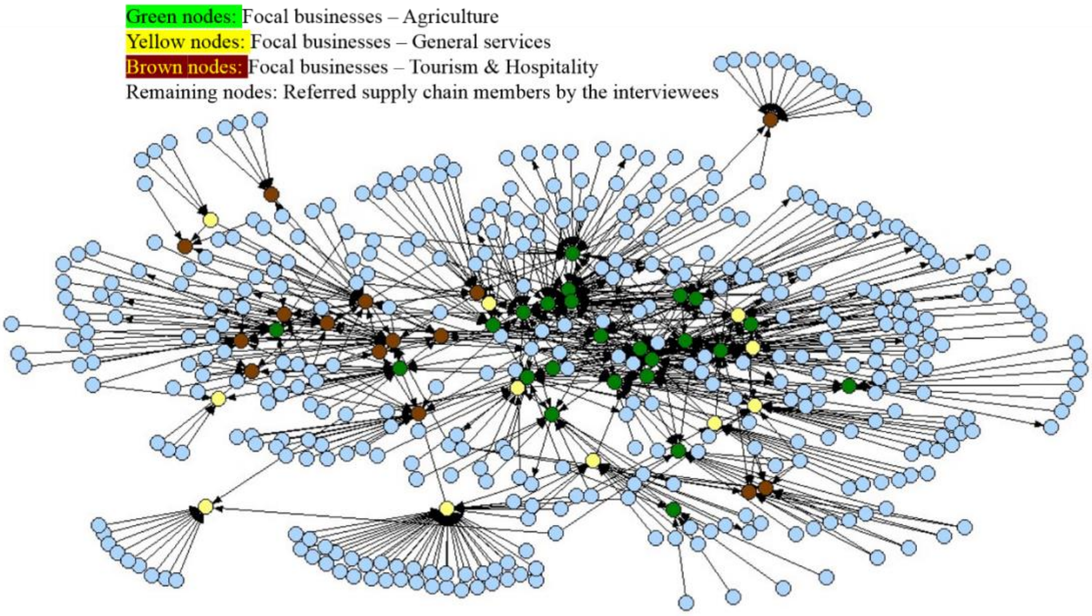

Figure 6 – The research network in the area being studied

Figure 6 indicates that the research network is completely connected. Each pair of actors can be linked together by either direct or indirect connections. Located in the network centre are mostly agriculture organisations that seem to have more business relations than the others. This network is not dominated by a single actor. Rather, the relationships of some central actors somewhat determine the core-periphery configuration.

When there is no ambiguity, the research network is understood as the transaction-based or inter-organisational network from which some subset networks can be extracted. Specifically, these subsets are of personal relationships embedded in business transactions, agriculture, and tourism and hospitality supply chains. The extraction as well as overall characteristics of these subsets are explained in the following section.

4.1.3. The subset networks

a. The personal network

The subset of personal relationships (PRs) is visualised in Figure 7 with the same colour codes for nodes as the transaction-based network. A tie in this subset network means the presence of personal relationships among staff of the entities which are exchanging economic benefits together. Since direction is irrelevant to personal relationships, the lines do not have arrow heads. From the same set of actors (50 interviewees and their 406 referrals), this subset contains 553 ties, fewer than that of the transaction-based network.

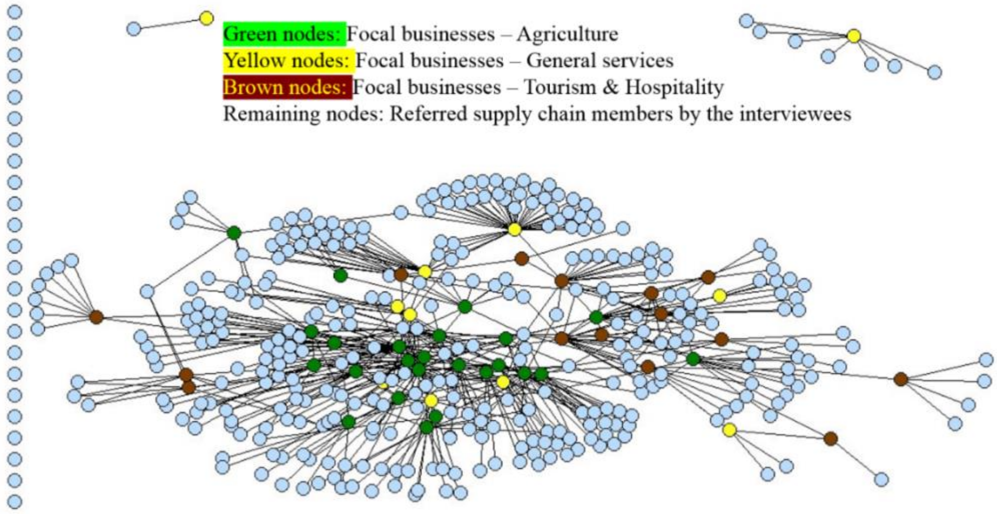

Figure 7 - The subset network of personal relationships embedded in transactional relations

The subset is not connected. Instead, it is fragmented into four main areas without any bridges in between. There are also many trivial components created by isolates who do not have any personal relationships with the interviewees' staff. Notably, all the focal businesses[13] of agriculture, tourism and hospitality, are embedded in the largest and densest area. This may imply the interconnectedness of business relations and of inter-personal relationships among these entities. Meanwhile, two general services providers lie in two small components which are separate from the remaining areas.

b. Agriculture and Tourism and Hospitality networks

Underlying the transaction-based network are two supply chains: agriculture and tourism and hospitality. These two subsets can be extracted by the same principle that considers all possible upstream and all possible downstream supply chain members. The extraction process starts from the existing ego-networks which has direct connections with tier-1 suppliers and customers of that focal business. Suppliers and customers of these tier-1 partners are then incorporated as tier-2 supply chain members of the focal businesses. The inclusion continues until it reaches tier-3, which is the boundary in this research.

There are 24 and 15 focal businesses of agriculture and tourism and hospitality sectors respectively. The number of ego-networks in agriculture is therefore bigger than that in tourism and hospitality. In order to generate a fair comparison between these two supply chains, another agriculture network was extracted from the total research network by the same principle but for

[13] Focal businesses in this research mean interviewed businesses/organisations

only 15 focal agricultural organisations. In this instance, the resized agriculture network and the full tourism and hospitality networks have the same number of egos – starting points of the tie inclusion process. As the researched area is dominated by farming activities, these agribusinesses were chosen to reflect typical farming operations. In cases where some entities had similar or identical products and services, random filtering was applied. Details of this selection process are in Appendix 8.

Table 7 summarises the results of the extraction process. Despite a smaller number of egos as starting points for extraction, the resized agriculture subset is almost of the same size as the full agriculture version. This implies that, in the area being researched, the richness in supply chain relationships of agribusinesses tend to remain unchanged, regardless of changes in the number of entities. The resized subset, as a stratified sample of the full agriculture network, also addresses potential questions about non-response bias in this research, and is an appropriate comparison for the full tourism and hospitality network in terms of relative agility from an SNA approach.

Table 7 - Summary of subset network extraction results

Comparable metrics	**Full agriculture network**	**Resized agriculture network**	**Full tourism and hospitality**
Number of starting egos	24	15	15
Number of entities	322	308	247
Number of interviewed businesses involved in the subset	39	39	43
Number of directed ties (materials & product flows)	546	532	440
Number of undirected ties (information flows)	1086	1040	854

From Table 7, the full network of tourism and hospitality is smaller than the agriculture subsets. This may be partly due to the nature of the industry and of the approach to data processing. Customers in tourism and hospitality are most often at the end of the supply chain, such as tourists and local consumers. Hence, there are seldom further tiers of customers to be included. Furthermore, as explained in Section 4.1.2., generic terms like “the locals”, “international tourists”, and “national consumers”, were removed during data processing.

4.2. Industry context - General characteristics

4.2.1. Agriculture supply chains

Agriculture supply chains (ASCs) are defined as systems wherein operational activities are sequential and require integration to deliver agricultural products to consumers (Parwez, 2014; Tsolakis, Keramydas, Toka, Aidonis, & Iakovou, 2014). There are two main classes of actors in a typical ASC: public authorities and private stakeholders (Tsolakis et al., 2014). They collaborate both vertically and horizontally. The former is a key governance factor that enforces and impacts legislation, regulations, and directives for food safety, public health, and environmental issues (Van Der Vorst, 2006). The latter can be classified into two main categories: the systems components and governing organisations (Vroegindewey & Hodbod, 2018). The first category includes organisations directly related to production and processing, for example, providers of input materials and services, farms, and processing firms. The second category is more involved in distribution such as logistics firms, wholesalers, retailers, and consumers.

An ASC is often characterised by seasonality, perishability, and long production lead time (Behzadi, O'Sullivan, Olsen, & Zhang, 2018). The unique nature of products distinguishes ASCs from manufacturing and service SCs (Routroy & Behera, 2017). Most agricultural goods have a short life cycle, requiring special means of transportation, storage, quality, and material recycling. High product differentiation together with regulatory compliance necessitates traceability, visibility, and transparency (Van Der Vorst, 2006).

4.2.2. Tourism supply chains

Tourism supply chains (TSCs) refer to a network of organisations ranging from suppliers of materials and inputs to distributors of outputs to deliver tourism products at a specific tourism destination (Zhang, Song, & Huang, 2009). TSCs entail a variety of operations including but not limited to accommodation, dining places, tourist adventure activities and attractions, and arts and crafts and souvenir shops (Ateljevic, 2009). Like ASCs, a typical TSC involves both public and private sectors of highly heterogeneous units (Ateljevic, 2009; Mandal & Saravanan, 2019).

Unlike other SCs, customers in a TSC need to travel to the destination to consume the products (Zhang et al., 2009). It is difficult to appraise the quality of a product before actually purchasing it. In the context of tourism, how products are presented and interpreted are key determinants of sales' growth. Because of their very nature, future demand for tourism products remain perpetually uncertain, which is one of the significant characteristics of TSCs (Mandal &

Saravanan, 2019). As such, agility and resilience are necessary capabilities in TSCs accordingly. While agility helps to fulfil the dynamic requirements of consumers, resilience ascertains SC continuity and minimises vulnerability impacts. (Mandal, Korasiga, & Das, 2017; Mandal & Saravanan, 2019). Indeed, these two capabilities are arguably two aspects of sustainability – a wider topic of increasing interest in tourism research (Zhang et al., 2009).

4.2.3. Commonalities and differences between agriculture and tourism supply chains

This thesis does not aim to provide a comprehensive comparison between agriculture supply chains (ASCs) and tourism supply chains (TSCs). Rather, it draws out some relevant similarities and differences from the literature in regard to how that context may affect the network agility determined within these SCs. Overall, ASCs and TSCs share several common characteristics. Both are complex and dynamically evolving over time according to internal and external changes (Routroy & Behera, 2017; Zhang et al., 2009). In most cases, agricultural and tourism products are hardly storable (Van Der Vorst, 2006; Zhang et al., 2009). Intensive coordination and information are critical to the survival and growth of these SCs (Handayati & Simatupang, 2015; Ţigu & Călăreţu, 2013). ASCs provide inputs to TSCs whereas TSCs can promote the identity of a place and motivate innovation within agricultural operations such as farming. The interconnectedness between these two SCs leads to the concept of agri-tourism (Liu, Yen, Tsai, & Lo, 2017).

The most noticeable difference between ASCs and TSCs lies in the nature of their respective products, as shown in Table 8. Agricultural products are diverse yet based on two basic categories: crops and livestock (Behzadi, O'Sullivan, Olsen, & Zhang, 2018a; Van Der Vorst, 2006). Although the quality might vary depending on inputs, agricultural products are often identical if they are given the same natural and institutional environmental conditions. For example, rice can be harvested in any location of similar conditions in tropical countries. Globalisation and technological advancements can contribute to the availability of agricultural products year-round (Sporleder & Boland, 2011). However, seasonality is still a typical feature, particularly for harvest-related products. In contrast, the complexity of tourism products stems from profoundly different components and a heavy reliance on environmental resources. These service-oriented products vary upon destination and source market (Mandal & Saravanan, 2019). Even at the same destination, the products are tailored in numerous ways to combine tourism-related elements (Vasant & Kalaivanthan, 2017). Balancing demand and supply by adjusting production capacity in TSCs is challenging due to high fixed costs (Zhang et al., 2009). In ASCs, perishability means deterioration over time, whereas the mostly intangible nature of tourism products in TSCs make them unfeasible to store (Zhang et al., 2009).

Table 8 - Main differences of agriculture and tourism supply chains at high level

	Agriculture supply chains	**Tourism supply chains**
Product complexity	Diverse yet usually not compound Often identical given same conditions Seasonal Deteriorating over time	Heterogeneous and compound Varying upon destination and source market High fixed cost Unable to store
Composition complexity	Different entities whose objectives and offerings are usually complementary	Profoundly different units of highly diverse objectives and offerings
Coordination	Vertically and horizontally Virtual, process, and network integration	More vertically than horizontally More about virtual and process integration
Demand	Usually forecasted	Forecasted yet more uncertainty

Both SCs are composed of numerous entities. However, competition seems to be more intensive in TSCs (Zhang et al., 2009). Therefore, it is more likely for the ASCs to collaborate vertically and horizontally. TSCs, on the other hand, tend to leverage virtual and process integration via information technology for market sensitivity and timely responses to customers' demands (Mandal & Saravanan, 2019). Demand forecasting for TSCs seems to be more challenging than for ASCs, partly due to the more unpredictable of consumers' behaviours and tastes (Mandal et al., 2017; Mandal & Saravanan, 2019; Ţigu & Călăreţu, 2013). Consequently, TSCs are seen as push systems in which inventory is of great importance (Zhang et al., 2009). In contrast, ASCs can be either push or pull systems, where buffer stock can play different roles, depending on product categories (Sporleder & Boland, 2011).

4.3. Chapter summary

This chapter portrays the setting not only to augment readers' understanding on the empirical data but also to pave the way for sensible interpretation and discussion of SNA application in the subsequent chapters. The research network is an aggregation of the ego-networks constructed from transactional relations, and hence, is so-called transaction-based network. The “egos” refer to interviewed organisations which primarily operate in agriculture and tourism. They are also mainly of small and medium sizes in terms of employee numbers and annual revenue. Underlying the research network are three subsets. The personal network derives from interpersonal relationships embedded in business ties whereas two SCs – agriculture, and tourism and hospitality– are extracted by the principle that includes as further SC tiers as possible.

The literature suggests a close connection between agriculture SC and tourism SC. The former usually provides the inputs for the latter that may contribute back to the innovation and development of the former. The interconnectedness between these SCs is evident by the network diagrams. While two SCs share some commonalities, they differ from each other in terms of the nature of products, the composition complexity, features of coordination, and demand management. Such background information is the basis for the next chapter to centre on relative agility comparison between these two SCs, through which the applicability of SNA to evaluate SCA becomes discernible.

Chapter 5: Network data analysis

Chapter 5 presents the results of an in-depth network data analysis in the form of a relative agility comparison between two prominent supply chains underlying the research network. As stated in section 4.1.3, to assure the fairness, the comparison is made between the resized agriculture network (Network A) and the full tourism and hospitality network (Network T&H). It encompasses all three levels, following the proposed data analysis approach. The similarities and differences in key network characteristics are linked to the variance in agility levels of these two networks. The feasibility and practicality of an SNA approach to assess agility aspects can be implied from this comparison.

5.1. Network-level analysis

From a macro view, Network A and Network T&H were compared in terms of network characteristics associated with key agility aspects. These two networks were first visualised to identify noticeable similarities and differences. A full analysis was then performed to reconfirm such initial observations and unveil features that might be missed by looking at only network diagrams. The examination of network configuration could reveal the dominance of some entities which may determine the levels of flexibility and responsiveness. Meanwhile, measuring network cohesion could shed light on the attributes of visibility and network capacity to receive and push information flows.

Network A and Network T&H are illustrated by Figure 8 and Figure 9 orderly. Both networks are completely connected, implying that a piece of information initiating from a certain entity can eventually reach the remaining organisations directly or indirectly. Furthermore, the network configuration of these two networks are similar in that a few central actors are connected to each other whereas the peripheral actors have ties with only the central entities. However, this kind of network shape appears to be less apparent in Network A (Figure 8) than that in Network T&H (Figure 9). The agriculture network also seems to be slightly sparser than tourism and hospitality network. Accordingly, Network A may less depend on the central actors, which may lead to greater flexibility than Network T&H.

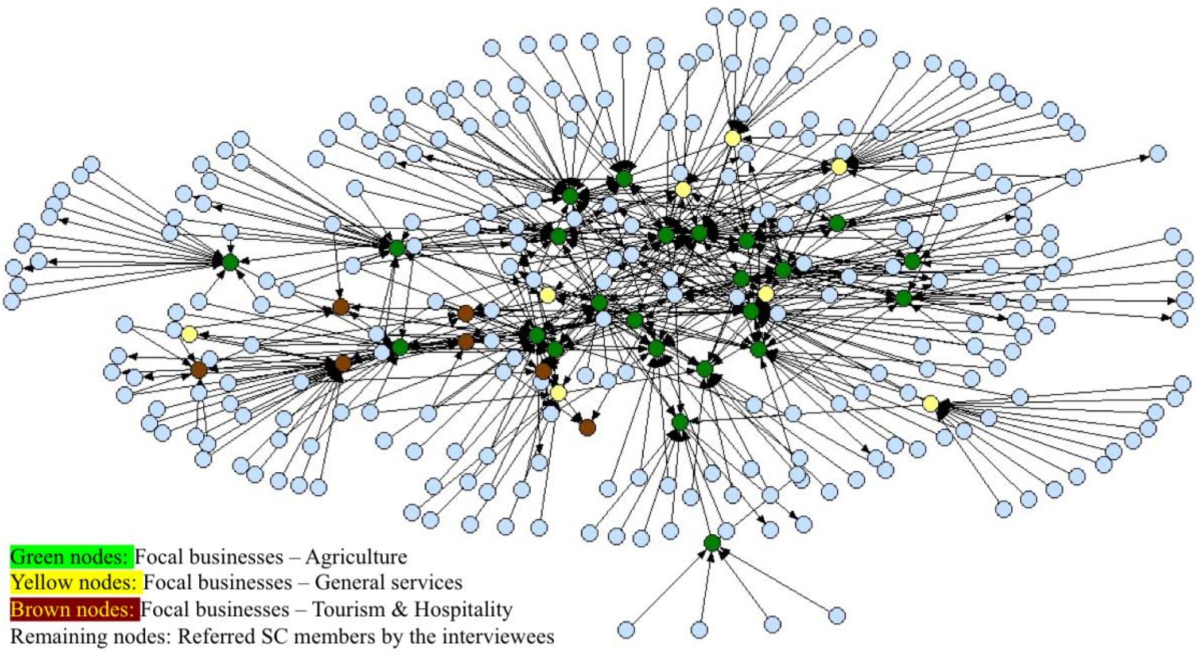

Figure 8 - The resized agriculture network (Network A) extracted from the transaction-based network

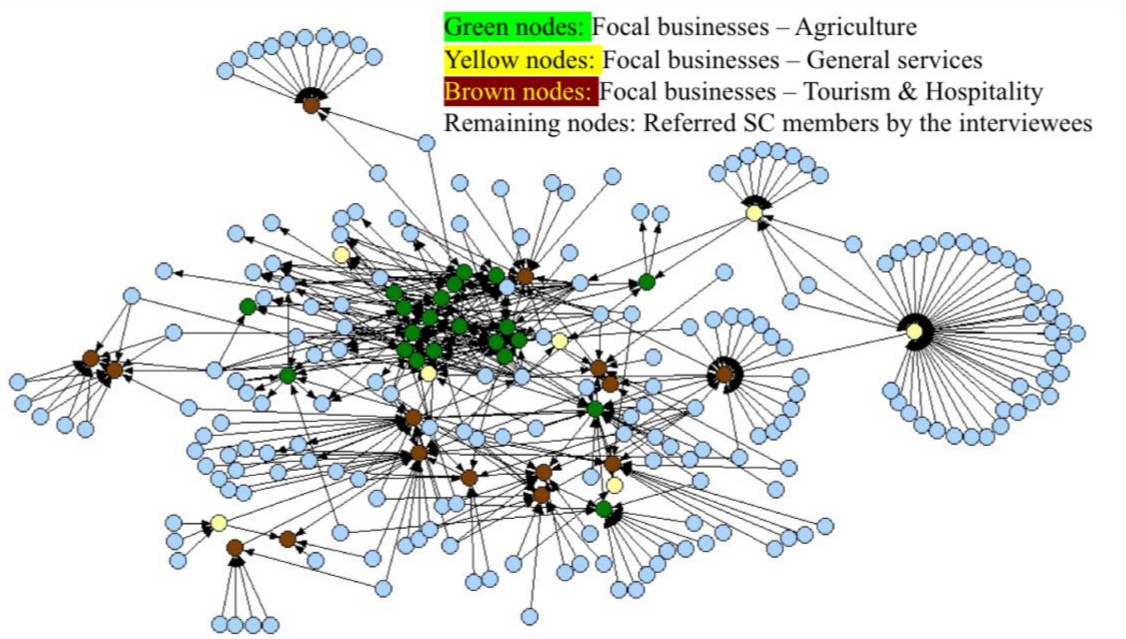

Figure 9 - The full tourism and hospitality network (Network T&H) extracted from the transaction-based network

The analysis results outlined in Table 9 support the above observation of two network diagrams. The degree centralisation indices skewed towards 0, reflecting the core-periphery model of both networks. With a slightly greater centralisation index, Network T&H may have less flexibility but better integration due to the greater control of central actors. Furthermore, thanks to full connectedness, the entities in both networks can equally benefit from accessibility to information.

Assuming that messages always take the possible shortest paths[14], on average, they travel through Network A faster than through Network T&H. There are fewer intermediaries lying between the two furthest actors in Network A, which might indicate faster responses and better exchanged information.

Table 9 – Relative comparison of agriculture and tourism & hospitality networks at the network level

Comparable metrics	**Network A (Agriculture)**	**Network T&H (Tourism and Hospitality)**
Degree centralisation	0.11	0.16
Measures of direct connections – Network as a whole		
▪ Average degree	3.38	3.46
▪ Density	1.10%	1.41%
Measures of direct connections – Focal businesses		
▪ Average degree of focal businesses	15.03	11.33
▪ Average density of 50 ego-networks	2.88%	5.13%
Connectedness	1	1
Fragmentation	0	0
Average distance	3.66	4.06
Diameter	6	8

Table 9 shows that the measures of direct connections were initially calculated based on a whole-network approach. On average, a given organisation in Network A has slightly fewer business relations than that in Network T&H, leading to a negligible lower density. Since the relational data from the referred entities were unavailable, these results may not be sufficiently fair to compare the two networks. Consequently, these measures were re-calculated with a focus on the interviewed organisations. On average, an interviewee in Network A has more business relationships than those in Network T&H, which implies a greater capacity to receive and transmit information. However, the average density of Network A is lower than that of Network T&H. This is coupled with a shorter graph-theoretical distance and a lower degree centralisation

[14] Known as 'geodesics' in social network terminology.

to imply that Network A may have greater autonomy to implement decisions faster than Network T&H.

In summary, the agriculture network is generally more agile than the tourism and hospitality network. The former may benefit from greater flexibility, faster responses, and better exchanged information flows in terms of both quality and scope. The latter seems to be more controlled by central actors which may somehow hinder flexibility, but facilitates network synchronisation and similar tasks requiring integration. The applicability of network-level metrics to evaluate overall network agility and agility dimensions could be therefore implied from this relative comparison. The analysis is then extended to the group level to examine cohesiveness and connectivity. These two kinds of analysis are associated with SC collaboration – an SCA enabler – and robustness – a necessary condition for SCA -- respectively.

5.2. Group-level analysis

At the group level, the structures of both networks were uncovered by locating cohesive and robust subgroups by tools and techniques explained in Appendix 6. While cohesiveness can somewhat indicate the level of cooperation between subgroups, the connectivity is associated with robustness. SC collaboration and robustness could be captured by these analyses accordingly. The relative comparison for these two networks was mainly based on the number of cohesive subgroups found, the linkage between these subgroups, and the profile of group members. The commonalities and differences between these networks became more discernible from this level.

5.2.1. Triad census analysis

The results of a triad census analysis for both networks are summarised in Table 10. Based on the absolute figures, Network A has more open triads and closed triads – triads of type 3 and 4 orderly – than Network T&H. Therefore, Network A may be more agile than Network T&H because of a better ability to capture novel information and opportunities (Burt, 2015) and because of better transparency and cooperation respectively (Rivera, Sheffi, & Gligor, 2016; Sonia et al., 2015). However, the proportion of open triads to all possible triads in Network T&H is larger. Moreover, the closed cycles account for bigger areas in Network T&H than in Network A. This means that Network T&H tends to benefit more from greater ratios of open triads and closed triads. Consequently, in terms of relative measurement, Network T&H appears to be more agile than Network A.

Table 10 - Summary of a triad census analysis of the two networks

Type of triad configuration	**Description**	**No. of triads in**		
		Transaction-based network (Full)	**Network A (Agriculture)**	**Network T&H (Tourism and Hospitality)**
1	No dyads have ties	15384800	4669482	2380601
2	Only one mutual dyad	306297	146671	96448
3	Two mutual dyads	8172	6160	4031
4	Three mutual dyads	51	43	35

5.2.2. Cohesive subgroups of complete mutuality

Table 11 summarises the results of examining subgroups of complete mutuality, or so-called cliques, in both networks. Interestingly, each of these cliques is the very closed triad identified in the above section with a fixed size of three organisations and three mutual dyads. Network A consists of more knots of nodes that are all interrelated compared to Network T&H. On average, a clique in Network A overlaps with more other subgroups than a clique in Network T&H. With the exception of B017, the list of top actors joining several cliques of Network A is fully included in that of Network T&H.

Table 11 - Summary of clique analysis results in the agriculture and tourism and hospitality networks

Comparable aspects	**Network A (Agriculture)**	**Network T&H (Tourism and Hospitality)**
Number of cliques	43	35
Linkages among cliques		
Number of clusters formed by cliques	1	3
Average number of other cliques sharing (a) common member(s) with a given clique	14.97	8.06
Actors joining at least four cliques	B003, B041, B042, A242, B043, B010, B009, B035, B046, A403, A005	B003, A242, B041, B035, A005, A403, B009, B017, B042, B046

The cliques of Network A and Network T&H are visualised in Figures 10 wherein the blue squares represent the cliques and the circles are clique members. The connections between cliques in Network A are denser than those in Network T&H. All the cliques in Network A form only one cluster dominated by agri-businesses. In contrast, the cliques in Network T&H are in three separate clusters due to varying amounts of interaction and the different nature of the industry. In both networks, B003, B041, and A242 are the most important brokers. B003 and B041 connect the central cliques together. Meanwhile, A242 is critical as it draws relatively peripheral cliques closer to the central subgroups.

Blue squares: Cliques
Green circles: Focal businesses – Agriculture
Yellow circles: Focal businesses – General services
Brown circles: Focal businesses – Tourism & hospitality
Other circles: SC partners of focal businesses

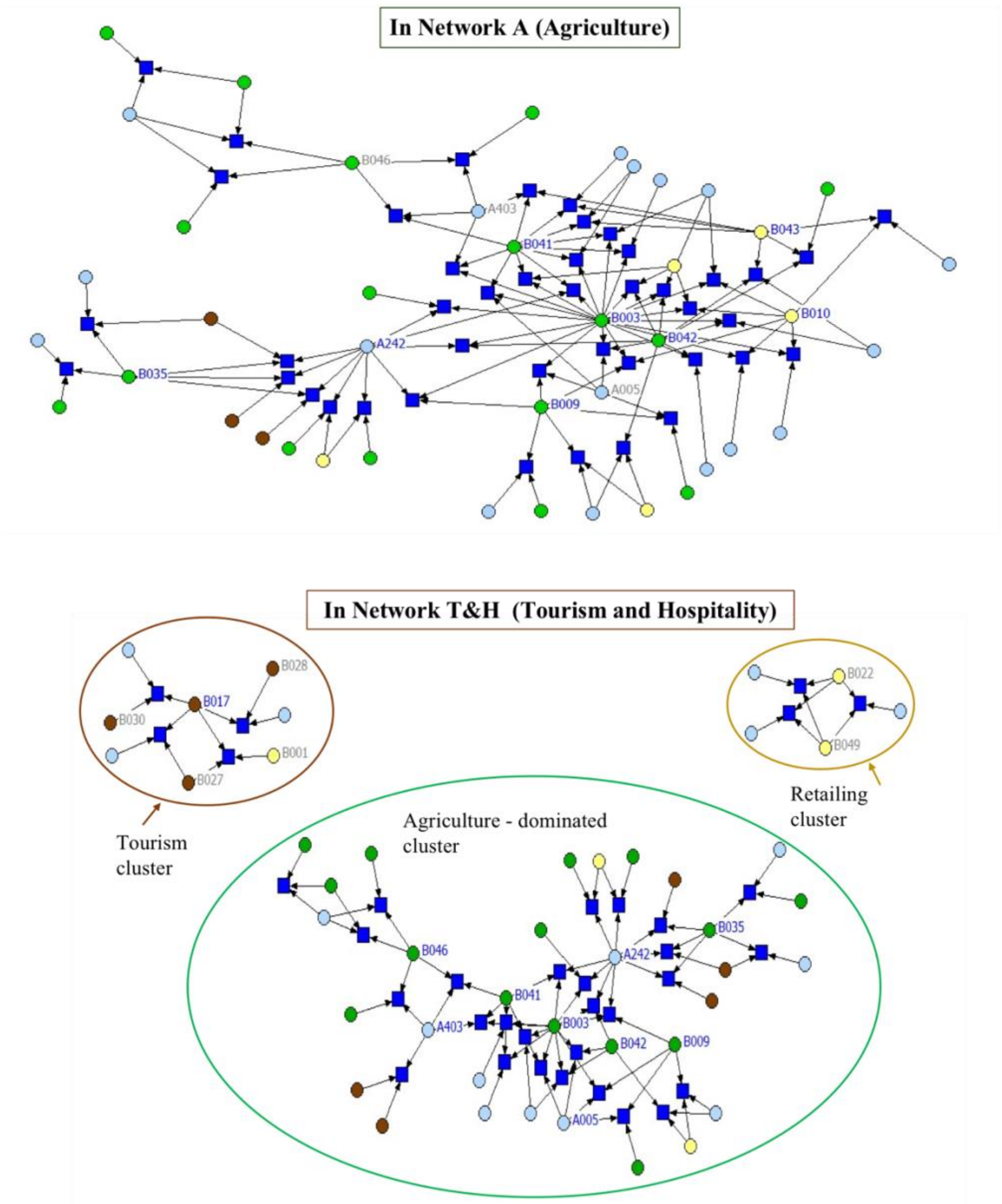

Figure 10 - The cliques and their members in Network A (above) and in Network T&H (below)

The above observations imply that Network A may benefit from better coordination and information transmission since almost its cliques are homegeneous in business nature or working practices. The heterogeneity of businesses may hinder Network T&H from the horizontal coordination. However, this feature might bring the entities of this network a greater likelihood to capture diverse information sources. Accordingly, Network A might have greater SC collaboration yet somewhat less market sensitivity than Netwokr T&H.

Regarding clique co-membership analysis, this research only considered pairs of organisations that co-exist in at least two different cliques. In other words, only pairs of actors that were in the same clique together at least twice were counted. Table 12 shows that Network A has more pairs of co-members than Network T&H. Even the same pair, for example, {B003 – B042}, occurs more frequently in Network A than in Network T&H. The results indicate that Network A has more strong ties than Network T&H. Such connections between the entities in the former also tend to be tighter than their counterparts in the latter network. Accordingly, the level of SC collaboration may be higher in Network A than that in Network T&H, leading to a variance in agility of these networks.

Table 12 - List of pairs of co-members and frequency of clique co-membership in the two networks

Pairs of co-members	**Frequency of being in the same clique together**	
	Network A (Agriculture)	**Network T&H (Tourism and Hospitality)**
B003 – B041	7	6
B003 – B042	6	3
B003 – B010	5	0
B003 – A242	4	4
B003 – A005	3	3
B003 – A379	3	2
B003 – B009	3	2
B003 – B020	3	0
B041 – B043	3	0
B041 – A403	3	2
B041 – A029	2	0
A242 – B035	3	3
A242 – B024	2	2
B042 – A329	2	0
B042 – B043	2	0
A005 – B009	2	2
A156 – B046	2	2
A156 – B015	2	2
A403 – B046	2	2
B035 – B032	2	2

The two networks differ yet still share two commonalities in the above analysis. In both networks, the link between B003 and B041 seems to be the strongest as they most often join the same cliques together. This aligns well with conventional evaluations. Specifically, this relationship is rated as rather critical for normal operations, highly reliable, with frequent communication and strong personal relationships. B003 is also a partner that shows great transparency and a high willingness to support other entities. Moreover, 9 pairs of co-members were observed to remain unchanged in both networks. They all involve at least one general service provider, particularly, insurance (A005), electricity (A156), telecommunication (A403), and governance agency (A242). This implies the importance of basic services as inputs for both networks.

In summary, the empirical results indicate the higher level of SC collaboration that enables greater SC agility in the agriculture network compared to the tourism and hospitality network. Furthermore, they suggest the potential of the clique analyses to assess this enabler, somewhat gauge market sensitivity, and corroborate the role of fundamental service providers. Such analyses can also provide an alternative approach of evaluating strength of ties that might determine the connectivity and partly contribute to the overall organisational agility.

5.2.3. Cohesive subgroups based on adjacency between members

Examining the k-plexes

Table 13 presents that in almost scenarios, there is a substantial gap between the number of *k*-plexes in Network A and that in Network T&H. The former network has much more cohesive subgroups than the latter network. In the case of {k=2 and n=5}, the subgroups identified in the research network is completely embedded in Network A whereas half of them are found to be missing in Network T&H. This might imply a possibility of gauging the overall agility of the fully constructed research network based on Network A - an extracted network.

Table 13 - Summary of k-plex analysis scenarios in the total network and two subset networks

Maximum number of missing ties (*k*)	**Minimum group size (n)**	**Number of robust groups found (*k*-plexes) in**		
		The research network (Full)	**Network A (Agriculture)**	**Network T&H (Tourism and Hospitality)**
2	3	7521	5603	3693
2	4	1406	1316	957
2	5	11	11	5
2	6-10	0	0	0
3	4	The software could not run		
3	5	4734	4539	2563
3	6	871	866	710
3	7-12	0	0	0

The examination of *k*-plexes could identify the role of organisations in maintaining information flows and signify how the organisational importance may change upon the size of subgroups. For example, in the scenario of {*k*=2 and *n*=5}, B003, B041, and B042 are the most critical in both networks. If any of them shut down, all of the subgroups will be severely impacted in terms of information accessibility. However, the contribution of these organisations to the robustness of their respective groups changes in the case of {*k*=3 and *n*=6}, despite the same minimum number of ties required (*n*-*k*=3)[15]. The most central role is now taken by B046, B042, A242, and A193. Except B042, the dominance of B003 and B041 reduces.

Due to technical limitations of the UCINET 6 software, only the scenario of {*k*=2 and *n*=5} could be illustrated in Figure 11. In both networks, none of the common members of these subgroups are in the tourism and hospitality sector. They are either agribusinesses or those who mainly serve in the agriculture sector. The bridging role of B003, B041, and B042 was evident from this following figure.

[15] The full lists of the *k*-plexes' shared members in these scenarios are in Appendix 9.

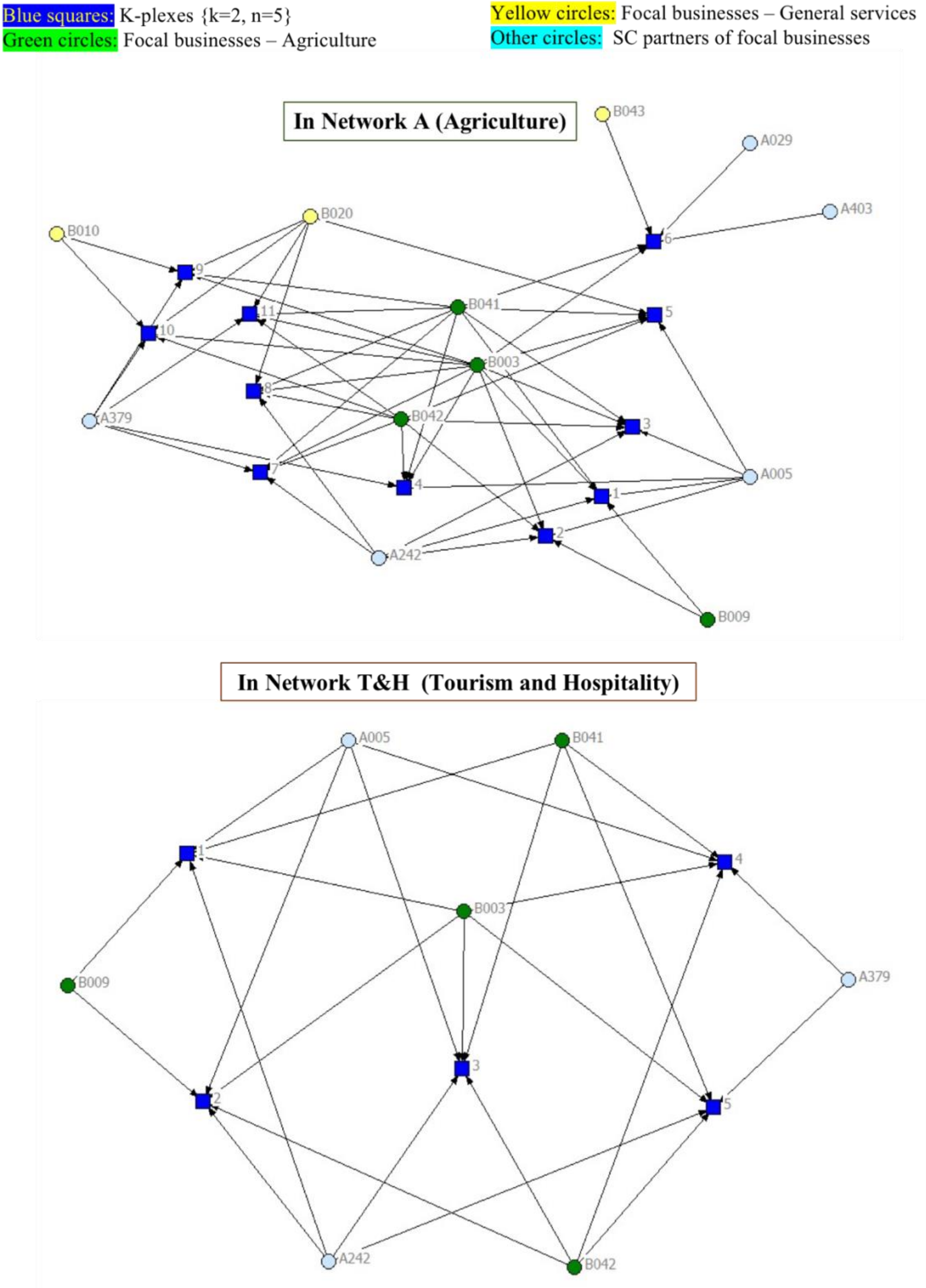

Figure 11 - 2-plexes containing a minimum of 5 members in Network A (above) and Network T&H (below)

In summary, the techniques of searching for *k*-plexes resulted in an indication of cohesiveness and relative connectivity, both of which then can be associated with SC collaboration and robustness aspects. The organisational importance could also be highlighted.

Examining the k-cores

Network A does not differ much from Network T&H in the analysis of *k*-cores as summarised in Table 14. Rather, they share some similarities. Both have five regions of varying connection levels, like the total network. 5-core is the innermost and is contained in the less inner layers. The 1-core region equates to a whole network as every actor is connected to at least one other. In their 5-core regions, the agribusinesses dominate and there is no presence of tourism or hospitality service providers. The 4-core region in each network is the seedbeds for most businesses and hospitality services, and contains almost the same number of entities. The agility distributed in these 4-core regions of both networks are at parity as they have similar accessibility to information and a similar speed of responses.

Table 14 - Summary of k-cores analysis in the total network and two subset networks

Region	Number of actors in		
	The research network (full)	**Network A (Agriculture)**	**Network T&H (Tourism and Hospitality)**
1-core	456	308	247
2-core	144	107	104
3-core	85	74	64
4-core	56	45	44
5-core	27	27	19

5.2.4. Cohesive subgroups based on comparison of relative strength

Examining the Lambda sets

The lambda value of 11 was chosen as the minimum edge-connectivity level to define and assess robust groups in this thesis. This is not only the average of the lambda value range of the full research network but it is also present in both subsets. At this level, the lambda sets in both agriculture and tourism and hospitality networks have more than 10 members, which allows for deeper analyses or appropriate comparisons among the subsets. Details of the subgroups which satisfied the criterion are in Appendix 10.

The investigation into the robust sets of the two subset networks is summarised in the following table. The lambda sets of Network A share three main similarities with those of Network T&H. The most noticeable point is the robustness of B042 and A242. In all instances, B042 stands out with the most ways to communicate with the other entities, by direct connection, via node intermediaries, and by edge-independent paths. A242 lies in almost robust sets of high connectivity levels. Furthermore, the dominance of agribusinesses in all robust subgroups implies their key role in maintaining the connectivity, not only for their SCs, but also for the tourism and hospitality network in the area being research. Another commonality is the co-presence of two competitors, A193 and A343, in the robust groups wherein the members have at least 11 alternative communication paths.

Table 15 - Comparison between Network A and Network T&H based on the Lambda set approach

	Network A (Agriculture)	**Network T&H (Tourism and Hospitality)**
Similarities	• The robustness of B042 and A242 • The dominance of agribusinesses • The co-presence of A193 & A343	
Differences		
▪ No. of the Lambda sets[16]	9	6
▪ No. of alternative communication routes of the most robust set	22	17
▪ At the same edge-connectivity level, per a Lamda set	More entities	Less entities
▪ Ratio of direct & strong connections between entities in each comparable robust group[17]	Slightly lower	Slightly higher

From the above table, the connectivity in Network A distincts from that in Network T&H in several ways. First, Network A has more robust groups of edge-connectivity than Network T&H. Second, the most robust group in Network A has more alternative routes to pass messages on than its counterpart in Network T&H. Third, even at the same edge-connectivity level, a robust group in Network A contains many more actors than a robust group in Network T&H. Consequently, of the two networks, the agriculture network seems to have better accessibility and reachability of communication flows, which may increase the overall network visibility. It may also benefit from greater level of robustness.

[16] These satisfied the criterion of lambda value at 11.
[17] Comparable criteria: The top three Lambda sets or the robust subgroups at the same line-connectivity level

At a comparable criterion, a Lambda set of Network T&H tends to have a higher ratio of direct and strong relations to all possible connections between any two members than its counterpart in Network A. For example, the most robust subgroup of Network A contains B041 and B042, which have no direct ties and are only connected by either intermediaries or edge-independent paths. They are both farms and share some key suppliers. Meanwhile, within the top Lambda set of Network T&H, A242 is directly connected to B042. This may indicate the relative strength of the relation between A242 and B042, regardless of their different operating sectors and lack of common suppliers and customers. Some similar instances could be found when a certain robust group of Network A has the same line-connectivity level as its counterpart of Network T&H. The above cases might imply a stronger level of cooperation in such a robust group of the tourism network, which may facilitate alignment and the quality and scope of exchanged flows.

In summary, the Lambda set approach could identify the robust groups wherein the members can have many choices[18] for communication and for accessing information. Network visibility in those sets of both networks may be minimally affected should a certain line of communication be broken. While Network T&H may be less agile than Network A, the above analysis suggests that the difference is not significant.

5.2.5. Section summary

At the group-level, the agriculture network is generally more agile than the tourism and hospitality network. A big gap between them is apparent when the tight and close connections of subgroups, cliques, and *k*-plexes are respectively examined. However, if robustness based on connectivity is the primary consideration, then the agility level in the agriculture network is not much higher than the agility level in the tourism and hospitality network. In fact, the two levels may be quite equal in the middle, inner, and innermost network regions where the connections concentrate through the *k*-cores approach. From such group-level analyses, some roles of organisations become discernible, which is then further examined in the next section.

5.3. Node-level analysis

The node-level analysis examined how the entities are embedded and linked with the others in the research network. By selected centrality measures and fragility analysis, it sought for critical organisations whose positions and connections presumably impact the network agility. The key

[18] At least 11 different paths of communicating – based on the criterion of this thesis.

actors of the two networks were compared in terms of their scores on centrality measures, main organisational attributes, and the manner in which they either enhance or threaten network agility.

5.3.1. Individual contribution

There were three main sets of important actors found by this analysis. Set I involves with cascading practices and behaviours through the popularity and potential influence of actors. Set II contributes to information diffusion and resource mobilisation through a graph-theoretical proximity. Set III facilitates the exchange flows by their coordinating roles. All these contributions impact key agility dimensions including, but not limited to, visibility and responsiveness, either directly or indirectly.

Set I: Individuals of popularity and potential influence

The popularity and potential influence of individuals were evaluated by eigenvector and beta centrality measures respectively as explained in Appendix 6. Interestingly, the most popular actors were also the most influential in the transaction-based network and in the two subsets. Network A and Network T&H share the same set of highly popular and potentially influential actors. The only difference is the order in which they were ranked in each network, as seen in Table 16. Highly popular and influential actors may contribute to the network agility of both supply chains by improving transparency and cascading practices. However, the extent to which they impact the agility of each network varies, depending on the network size, the business nature of the entities, and inherent channels of influence.

Table 16 - Top 10 actors of high popularity and potential influence in Network A and Network T&H

Ranking	Network A (Agriculture)			Network T&H (Tourism and Hospitality)		
	Actor	***Popularity - Eigenvector centrality***	***Potential influence - Beta centrality***	**Actor**	***Popularity - Eigenvector centrality***	***Potential influence - Beta centrality***
1	B042	39.60	86.15	A242	43.01	75.13
2	B041	35.01	76.14	B046	36.83	64.16
3	A242	34.60	75.36	B042	36.43	63.45
4	B015	33.78	73.63	B041	32.04	55.77
5	B046	33.14	72.17	B009	31.16	54.24
6	B009	30.28	65.92	A193	30.58	53.27
7	B037	28.46	62.05	A343	29.68	51.62
8	B003	27.72	60.29	B015	27.32	47.56
9	A193	27.11	58.96	B037	25.35	44.11
10	A343	26.43	57.47	B003	25.22	43.89

As described in Section 4.1.3, Network A is bigger than Network T&H in terms of total numbers of entities and undirected ties. Consequently, the highly popular actors in Network A tend to have a greater capacity to receive and transmit information than those in Network T&H. All these actors are agribusinesses, except A242, as shown in the above table. The practices and/or behaviours they share may be most relevant to organisations of a similar nature, such as farms or farming service firms rather than the organisations in other sectors. However, B046, B009, and B037 can be role models in cascading the supply chain collaboration practices which are currently rare in Network T&H. As a local agency, A242 has the greatest potential to influence the services providers, especially on the adoption of agility practices. The highly popular actors tend to influence others through shorter channels in Network A and through slightly longer channels in Network T&H. This finding is based on the largest permissible value of beta found in each network: around 0.094 and 0.109 respectively.

Set II: Individuals of graph-theoretical proximity

Table 17 lists the actors of greatest degree of closeness in terms of proximity in each network. In Network A, the top actors are both the most popular and the most potentially influential. In the Network T&H, however, with the exception of A242, B046, B042, and A193, the remaining actors only have average levels of popularity and potential influence. Except for A242, the list of top actors in Network A is dominated by the agribusinesses whereas that of Network T&H includes a variety of business types, such as farms, food service providers, and electricity generators. The top actors in Network T&H may have more opportunities to receive within a short time diverse sources of information that are highly accurate compared to their counterparts in Network A. Similarly, these actors in Network T&H may better facilitate the capture and exchange of new ideas or new opportunities than those in Network A.

Table 17 - Top 10 actors of high closeness in Network A and Network T&H

Ranking	Network A (Agriculture)		Network T&H (Tourism and Hospitality)	
	Actor	***Distance to other actors - Closeness centrality***	**Actor**	***Distance to other actors - Closeness centrality***
1	A242	0.440	A242	0.399
2	B046	0.427	B035	0.378
3	A193	0.389	B032	0.375
4	B042	0.383	B019	0.338
5	A343	0.383	B046	0.332
6	B015	0.382	B038	0.331
7	B041	0.381	B042	0.328
8	B003	0.375	A156	0.328
9	B037	0.373	A193	0.328
10	B009	0.373	A404	0.322

Set III: Individuals of coordinating roles

The examination of actors' brokerage in Network A and Network T&H provided some interesting results. As Table 18 shows, the dominance of agribusinesses declines, particularly in Network T&H, compared to the previous lists. The actors with the highest levels of betweenness in Network A may contribute to network agility differently compared to their counterparts in Network T&H. In Network A, these actors may control the flows and/or they may facilitate collaboration through their membership in several cohesive subgroups. In Network T&H, such actors seem to occupy positions that are favourable for information diffusion, which is evident via the simulations in the Section 5.4.

Table 18 - Top 10 actors that most frequently lie between the others in the two networks

Ranking	Network A (Agriculture)		Network T&H (Tourism and Hospitality)	
	Actor	***Frequency of being between - Betweenness centrality***	**Actor**	***Frequency of being between - Betweenness centrality***
1	A242	8884	B032	9367
2	B046	7358	B022	8950
3	B015	6735	B035	7184
4	B035	6049	A242	7063
5	B037	5299	B017	5179
6	B019	5137	B019	4011
7	B042	4881	B049	3576
8	B009	4574	A193	2902
9	A193	4529	B021	2642
10	B016	4399	B036	2174

5.3.2. Fragile spots

The analysis of key 'weak' points – cut points – in the two networks is summarised in Table 19. All cut points in these networks are focal businesses. The interviewed businesses in Network A are more likely to be fragile than those in Network T&H. 72% of them were identified as the cut points in Network A, compared to 58% in Network T&H. However, none of them have a special role in Network A whereas a critical point of communication was identified in Network T&H.

Table 19 – Summary of cut-point analysis in the agriculture and tourism and hospitality networks

Comparable aspects	**Network A (Agriculture)**	**Network T&H (Tourism and Hospitality)**
Number of cut-points	28	25
% of focal businesses being cut points	72%	58%
Special cut-point	0	1
Number of blocks created by cut points	202	146
Trivial blocks (parts)	201	143
Central blocks (parts)	1	3

The following figure of two graphs visualises the fragility analysis of the two networks. The first graph shows that the cut points of Network A link the trivial blocks of peripheral actors to the central part in a graph-theoretically equal way. Conversely, from the second graph, B017 seems to be the main bottleneck for communication in Network T&H. In addition to trivial blocks, it connects three central parts together. Without B017, information cannot flow across these parts. Service-based areas would be disconnected from the agriculture-dominated block.

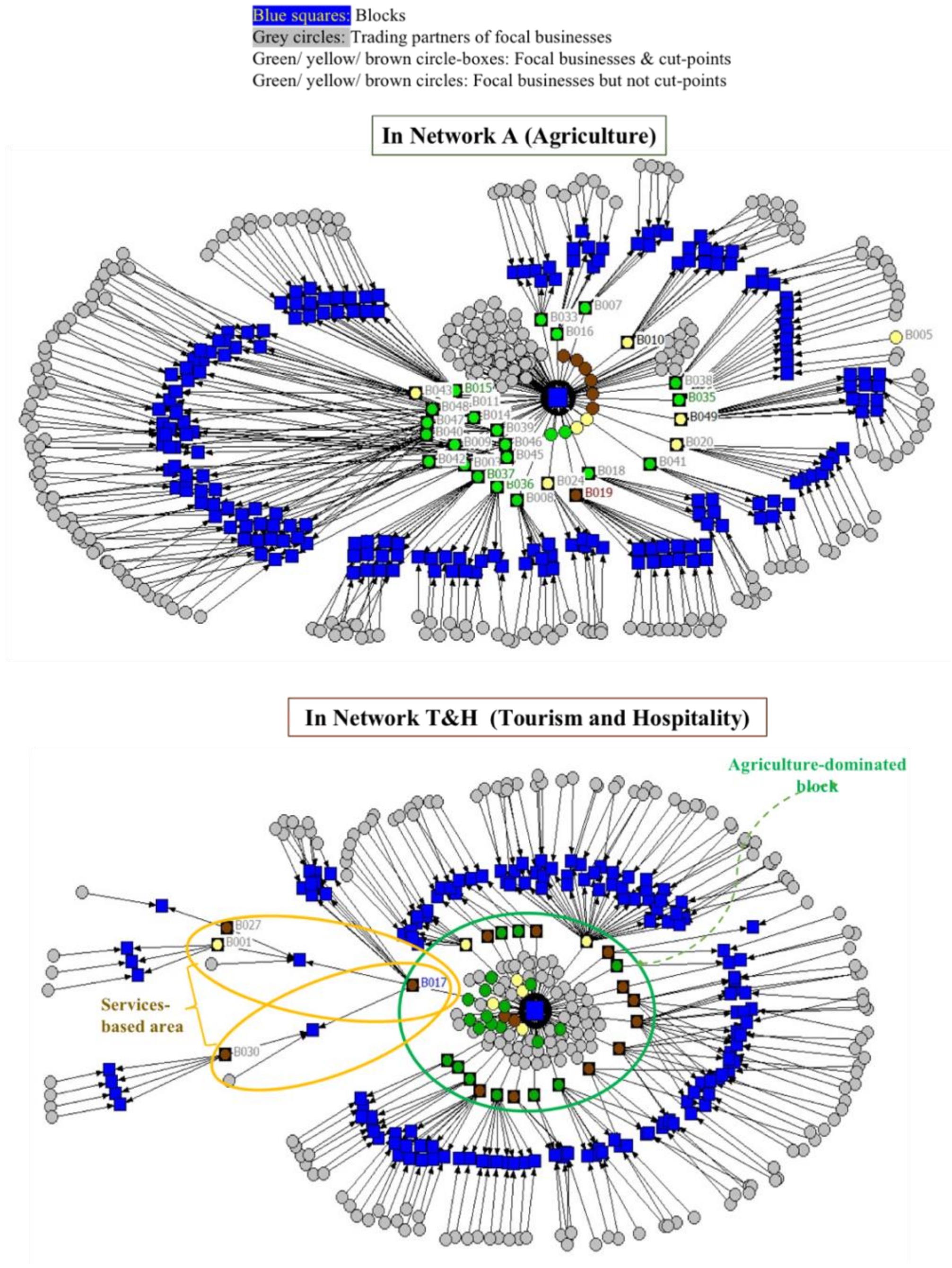

Figure 12 - Cut points and blocks in Network A (above) and Network T&H (below)

Measuring the fragmentation centrality of individuals in each network yielded some complementary results. As Table 20 shows, the most fragile spots in Network A each have a relatively equal impact on the network fragmentation. In contrast, in Network T&H, there is noticeable discrepancy between the extent in which the top two actors, B022 and B017, have an impact on network fragmentation and the impact made by the rest of the actors. If all of the eight most fragile entities in each network were to shut down simultaneously, the effects on Network A would be far less severe than the impact on Network T&H.

Table 20- Top 8 actors of highest fragmentation centrality in the agriculture

Ranking	**Network A (Agriculture)**		**Network T&H (Tourism and Hospitality)**	
	Actor	**Network fragmentation change if actor is removed**	**Actor**	**Network fragmentation change if actor is removed**
1	B015	10.8%	B022	27.9%
2	B019	7.7%	B017	16.3%
3	B037	7.7%	B032	9.5%
4	B036	7.0%	B021	8.8%
5	B049	7.0%	B035	7.2%
6	B010	6.4%	B019	6.4%
7	B035	6.4%	B036	6.4%
8	B040	5.8%	B049	6.4%
	All 8	*54%*	*All 8*	*75%*

The results of the fragility analysis provide a complementary view on the importance of certain organisations to their supply chains and to the area being researched. 78% of business owners thought that their closure would not affect the entire supply chain in which they operated as they were small in size and only had a local reach. 60% of the interviewees tended to underrate their importance to the larger economy and their supply chains. To some extent, it is true that the absence of these entities would not shut down the entire supply chain. However, from a network perspective, the closure of some of these entities would significantly affect the network in which they are embedded, regardless of their business size, revenue, and sectors.

Among the actors with the highest fragmentation centrality, B022, B021, B015, and B036 acknowledged their potential effects on the local economy and supply chains. B022 serves both the local businesses and local residents. Its closure would disconnect the links between its suppliers and customers, disrupting the flows of materials and products. This entity is also central to the retailing cluster identified in the clique analysis of Network T&H (see Figure 10). B021 rated its role based on the number of suppliers with which it is involved. B015 saw itself as essential to the survival of a special supply chain, and hence, crucial to the local economy.

B036 was not identified as important in the previous centrality measures. However, its fragmentation centrality score aligns with its self-evaluation and with the actual business demographics. This entity is one of the few agribusinesses specialising in one type of agricultural output, not only in the researched area but also in the wider region. B036 is the only local business that is global sized in terms of its staff numbers, and its revenue far exceeds the average revenue of the remaining local organisations. It also seems to be better prepared for unexpected events than other local businesses, in undertaking more practice for such scenarios.

Neither B017 nor B032 considered themselves as important although both were among the four biggest employers of the area being researched. B017 was even sure that its absence would not matter to the local economy and its supply chains. This self-assessment is in contrast with the findings of this study. Without this entity, the flows of exchanged information would be disconnected between the two main supply chains in the region, greatly affecting network agility.

5.3.3. Section summary

By the node-level analysis, the role of agribusinesses identified in the previous sections was reinforced. In both networks, their importance stems from their popularity and potential influence for information accessibility and process integration. They also appear to be vital to information diffusion and supply chain coordination in the agriculture network. Their dominance is less pronounced in the tourism and hospitality network, where a wider range of businesses appear to dominate, based on graph-theoretical distance-based measures, including closeness centrality and betweenness centrality. The tourism and hospitality network tends to depend rather heavily on its brokers, making it more vulnerable than the agriculture network. Whether the organisations scoring the highest by centrality measures are those worth most attention was then closely investigated by the simulation analysis as follows.

5.4. Simulation analysis

5.4.1. Information diffusion

This section examined the scenarios wherein a few organisations, so-called a seeding group, receive a piece of information and then transmit that message to the others in each of the two subset networks. The simulations were carried out by both approaches: selecting top actors of highest scores on centrality measures (naïve) and combinational optimisation (using KeyPlayer software). Each seeding group accounts for less than 5% of the network and was stimulated to diffuse information within two steps. The results were summarised in the following table.

Table 21 - Summary of simulating information diffusion in the two networks in two steps

Simulation approach	**Network A (Agriculture)**	**Network T&H (Tourism and Hospitality)**
Naïve approach	***% of network reached***	***% of network reached***
Based on eigenvector/ beta centraility		
Seeding group 1: Top 10 actors	95%	66%
Seeding group 2: Top 5 actors	86%	59%
Based on closeness centraility		
Seeding group 3: Top 10 actors	95%	88%
Seeding group 4: Top 5 actors	92%	82%
Based on betweenness centraility		
Seeding group 5: Top 10 actors	100%	96%
Seeding group 6: Top 5 actors	90%	87%
Combinatorial Optimisation using KeyPlayer software		
Seeding group 7: 5 optimal actors	99%	94%
Seeding group 8: 6 optimal actors	100%	98%
Seeding group 9: 8 optimal actors	100%	100%

As can be seen from Table 21, by the naïve approach, the entities with the highest scores on eigenvector and beta centrality measures are not the best actors for diffusing information. This might be explained by the nature of the above-mentioned two measures that can count duplicated connections (Borgatti, 2006). It means that the most popular actors can share many common trading partners. Some organisations may receive the message several times whereas many of the others may not yet be reached. This particularly holds true in Network T&H which has three separate clusters whereas the most popular and potentially influential organisations are all agribusinesses[19]. Likewise, the ability to receive high quality information flows early does not equate to the ability to transmit such flows to other entities. In both networks, the key contributors to information diffusion are those with the highest betweenness centrality measure.

19 As identified in the clique analysis (Section 5.2.2) and the individual contribution (Section 5.2.3) respectively.

Table 21 indicates that by the combinational optimisation approach of Borgatti (2006), it is possible to select a smaller seeding group to achieve a wider coverage of the network. It is the appropriateness, not the quantity, that matters. Furthermore, this approach could provide numerous optimal seeding groups which can equally disseminate information given the same size. The larger the optimal group size, the more options yielded[20], which opens alternative avenues of diffusing information, especially in emergency and/ or resource constraints. The advantages of this approach over the conventional approach could be therefore demonstrated.

The importance of those with coordinating roles was reinforced by the approach of Borgatti (2006). For instance, B035, B017, B049, and A193 are present in all optimal sets run by KeyPlayer software in Network T&H. From both approaches, given a parallel process, the speed of information diffusion in Network A is faster than that in Network T&H[21]. Consequently, Network A may benefit from better responsiveness than Network T&H. This aligns with the network-level analysis wherein that strength could be attributed to the shorter graph-theoretical average distance and diameter of Network A compared to Network T&H.

5.4.2. Supply chain disruption

This section explored how the network would be fragmented if some SC members unexpectedly shut down or halt their operations. The simulation results, as shown in Table 22, reconfirm that Network A is less vulnerable than Network T&H. Removing a set of key players of the same size leaves less severe aftermath on Network A than on Network T&H, which aligns with the fragility analysis in Section 5.3.2.

Table 22 - Summary of simulating SC disruptions in the two networks

Simulation approach	Network A (Agriculture)	Network T&H (Tourism and Hospitality)
Naïve approach	***% of network fragmented***	***% of network fragmented***
Based on fragmentation centraility		
Group 1: 8 most fragile spots	54%	75%
Group 2: 14 most fragile spots	74%	84%
Combinatorial Optimisation using KeyPlayer software		
Group 3: 8 actors of highest risk	56%	77%
Group 4: 14 actors of highest risk	79%	89%

20 Refer to Appendix 11 for more details.
21 Refer to Appendix 12 for an illustration of how information would be disseminated in each of the two networks.

The simulations run by KeyPlayer found out that apart from focal businesses, there are several critical entities who are directly or indirectly present in almost SCs of the interviewed organisations[22]. Specifically, A242, A193, and A343 are instrumental to remain the connectedness of Network A whereas A242 may remarkably disrupt the connectivity and coordination of Network T&H[23]. Furthermore, a majority of the actors of highest risk in Network A also score highest on betweenness centrality measure while such actors in Network T&H appear to be more diverse. Therefore, the results complement the node-level analysis.

In summary, the simulation analysis provided an alternative view on the importance of individual entities. It also sheds light on the mechanisms of information dissemination and SC disruption in the two subsets. Throughout the simulations, Network A is apparently more agile than Network T&H in terms of speed of disseminating information and less vulnerability. It is therefore implied that such agility aspects as responsiveness and robustness can be relatively evaluated. The advantages of the combinational optimisation was also demonstrated in this section. This approach can be worth applying, particularly for resource constraint scenarios.

5.5. Chapter summary

Chapter 5 illustrates the application of particular SNA tools and techniques in a real network case and simulateneously demonstrates the association between agility aspects with appropriate network indicators. The empirical results are summarised in the following table. The agriculture network generally outperforms the tourism and hospitality network at most agility attributes across a wide range of network indicators drawn on various analysis types. However, the tourism network has its own strengths from which the agriculture network could learn to bolster its agility. This might be attributed to network characteristics, which will be further explored and discussed in Chapter 6. Furthermore, the gap in agility levels between the two SCs was observed to vary across the SNA tools, techniques, and levels of analysis employed. This suggests the potential of SNA as an investigative approach into a concept as multidimensional as SCA since SNA supports comparisons from various viewpoints. The applicability of SNA to evaluate SCA will then be compared with the extant approaches of the previous works in the next chapter.

22 Refer to Appendix 13 for a full list of key players on SC disruptions
23 Refer to Appendix 14 for an illustration of how each of the two networks would be disrupted.

Table 23 - Summary of relative agility comparison by different types of network analysis

Types of analyses	Network indicators	Comparison results of network characteristics		Interpretation	
		Network A	Network T&H	Associated agility capabilities with network indicators	More capable network
Network configuration	Degree centralisation		Greater	Flexibility (Degree of freedom)	Network A
	Core-periphery pattern		Clearer	Integration	Network T&H
Network cohesion	Connectedness	Equal		Accessibility to information	Both: equal
	Average degree of focal businesses	Greater		Capacity to receive and transmit information and resources	Network A
	Density		Greater	Flexibility (Degree of freedom)	Network A
	Path length	Shorter		Speed and quality of exchanged information and resource	Network A
				Speed of responses	Network A
Cohesiveness	Ratio of open triads		Higher	Market sensitivity	Network T&H
	Number of cohesive subgroups	Greater		SC collaboration	Network A
	Linkage between subgroups	Denser			
	Tie strength between entities	Relatively stronger			
Connectivity	Number of robust subgroups	Greater		Robustness	Network A
	Number of alternative paths per a robust subgroup	Greater		Flexibility (of relationships)	Network A
Individual contribution	Popularity - key actors	Same - agribusinesses dominate		Visibility Cascading agility practices	Both: probably equal yet in different ways
	Potential influence - key actors	Same - agribusinesses dominate			
	Potential influence - channels		Slightly longer		
	Graph-theoretical promixity - key actors	Agribusinesses dominate	Diverse businesses	Market sensitivity	Network T&H
				Ability to receive quality information at earliest time	Both: probably equal yet in different ways
	Coordinating roles - key actors	Agribusinesses dominate	Diverse businesses	Information coordination & exchange	
Fragile spots	Bottleneck for communication	None	Yes	Robustness	Network A
	Risks to network connectedness		Higher		
Simulation	% of network reached in *n* steps	Larger		Responsiveness	Network A
	% of network fragmentation		Larger	Robustness	

Chapter 6: Discussion

Chapter 6 sets out to discuss the main findings with the extant studies and to provide a critique of this thesis. It starts by a discussion on overall agility comparison, followed by an appraisal of the applicability of SNA to evaluate SCA in comparison with the extant approaches. Subsequently, the limitations of this study are acknowledged. The chapter ends with an outline of several future research directions.

6.1. Discussion on overall relative agility comparison

In general, the agriculture network outperforms the tourism and hospitality network at most agility attributes across a wide range of network indicators, as can be seen in the previous Table 23. In particular, the agriculture network has greater visibility, faster responses, greater flexibility, and better information exchange. It also benefits from greater SC collaboration and higher levels of robustness. This can be explained by the more favourable characteristics of the network properties in the agriculture network.

In terms of network topology, the agriculture network, with a lower network centralisation, has more freedom, and hence, greater flexibility, and better responsiveness to changes and disruptions. This finding may contrast with previous research in manufacturing contexts wherein a highly centralised network structure accommodates flexibility that in turn contributes to operational effectiveness (Hernández & Pedroza-Gutiérrez, 2019). However, the result aligns with the performance implications of controllability asserted by Kim et al. (2011) that the higher centralisation, the less effective and responsive the network becomes.

The agriculture network is more robust than the tourism and hospitality network although the latter has a clearer core-periphery pattern. This goes against the common theoretical proposition that resilient supply networks tend to follow a power-law distribution (Kim et al., 2015). A possible reason may lie in the latter network's higher level of dependency on just a few important intermediaries. To some extent, like food supply chains, the tourism and hospitality network reflects a restricted relationship structure that seems to be prevalent in rural settings (Hernández & Pedroza-Gutiérrez, 2019). Specifically, the current catering service providers do not purchase agri-based food and materials directly from local producers. Instead, they are supplied by middlemen who are in turn supplied by farmers and growers. The middlemen in this rural network case include food processors, wholesalers, and retailers who link the agriculture sector to this service sector. As Hernández and Pedroza-Gutiérrez (2019) argue, in such a SC, "homogeneous distribution of links may favor agility more than heterogeneous distributions" (p. 7). This means that a power-law degree distribution may not, in supply networks that heavily depend on the middlemen, necessarily apply to aspects of robustness and agility. The result of this thesis, therefore, supports the statement by Hernández and Pedroza-Gutiérrez (2019).

The shorter path length benefits the agriculture network in terms of faster responses and greater visibility. This then can confirm the proposition of Hearnshaw and Wilson (2013) about the relationship between SC efficiency and short path length, particularly in information flows. The result may also prove the validity of a method of using the average path length to measure the responsiveness of resilient SCs proposed by Sonia et al. (2015). Certainly, the longer path length observed in the tourism and hospitality network indicates a higher intermediation level. While the go-between actors facilitate information exchanges, they may risk network efficiency by being communication bottlenecks or being overloaded in their individual roles (Long, Cunningham, & Braithwaite, 2013). The lower level of responsiveness and robustness of the tourism network, therefore, serves as a piece of evidence to the few empirical studies that exist on the undesirable effects of intermediation.

The agriculture network is less complex than the tourism and hospitality network. Although the former is bigger in size, it has a lower density and a shorter graph-theoretical distance. According to Kim et al. (2011), since network complexity is related to network centralisation and density, the less dense and centralised, the more reduced the operational burden for the network. Consequently, the network may be more efficient and robust. It is certainly the case in this study, wherein the agriculture network displays higher agility and robustness levels. The result also supports Kim et al. (2015) who suggest that high levels of density or complexity do not always equate to high resilience.

In their theoretical study, Hearnshaw and Wilson (2013) suggest the presence of communities with overlapping boundaries as one of the key features of an efficient supply chain. The agriculture network mirrors this characteristic better than the tourism and hospitality network. The former has more cohesive subgroups. Furthermore, the overlapping boundaries are more evident in the agriculture network. An actor in this network is more likely to be a shared member between subgroups than an actor in the tourism and hospitality network. Likewise, a pair of actors in the agriculture network has a higher chance of joining the same subgroups together. With denser and relatively stronger connections among subgroups, the agriculture network has better horizontal coordination of information flows. This is evidenced in the two simulation approaches which revealed that there was better information diffusion in the agriculture network. Consequently, this study corroborates with the proposition of Hearnshaw and Wilson (2013).

The agriculture network possesses more robust subgroups of high edge connectivity levels than the tourism and hospitality network. This indicates that the former is not only more robust but also more flexible. Its greater flexibility comes from the availability of more edge-independent paths for messages to travel between any two organisations in these robust areas. In other words, the agriculture network has more options to reconfigure in terms of information flows. The co-existence of both higher robustness and greater flexibility may go against the conventional thinking that presumes a trade-off between resilience and efficiency, or between resilience and flexibility (Ali et al., 2017; Gligor et al., 2019; Lotfi & Saghiri, 2018). However, the result is in agreement with the proposition by Wieland and Marcus Wallenburg (2012) that both agility and robustness constitute effective supply chain risk management strategies.

The sets of key actors in the agriculture network differ upon types of contribution to network agility, but they are all dominated by agribusinesses that are relatively homogeneous in terms of business nature. Such homogeneity implies a higher possibility of shared working practices and common supplies, which in turn may translate into better fitness for each of these hub firms, as suggested by Choi et al. (2001). Supply chain resilience is assumed to be influenced by the fitness of hub firms (Hearnshaw & Wilson, 2013). This assumption is partly validated by the results of the individual contribution analysis. In this thesis, the fitness is considered as a combination of centrality and presence in robust groups. The current agility and relative resilience of the agriculture network is determined by the key actors who are highly popular, potentially influential, of high reach capacity, information facilitators, and relatively robust.

The results from the three levels of analysis confirm that, as with other supply chain concepts like flexibility (Stevenson & Spring, 2007) and resilience (Adobor & McMullen, 2018), agility has a multidimensional nature. Two networks may be at parity at a certain agility dimension but in different ways. While the agriculture network basically outperforms the tourism and hospitality network at most agility attributes, there are still some aspects where the tourism and hospitality network demonstrates a better capability. In other words, the tourism and hospitality network has relative strength that the agriculture network can learn from to further enhance its overall agility.

Market sensitivity is the most noticeable attribute in which the tourism and hospitality network performed better than the agriculture network. The organisations in the tourism and hospitality network are more diverse in terms of business demographics. In particular, the key actors for information dissemination, resource mobilisation, and exchanged flow coordination are diverse in their nature of business. Unlike their counterparts in the agriculture network, they are not dominated by a single sector. This implies that this subset network can benefit from diverse sources of information and ideas. This finding is supported by the literature of tourism supply chains (TSCs) which commonly assert profound diversity as a typical feature of a TSC (Zhang et al., 2009).

The higher proportion of open triads alone cannot confirm the higher chances of receiving the benefits of 'structural holes' advocated by Burt (2015). However, the heterogeneity of key actors of coordinating roles, coupled with the current triad configuration, imply that the tourism and hospitality network has more capacity to capture novel information and new opportunities than the agriculture network. Furthermore, the tourism and hospitality network is better able to detect changes, perhaps because its key coordinators are more likely to receive information or detect changes. To the best knowledge of the researcher, no studies have discussed or examined the ability to anticipate in service based SCs including TSCs. Therefore, this finding is arguably an example of the different characteristics and/or capabilities between service-based SCs and product-based SCs.

6.2. Discussion on the applicability of SNA to evaluate SCA

The applicability of SNA to evaluate SCA was apparent during a relative agility comparison between the two networks. This approach is demonstrated to be appropriate to assess not only an overall agility level but also agility dimensions, foundations, and enablers. The discussion is structured into three sub-sections as follows.

6.2.1. A final research framework of SNA application for SCA evaluation

The following research framework maps various appropriate SNA tools and techniques deployed in this thesis with chosen agility aspects. This is synthesised from the analysis results of Chapter 5 and built on the propositions of network properties and SCA dimensions in Chapter 2. This framework may serve as guidance for future empirical studies, particularly for those examining information flows.

Table 24 - Final proposed framework to evaluate SCA from SNA tools and techniques

Social network analysis approach			**Visibility**			**Responsiveness**			**Flexibility**	**Robustness - Foundation**	**SC collaboration - Enabler**
Level of analysis	Type of analysis	SNA metrics, tools, techniques	Accessibility	Transparency	Quality & scope of exchanged information	Speed	Synchronisation	Market sensitivity			
Network	Network configuration	Degree centralisation				x	x		x	x	
	Network cohesion	Average degree			x				x		
		Density		x		x		x	x		
		Connectedness	x		x					x	
		Average distance			x	x					
		Diameter			x	x					
Group	Cohesiveness	Triad census	x	x	x			x			x
		Cliques	x	x		x			x	x	x
		K-plexes	x	x		x			x	x	x
		K-cores	x	x						x	x
		Shared membership	x		x	x	x	x	x		x
		Linkages across subgroups	x	x	x		x		x	x	x
	Connectivity	Line -connectivity (Lambda sets)	x						x	x	x
Node	Individual contribution	Eigenvector centrality		x	x		x				x
		Beta centrality			x		x				x
		Closeness centrality		x	x	x		x			x
		Betweenness centrality	x		x			x			x
	Fragile spots	Block and cutpoints								x	
		Fragmentation centrality								x	
All	Simulation	Information diffusion	x			x	x				
		Disruption	x	x	x					x	

As Table 24 shows, at the network level, the metrics of network configuration and network cohesion can indicate the overall levels of accessibility, transparency, responsiveness, robustness, and degree of dependency – a counter measure for overall flexibility. At the group level, the agility distribution in network regions and areas can be examined by varying techniques that partly uncover hidden network structures. Specifically, a triad census analysis can be useful to gauge market sensitivity, transparency, and cooperation. Cliques, *k*-plexes, and *k*-cores reveal areas of dense connections where the agility level is likely to be higher than in the other locations. An estimation of visibility, responsiveness, and flexibility could be implied by such techniques of looking for cohesive subgroups. At the node level, the impact and importance of entities can be assessed by centrality measures. Based on direct and indirect connections, eigenvector and beta centrality measures can be indicators for the impact on transparency, network synchronisation, and scope of exchanged information. Based on proximity and positions on geodesic paths, closeness and betweeness centrality measures can be used to estimate speed of responses, reach capability, and the quality of exchanged information.

As an analytical method, SNA allows the estimation of network fragility and robustness that then can augment the agility evaluation. As the above framework summarises, the secondary analyses on shared membership and linkages across cohesive subgroups indicate tie strength and relative connectivity that may determine not only SC collaboration but also robustness. Likewise, the Lambda set technique can capture the line connectivity aspect of robustness by identifying the subgroups wherein any two members can exchange information, directly or indirectly, by varying line-independent routes. Meanwhile, the fragility analysis performed by the approach of blocks and cutpoints as well as the measure of fragmentation, to some extent, can shed light on the node connectivity of each network. This then also adds to the assessment of robustness.

SNA offers the simulation techniques that can provide a complementary view on network agility assessment. These techniques do not directly evaluate agility. Rather, they take into account the complexity and non-linearity of supply network to indicate potential outcomes if the current network elements or properties change. To some extent, they can also reveal responsiveness and robustness as implied from empirical results of the simulations run for information diffusion and SC disruption scenarios respectively in Chapter 5. This next sub-section elaborates on this framework in terms of which agility aspects are potentially more appropriate to be evaluated by SNA than by the extant approaches.

6.2.2. How and in what respects SNA can evaluate SCA dimensions in view of the conventional approaches

By integrating and challenging the findings with the current literature, it can shed light on how SNA is appropriate to tap into areas that are barely recognised by extant research techniques. While SNA is shown as a potentially powerful approach, there are some aspects of agility assessment that conventional approaches might address better than SNA. A reflection on the research findings in view of the current studies also leads to tailoring the definitions of some terms to fit with the research context.

a. Visibility

From the literature review, existing studies usually capture one aspect of SC visibility and give little consideration to complex network contexts. Of the three attributes of structural visibility, accessibility is the most studied. Conventional studies usually evaluate accessibility using rating scales. For instance, Lin et al. (2006) evaluate the extent to which information is accessible across the whole supply chain using a performance rating scale ranging from worst to excellent. In contrast, Sonia et al. (2015) assess network accessibility by analysing the total number of demand nodes (retailers) connected with supply nodes (suppliers). SC transparency is equally important to network visibility. The literature review reveals that this aspect is not explicitly evaluated in studies on agility or resilience. While quality and scope of exchanged information are recognised as one key component of structural visibility (Basole & Bellamy, 2014), this aspect seems to be little examined or measured, even in the wider literature of SCM. A common feature of existing studies is that agility attributes are evaluated as the capability of either the organisation or their own SCs.

The research framework (Table 24) shows that all three attributes of network visibility could be evaluated by SNA by considering the interconnectedness of relationships among supply chains. Each of the visibility attributes was evaluated via a set of SNA tools and techniques. Accessibility was evident from the connectedness metric, line connectivity, cohesiveness, and the role of information coordinators in the network. SC transparency was examined via SNA tools, such as triad configuration analysis and the popularity of organisations. The quality and scope of exchanged flows were estimated by average distance, diameter, co-membership status, and individual graph-based favourable positions. The results therefore demonstrate that SNA is appropriate to evaluate network visibility attributes and has the potential to complement existing measurement methods for this agility dimension.

b. Responsiveness

Fast responses are usually regarded as velocity and hence velocity metrics are often adopted to evaluate the speed at which SCs can respond to changes (Christopher, 2000; Christopher & Peck, 2004). Building on the work of van Hoek et al. (2001), Charles et al. (2010) evaluate velocity as an organisational capability rather than a SC capability via workforce, authority level, emergency team, and contingency plans. SNA is potentially appropriate to supplement the authority level metric in their work. Specifically, swiftness in decision making could be estimated by network centralisation, the number of intermediaries between the two furthest organisations, and simulations, as Table 24 shows. Furthermore, this thesis extends the work of Sonia et al. (2015) by determining fast responses via organisations' graph-theoretical proximity and potential influence via shorter channels, in addition to the use of average path length as a common indicator.

The analysis could not provide a holistic picture of network synchronisation. This attribute could be evaluated partly via information diffusion simulations and orchestrating the roles of key actors. SNA showed a degree of potential as a means to investigate the synchronisation that is commonly perceived by organisations in relation to their own SCs rather than in relation to the wider network they are embedded within. Furthermore, this thesis offers an initial example of further explorations of network synchronisation, for which there is currently a paucity of research (Hearnshaw & Wilson, 2013).

The results of this thesis showed that the integration level was barely evident through the SNA approach. This may be because the analysis was based on a selection of tools and techniques that focused on interrelationships whereas integration is related to the sharing of processes and practices. Furthermore, this attribute incorporates such 'qualitative' elements as team-based goals and top management commitment, which might be better investigated through traditional measurement methods. Additionally, examinations of how well the network aligns its working practices may require more in-depth non-network data which the data of this study did not cover. Therefore, this attribute is excluded from Table 24.

Market sensitivity is widely agreed as the ability to understand and meet customer changes (Christopher, 2000). Lin et al. (2006) and Faisal et al. (2007) share a similar view in defining and measuring market sensitivity in agile SCs. According to them, this attribute equates to understanding customer requirements. They propose a range of customer-based indicators to evaluate this attribute, for example, product customisation, fast introduction of new products, and opportunities to enhance customer satisfaction and give them good value. Likewise, Patel, Samuel, and Sharma (2017) adapt earlier studies and add market trend analysis. In contrast, this thesis approaches market sensitivity as encompassing the ability to anticipate, to detect changes, and to capture novel information and opportunities. The results, particularly evident in the tourism and hospitality network, demonstrate the applicability of SNA to evaluate this attribute under the new definition. For example, this attribute can be evaluated by triad census analysis, shared membership analysis, and centrality measures, as Table 24 shows. Therefore, the findings add a new view of, and evaluation approach for, market sensitivity, contributing to the literature of SCA assessment.

c. Flexibility

The line connectivity analysis managed to demonstrate to some degree the aspect of reconfiguration through the Lambda set examination of SNA. The selected tools and techniques could barely evaluate relationship flexibility, specifically the ability of organisations to switch their types of collaborative relationships. This may partly derive from the limitations of this thesis, which is discussed in greater detail in the next section. Another possible reason may lie in the vast number of measures inherent in the concept of flexibility. The total flexibility level of an organisation is often quantified as the aggregation of many flexibility types that organisation needs throughout its SCs including but not limited to its suppliers, customers, and distribution centres (see the works of Charles et al. (2010), Stevenson and Spring (2007), and Patel et al. (2017)). Furthermore, adaptability, or reconfiguration is often associated with the willingness to adjust the exchange relationships (Hearnshaw & Wilson, 2013). Such a 'qualitative' characteristic is better explored through conventional approaches. In short, SNA has the potential to evaluate reconfiguration only to a limited degree and is better suited to evaluating other attributes. Therefore, in the final research framework, the attribute of relationship flexibility is excluded. The flexibility dimension is redefined as the degree of freedom (autonomy) and the availability of alternative options for entities to remain connected. By this adjustment, the attributes of flexibility can be assessed by such network-level metrics as degree centralisation and the group-level analyses of cohesiveness and connectivity (see Table 24).

d. Robustness

During the analysis, robustness emerged as the network's ability to remain functional or capacity to minimise damage to the network structure should a disruption strike. This adds a supplementary view to robustness which commonly refers to the ability of certain SC structures to handle a range of events (Stevenson & Spring, 2007). As explained in Section 6.2.1 and as shown in the research framework, robustness can be assessed not only by the analyses at three levels but also by simulations of SC disruption. This finding complements the approach of Sonia et al. (2015) who contend that robustness equates to the size of the functional network after a disruption. It also offers another way of predicting robustness besides the existing method that is based on network models (Kim et al., 2015).

e. SC collaboration

The findings of this thesis indicate that an SNA approach enables an assessment of the extent to which SC collaboration can enable SCA. A variety of SNA tools and techniques allow examinations of collaboration in a complex supply network context from both vertical and horizontal angles. From the above final research framework, SC collaboration could be well studied by the group-level analysis such as the clique analyses and by the analysis of information coordinator roles of organisations, to name but a few. This then extends the current literature wherein SC collaboration is usually included in measures of integration (Faisal et al., 2007) and collaborative relationships (Lin et al., 2006).

6.2.3. How SNA differs from extant approaches in overall agility evaluation

The results show that, like existing approaches of agility assessment, SNA has some capacity to address the subjectivity of human evaluation and the multidimensionality of the concept of SCA, but in different ways. The literature review showed that surveys and case studies are often the methods chosen and the focus is typically on the firm level. The evaluators in these studies give their opinion or rate how well they are managing their supply chains, which most often include key partners, particularly direct suppliers and customers. The overall agility level is usually an aggregation with or without a weighting scheme of agility attributes or sub-capabilities. Rating forms are commonly applied such as Likert scales and evaluation grids. Existing approaches tend to provide either numerical results like an agility index (Lin et al., 2006), an indicative agility maturity range (Charles et al., 2010), or a relative agility grade (Faisal et al., 2007). The agility is evaluated from the viewpoint of the firm for its own SCs.

By using SNA, this thesis has evaluated network agility with respect to relationship interconnectedness rather than merely from the viewpoint of the firm. The results were neither a specific number, figure, nor index, which would have been yielded from conventional approaches such as fuzzy logic, symbolic modelling, and case studies. In other words, the overall agility level of each SC could not be determined statistically. However, the findings support SNA proponents in demonstrating that SNA allows for a comparative analysis of different network structures between two supply chains. This then can complement the approach of Faisal et al. (2007) in relation to agility comparisons between SCs. Furthermore, the SNA approach was able to uncover partly hidden structures and processes that might be missed or rarely evident from conventional approaches (Kim et al., 2011). For example, the results at group level revealed the co-presence of competitors in the same robust subgroups and the horizontal collaboration of long-distance connections, of which the entities themselves might not have been aware.

The results from the three levels were not mutually exclusive or independent of each other. Rather, the overall network agility and even a single dimension of agility could be evaluated from different yet complementary angles. The fact that multiple approaches could be used to capture one agility demonstrates the measurement validity of this study. For example, as shown in Table 24, visibility was evaluated based on the reachability and cohesiveness of the network, membership of cohesive subgroups, and the popularity of organisations within the network. The different roles of individual organisations and their relative importance with respect to others in the same network were assessed by node-level metrics and by a close examination of the network regions and subgroups they join. For this reason, the SNA approach has the potential to address the shortcomings of previous studies on SCA evaluation. In conventional approaches, one agility dimension is measured by a set of associated metrics at a fixed level. The organisational importance is assessed by the organisations themselves with little consideration of their surrounding relationships in other SCs (see (Jain et al., 2008; Kumar & Ramakrishna, 2011; Lin et al., 2006; Seyed Hosseini et al., 2010; Swafford, Ghosh, & Murthy, 2006) as examples).

The works of Xu and Liu (2015) and Hernández and Pedroza-Gutiérrez (2019) are the few exceptions in taking a complex network approach to evaluate supply chain agility. As Hearnshaw and Wilson (2013) note, different units of analysis can be applied from this approach. However, none of the studies have utilised this advantage. Xu and Liu (2015) used three node-level centrality metrics to calculate the weight of entities: betweenness centrality, node strength centrality, and network centrality. Network structure was examined from the point of the individual actor’s position in the supply chains, leaving characteristics of the whole network unexplored. This thesis fills this very gap. The tools themselves were blended at three levels as demonstrated throughout the analysis chapter. Thus, this thesis addresses the gap in the work of

Xu and Liu (2015) by evaluating the agility of two networks via network characteristics at network level and by examining the linkages within and across subgroups at group level.

This study's finding relating to the agility level of the tourism network partly supports the simulation model and their proposition of Hernández and Pedroza-Gutiérrez (2019) in that product distribution determines the suitable structure of a network. These authors simulated the effects of different network topologies on the overall agility measured by two operational metrics: the immediate effect of sudden demand change on order fulfilment rate and the recovery time. They suggested how SCA could be estimated based on network configuration rather than proposing or demonstrating a set of tools and techniques for evaluation. Therefore, to some extent, this study also extends their work by illustrating the application of an SNA approach for estimating effects of varying network elements on network agility.

6.3. Limitations of the study

This thesis is not without its limitations. Like any SNA study, this thesis grappled with the challenge of collecting relational data which was solicited only from interviewees. This secondary source of information may affect the accuracy of results and potentially undermine the value of this research. The metrics related to direct connections, such as network density, could not be interpreted in sensible ways that the researcher had expected. Similarly, there may have been hidden network regions and subgroups that, if uncovered, would tell a different story. It is worth noting that the key actors identified are only critical within the current research network and in the current research context.

No specific formula for estimating the value of each agility dimension was used nor was a weighting scheme applied for agility attributes in the proposed assessment framework. The evaluation of overall agility was mainly based on the researcher's interpretation when linking some network metrics with the agility dimensions. The final effect of a certain network characteristic on one dimension could not be quantified. Therefore, the agility comparison between SCs is interpreted in a subjective rather than objective manner.

Due to restricted resources, this research was conducted at a given point of time. The results are just a snapshot of a given point of time and they do not provide a picture of how agility dimensions interact with each other and change over time. Network dynamics were not examined either. Additionally, the dataset is only a small fraction of the local population. This means the constructed network of this thesis could represent only a portion of the local network. To some extent, the agriculture network may function as an acceptable representative of wider agriculture SCs in the area being research. This can be implied from the fact that when this network was scaled down to ensure a fair comparison between two prominent SCs, the resized subset was shown as a stratified sample that could mirror the characteristics of the full version, as described in Section 4.1.3. However, the tourism and hospitality network may not well represent the wider tourism SCs as it was constructed by only 15 ego-networks. A remarkable number of tourism and hospitality service providers were not yet contacted. The results therefore could not be generalised for a whole region.

This thesis only used a selected set of metrics, tools, and techniques, leaving a pool of potential tools unexplored. For example, network wiring was not applied to evaluate the reconfiguration aspect of flexibility. Likewise, only a small part of the rich data yielded in the Scion project were utilised. Aspects of SC relationship evaluation such as dependency, reliability, and transparency were not fully incorporated into the analysis. Tie strength based on transaction value, frequency of communication, or amount of personal relationships were not examined. Furthermore, this research did not investigate the flows of materials, products, and services although these flows are as important as information flows. One reason is that the lack of SC data, particularly from the referred entities, made the directed network look fragmented. As such, SNA metrics, particularly at network level, do not work well. Another reason lies in the algorithms of SNA software packages, including UCINET 6. They automatically symmetrise network data even for directed networks because a vast majority of SNA tools can only run by ignoring the direction of ties. Such technical limitations cause challenges and generate a greater chance of misinterpretation when studying directed flows.

6.4. Future research

The above limitations open several main avenues for further investigation. Future research can address the methodology shortfalls of this thesis either by increasing the sample size or by combining both quantitative and qualitative approaches for more insights into the network agility. SNA can be combined with traditional approaches for comparative and complementary analyses. If resources allow, longitudinal studies are recommended to explore how network agility is maintained and modified over time. Another potential avenue is exploring different connection types. As Hearnshaw and Wilson (2013) posit, material flow-based networks have the same key properties as those of information flows. The examination of directed flows should not be discouraged from the aforementioned technical limitation. Rather, it can be achieved with careful consideration of appropriate techniques drawn from SNA and traditional methods and if it is subject to cautious interpretation. Alternatively, the data that is left unexamined by this thesis represents a major research avenue to be explored in the future. This promises not only to elevate the Scion's project but also to explore SNA application to the networks constructed by valued ties that are assigned with certain values of such evaluative metrics as frequency of communication.

The unexplored aspects of this thesis would be worth considering as potential research directions. First, a specific assessment model with a weighting scheme can be defined to provide a more objective conclusion of the agility state of a given network. The weighting scheme can be either for agility components, which can be referred from Jain et al. (2008); Lin et al. (2006); Seyed Hosseini et al. (2010), or for the entities as proposed by Xu and Liu (2015). SC relationships can be weighted too. The weighting criteria can include transaction value or volume, frequency of communication or interaction, the criticality of flows, and even other qualitative factors such as reciprocity and trustworthiness. Second, a closer look into the interaction of agility dimensions from the integrated lens of CAS and network may be warranted. In this instance, the graph theory-based model for agility assessment by Faisal et al. (2007) can be applied together with SNA to discover the dynamics of both agility dimensions and SC relationships. Third, a further investigation can be extended to supply chain resilience. SCA can be levelled up to resilience as these two concepts share some commonalities. The literature has recognised that agility without resilience can negatively impact organisational performance and even the supply chain's survival (Ali et al., 2017; Gligor et al., 2019; Lotfi & Saghiri, 2018; Wieland & Marcus Wallenburg, 2012). Researchers pursuing this direction can refer to or build on the wider project of Scion – as briefly introduced in Chapter 1 – and the recent work of Le (2019) on studying supply chain resilience from SNA approach.

6.5. Chapter summary

This chapter focuses on integrating, elevating, and challenging the empirical results with the current body of research. The discussion leads to the final research framework to evaluate SCA by SNA approach, one of the most meaningful contributions of this thesis. As an approach, SNA is demonstrated to be appropriate and applicable to evaluate not only an overall agility level but also agility dimensions, foundation, and enablers. The overall network agility and such agility aspects as visibility, flexibility, and responsiveness can be estimated by network-level metrics.

SC collaboration associated with the distribution of connections and connectivity can be examined by group-level analytical techniques. Individual impacts on network agility can be assessed by centrality measures. The simulation analysis supports the anticipation of network robustness and responsiveness if SC disruptions strike any network element.

SNA could not adequately assess all agility aspects nor could it surpass the effectiveness of conventional approaches in measuring agility attributes with qualitative elements, organisational structure, and firm operations such as degrees of sharing working practices. In general, SNA is appropriate for evaluating visibility, responsiveness, and flexibility. While all the attributes of visibility are well assessed by SNA, responsiveness can also be determined by speed and market sensitivity. Although synchronisation might be implied, forms of integration were not made evident from the SNA measures and tools. In particular, the concept of flexibility needed redefining to encompass notions of the actors' freedom to switch connection options rather than remaining tied to common definitions of it in the literature.

Any two supply chains would not achieve the same agility level, as Faisal et al. (2007) concluded in their theoretical study. This contention partially holds true in relation to the findings of this thesis which show that SCs with different characteristics distinguish from each other not only in overall agility levels but also in agility dimensions and attributes. The agriculture network, representing product-based and relatively homogeneous SCs, tends to perform better than the tourism and hospitality network, which exemplifies service-based and relatively heterogeneous SCs. Network characteristics presumably account for such variances in agility levels, which is evidenced by the discussion with the current literature.

The most noticeable shortcoming of this thesis is that the secondary supply chain data, in being only solicited from interviewees, may undermine the accuracy of the analysis results. Due to restricted resources, this research is cross-sectional, and hence, the results are a snapshot rather than a complete picture of the agility in underlying SCs. Furthermore, this thesis only takes a small part of the available data from the larger Scion project to examine three agility dimensions under a selective set of SNA analytical tools and techniques. Additionally, the comparison between supply chains should be treated relatively, considering the unavailability of the SCA benchmark. Such shortfalls and the unexplored areas of this thesis open potential avenues for further research. The thesis comes to an end in the next chapter.

Chapter 7: Conclusion

This piece of research was primarily motivated by the literature gaps in supply chain agility (SCA) evaluation approaches and social network analysis (SNA) application to study supply chain management (SCM) phenomena. The empirical data were analysed as a network case in the research context, then discussed and challenged with the extant literature. This chapter provides conclusions on the main findings and outlines original contribution of this thesis.

7.1. Conclusions on key research findings

The empirical results give rise to a more theoretical question: "How should SCA be evaluated?" The thesis posits that an integrated lens of network and complex adaptive system (CAS) potentially has the capacity to evaluate SCA in a comprehensive and systematic manner. It showed that SNA can model SCs and can evaluate SC capabilities through agility aspects. Using a wide range of SNA tools and techniques, this thesis demonstrated that SNA is well able to consider interactions and linkages in complex networks, and it also enabled the integrated lens to examine network agility. SNA can make parts of hidden structures and processes explicit through visualisation and it can support intuitive judgements of network agility. Therefore, it lends itself well to phenomena that directly relate to, or result from, network topology, connectivity, and interconnectedness, such as network visibility, speed of responses, and the ability to have multiple connection options.

SNA does not necessarily lend itself to evaluating all agility dimensions and attributes, although it is a potentially powerful methodology. The attributes of integration and relationship flexibility were not well demonstrated by this thesis' SNA approach. However, this does not mean that such attributes cannot be explored by SNA outright; rather, the specific tools and techniques used in this study may have been insufficient or inappropriate to capture such agility attributes. If used exclusively, SNA is less appropriate to examine attributes that either have qualitative elements or which are associated with firm operations. Such attributes require in-depth non-network data rather than network data. Consequently, it is more appropriate to conclude that SNA is an alternative approach to evaluating SCA from a network perspective than to claim the overall superiority of SNA, compared to conventional approaches.

In terms of relative agility comparison, the findings suggest that the network characteristics at the three levels -- node, group, and network -- are key determinants of overall agility levels and the relative strengths at certain agility attributes of varying SCs. This means the differences in agility aspects among SCs are more likely to derive from network properties besides the inherent industry characteristics. Additionally, such discrepancies are substantial in some measures and may be moderate if measured by other analysis tools. It can be therefore concluded that the differences in SCA among SCs using an SNA approach will vary, depending on the tools, techniques, and the level of analysis employed. This does not mean that conventional approaches are superior to SNA because they tend to provide a relatively clearcut picture of agility level discrepancies by determining these gaps only in one way nor is this thesis suggesting that the SNA approach is inherently better. Rather SNA allows the analysis of gaps to be undertaken from various viewpoints, which can then complement conventional and traditional techniques.

7.2. Contribution of this study

7.2.1. Contribution to literature

This thesis contributes to the literature of SCA by filling several gaps. First, the research shows the potential use of SNA to evaluate SCA, supplementing the minimal research on agility assessment approaches and methods (AlKahtani et al., 2019). Second, it uses a real network case to demonstrate the applicability of SNA, which is a valuable contribution given that extant SCA papers are dominated by theoretical and qualitative methodologies. Third, it shifts the usual focus away from the manufacturing environment to non-manufacturing and services supply chains, and from urban areas to rural settings (AlKahtani et al., 2019). Fourth, this study supports one stream of SCA research which holds that SCA is a supply chain-wide capability that draws strength from inter-firm relationships (Sharma et al., 2017). The network analysis in this thesis clearly shows how the overall network agility could not be determined simply by the efforts of individuals. Rather, the agility dimensions were impacted by interdependency and by network interconnectedness. In addition, though SC collaboration is widely agreed as an enabler for SCA, empirical evidence of this is rare (Sharma et al., 2017). The impact of vertical and horizontal collaboration on the network's agility was evident across the analysis. Consequently, this thesis offers evidence of the effects of SC collaboration on SCA. Furthermore, the local agency emerged from the analysis as a SC member that maintains connectivity to ensure the overall network agility. As far as the researcher knows, this is one of the few studies to suggest this critical role in SCM instead of roles around establishing policies or enforcing regulations, which are commonly discussed.

This research has also extended the application of SNA beyond the SCM phenomena to tourism research which usually examines tourism destination networks from a governance lens (Casanueva, Gallego, & Garcia-Sanchez, 2016). To the best knowledge of the researcher, this thesis is one of the few studies to examine a specific SCM phenomenon from a network perspective at all three analysis levels. The illustration of SNA tools and techniques in a real network case, particularly at group level, supplements the abundant literature focusing on network level and node level. This study has also highlighted the two sides of brokerage, particularly in relation to the tourism and hospitality network. On one side, the actors who frequently lie in the shortest paths of the most pairs of entities coordinate the network flows. They contribute to the agility of the network via the accessibility and quality of exchanged flows. On the other side, they pose a threat to the operations of the network, which then may affect the overall network visibility and responsiveness. This study therefore provides evidence of the effects of brokerage which, despite being theoretically recognised, are lacking in empirical evidence (Everett & Valente, 2016; Long et al., 2013).

7.2.2. Contribution to practice

a. For local/ regional/ national councils and policy makers

This thesis promises to leave three main implications at the macro level. First, the research framework can serve as a guidance for investigating network characteristics, by which a local council may understand their local network clearly and holistically. Accordingly, they may take an appropriate lens to assess current network capabilities, to anticipate plausible effects on network agility if any changes happen, and then to make right decisions. Second, the councils can refer to the research framework to evaluate and classify entities based on their different roles to, and impacts on, network agility. As the findings demonstrate, some organisations are better at diffusing information while others enable the adoption of agility practices. Some may be bottlenecks for communication and pose a risk to network operations. To a local agency, it is vital to identify and reach the right actors of right capacity as well as timely protect fragile spots to enhance overall network agility, or at least maintain information flows, particularly in emergency cases. Third, the final research framework can be used to identify key entities and critical relationships that may often be overlooked by conventional approaches for further regional development plans. As the findings reveal, a council not only influences the adoption of agility practices, but also plays an indispensable role in network connectivity and horizontal cooperation as it glues different sectors together. Such a role goes beyond a common governance factor and is barely recognised by any entities embedded within the local network, even by the policy makers themselves. Similarly, some connections, albeit indirect or unaware by the entities, are worth the attention and probably the support of local councils, to assure responsiveness, robustness, and visibility.

b. For SC managers

This thesis potentially benefits SC managers by several ways. They can utilise the research framework to evaluate their own networks' agility, relatively compare with the others', and identify areas for further improvement. As each SC has its own strengths from which the other can learn to bolster agility, mutual learning is encouraged yet this needs tailoring to their respective context. Additionally, SC managers can adopt an SNA approach for relationship management. While such conventional criteria as transaction value and frequency of communication are still valid, it may be more appropriate for SC managers to determine the importance of business relations by the potential impact on network connectivity and performance. SC managers can take a similar viewpoint to evaluate and classify their SC members besides the coventional approaches. Through the development of strong relationships and the right focus on critical SC members, they can develop appropriate strategies for a more agile SC.

7.3. Closing comments

This research has added to the increasing body of knowledge regarding the applicability of SNA to evaluate SCA and to model supply chains. The findings offer both local authorities and businesness owners a clearer understanding of the local network as well as a potential approach to SC relationship management, particularly in SC disruption cases. However, this project had some limitations, which may undermine data accuracy and limit the investigation, despite the researcher's best efforts to ensure the reliability and validity of the study's findings. It is also worth noting that the thesis could explore only a small fraction of numerous analytical methods and views under the SNA approach. There is a wide variety of tools available for examining either a whole network or ego-networks, looking for subgroup-like structures, and determining the roles and positions of individuals. Selecting the right tools and techniques depends on research purposes, research questions, and areas of interest when assessing SCA. The significant potential of SNA is waiting to be realised by future SCM research. The alternative research directions identified in this thesis promise to enrich the literature of both SCM and SNA.

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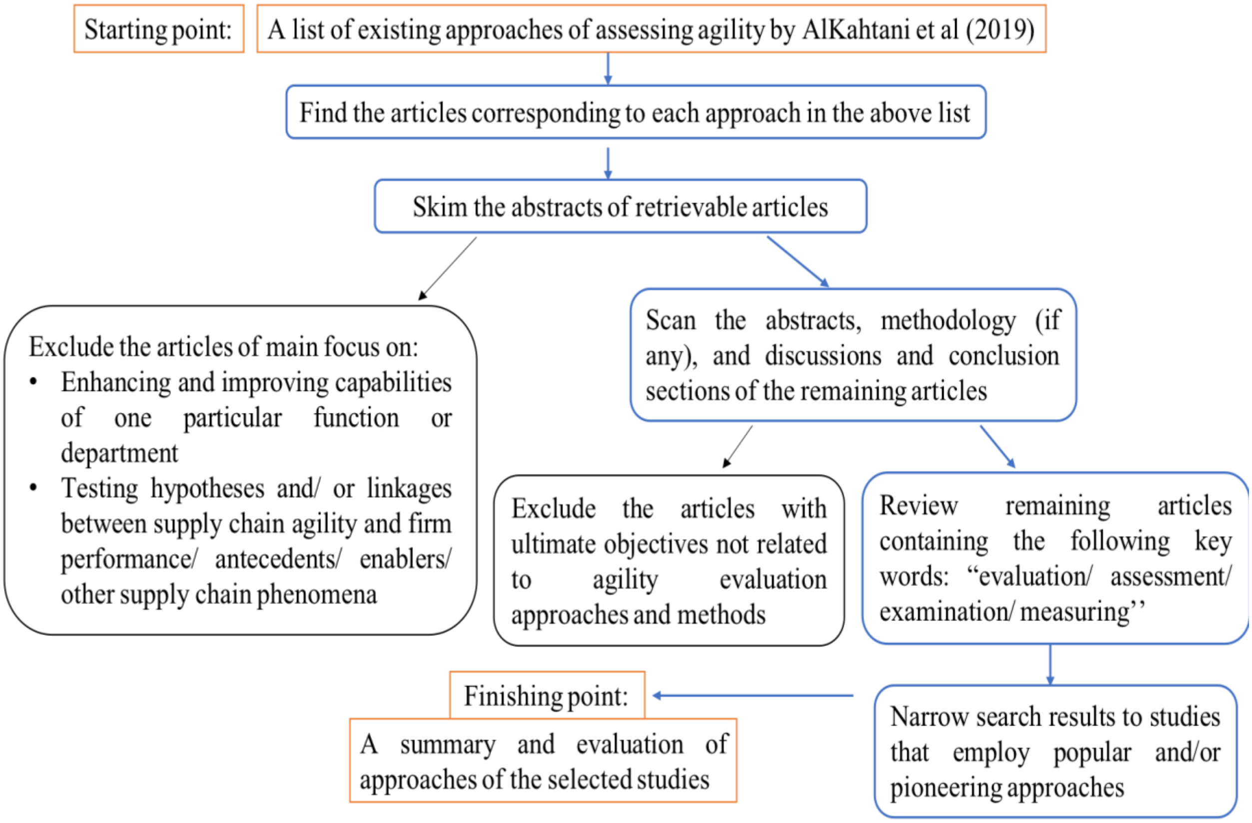
Appendices

Appendix 1: Process of selecting studies of supply chain agility evaluation approaches



Appendix 2: Main variables of primary data in the Scion's project

Attributes		Relations
Business information	**Self-assessment**	
Industry/ Sector	Outcomes of closure scenarios	Value of transactions
Revenue/ Income/ Turnover	State of readiness against unforeseen events	Dependency degree
Expenditure/ Spending		Reliability level
Staff/ Employees		Frequency of communication
Minimum output to continue operations		Strength of personal relationships of staff between two organisations
		Willingness to compensate
		Transparency level

Appendix 3: Design of the simplified questionnaire

Project "Evaluating the Resilience of NZ Rural Value Chains against Natural Hazards" hosted by Scion and funded by Resilience to Nature's Challenges

1. Name of the business
2. Annual production in $
3. Minimum rate of revenue to sustain the business (%)
4. List of suppliers (cover ~80% of supply in $)
   a. Largest supplier's name
      i. What provides
      ii. $
      iii. How easily could you do business without it? Scale
      iv. Are they more powerful in negotiation?
      v. Are they reliable? Scale
      vi. Communication frequency? Scale
      vii. Good personal relationship? Scale
   b. Second largest supplier's name
      …
   c. Third largest supplier's name
      …
   d. Do you want to add more suppliers?
      …
5. Labour
   a. Professional – number
   b. Skilled – number
   c. Unskilled –number

6. List of clients (cover ~80% of supply in $)
   a. Largest client's name
      i. What do they buy?
      ii. $
      iii. How easily could you do business without it? Scale
      iv. Are they more powerful in negotiation?
      v. Are they reliable? Scale
      vi. Communication frequency? Scale
      vii. Good personal relationship? Scale
   b. Second largest client's name
      …
   c. Third largest client's name
      …
   d. Do you want to add more clients?
      …

These are compressed to 2 tables, one monitor size each:

7. Assume your business unit has to close down for one year due to unforeseen circumstances; how likely are the following outcomes as a result of your closure? (Select 1 for highly unlikely and 10 for almost definitely):

Our products will be replaced by imports from another country:

Our products will be replaced by imports from another region inside NZ:

Our competition will take our market share:

The entire supply chain will shut down without us:

We are very small and our absence will not significantly affect the larger economy and supply chains in the region:

Our suppliers and customers will compensate for us and try to "help us out" as much as possible:

It will be almost impossible for us to re-initiate our business after some time of closure:

8. In terms of preparing for large natural unforeseen events such as earthquakes, volcanic activity, flooding, drought, heatwave etc., to what extent is your business in a state of readiness?
(Select 1 for unprepared and 10 if you feel you have done everything possible to prepare the business)

- We carry additional stock and equipment to help us cope with eventualities:

- We have a pot of reserved savings to help us deal with eventualities:

- We have spoken to our supply chain partners about our limitations and capabilities in the case of an event:

- We have comprehensive insurance:

- We have developed joint risk management with our supply chain partners:

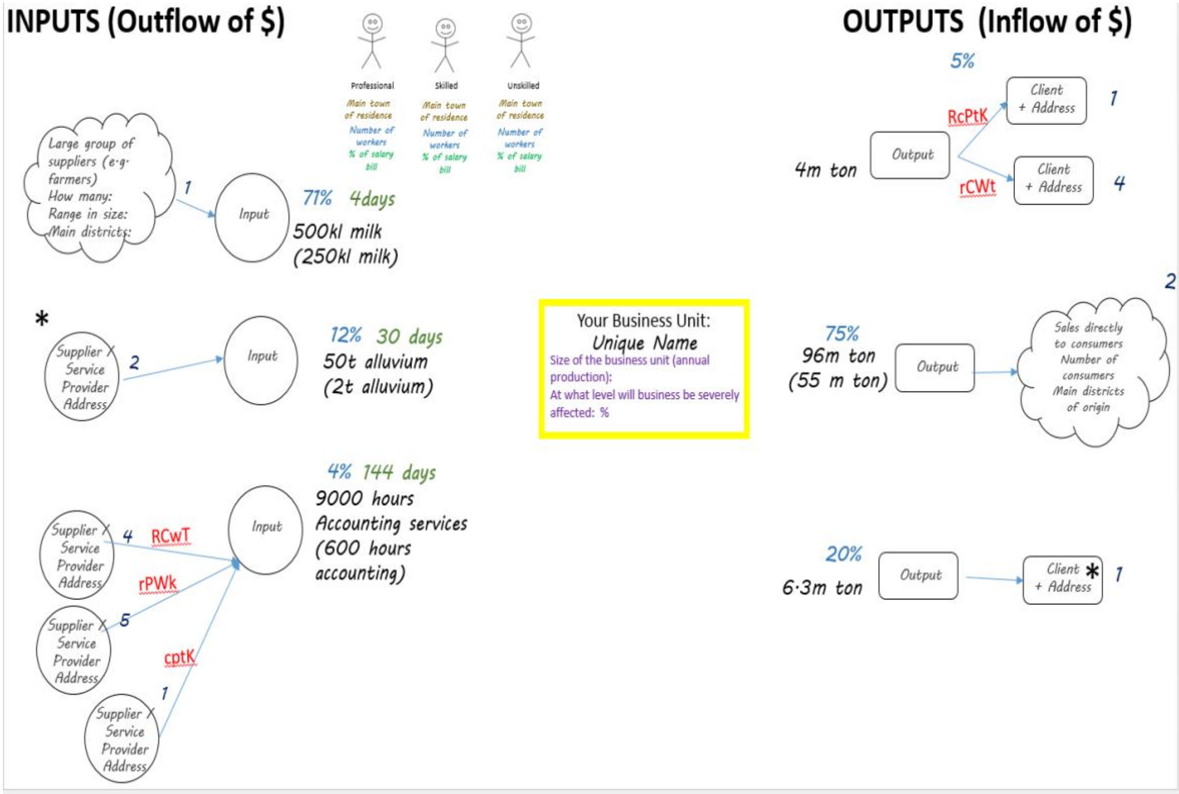
- For redundancy purposes, we deliberately maintain business links with more than one service provider, especially for the critical components of the business:

- We can easily obtain additional cash (or loans) from external sources, if necessary:

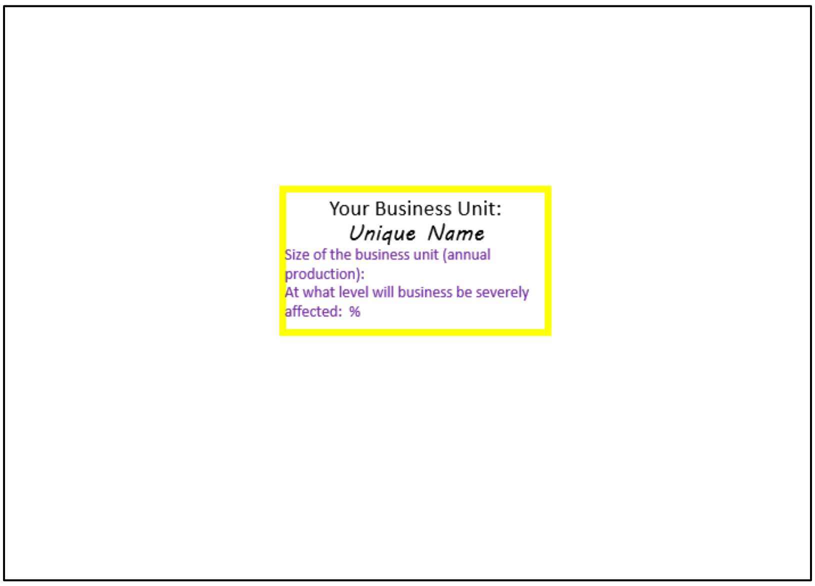
- We have sufficient staff and they are trained to do the work of others who may not make it to work:

Appendix 4: Step-by-step instructions of value chain mapping

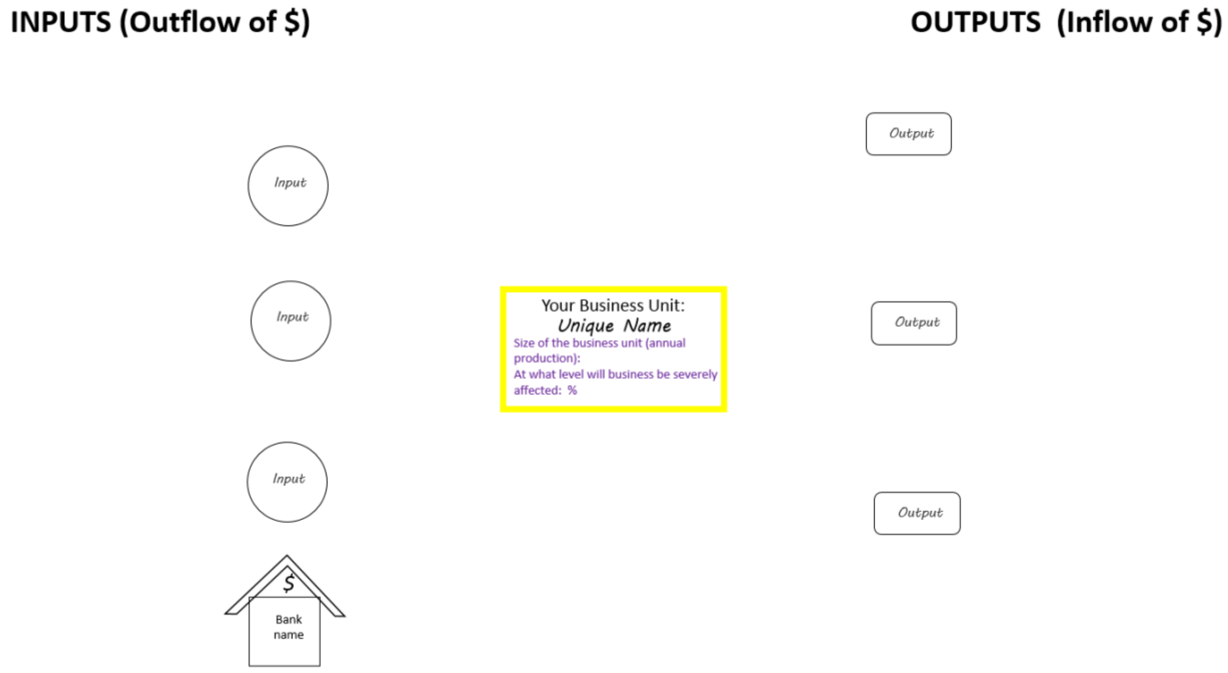
Project "Evaluating the Resilience of NZ Rural Value Chains against Natural Hazards" hosted by Scion



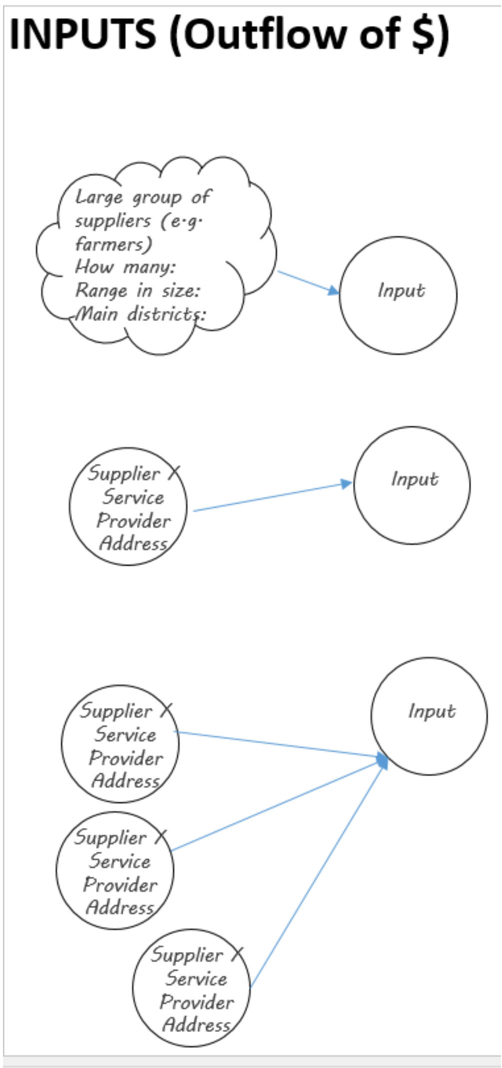
1. In the middle of a blank piece of paper place your business unit name, annual production and the minimum % of annual production at which the business could operate as normal, without being severely affected.



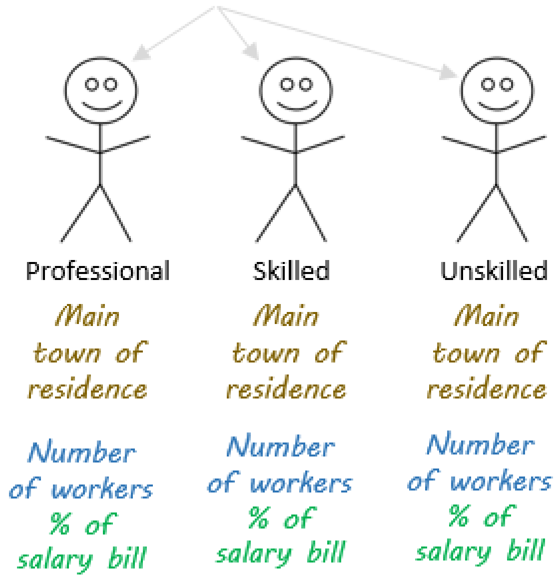
2. To the left, list the major inputs to the business. To the right of your business, list the major outputs of your business



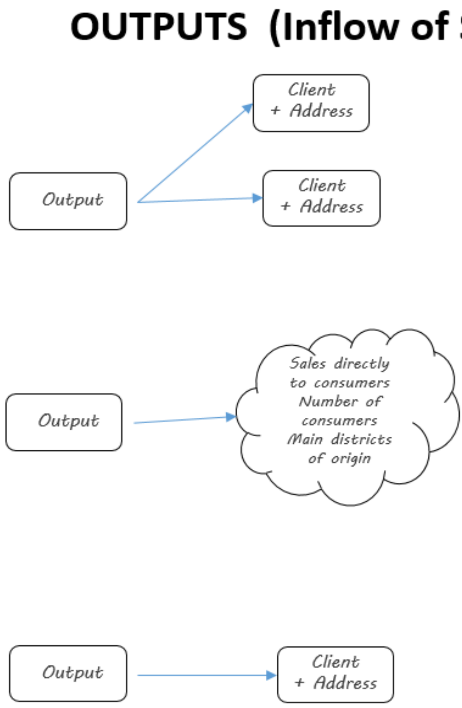
3. For each of the inputs, identify to the left the major suppliers who provide this service or product to your business and their location details. If there are a large group of suppliers they can be identified as a cloud; if a cloud is used, please describe the number of suppliers it represents, the range in size of those supplier,s and the main districts in which they are based.

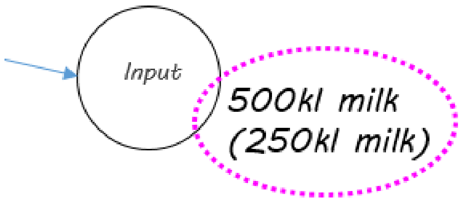


4. Include labour on the input side of the paper. Please indicate how many employees your business has, categorising them as professional, skilled and unskilled workers. For each of the 3 categories, indicate the % of the salary bill attributed to that group and the main area of residence of the employees

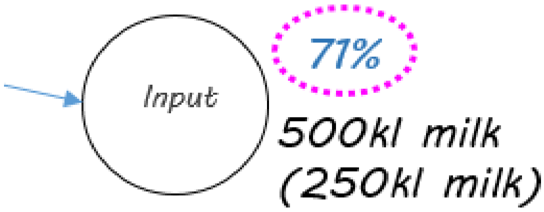


5. For each of the outputs, identify to the left the major customers who purchase this service or product from your business and their location details. If there are a large number of customers they can also be represented by a cloud; for each cloud please indicate the number of customers and the main districts where sales occur.



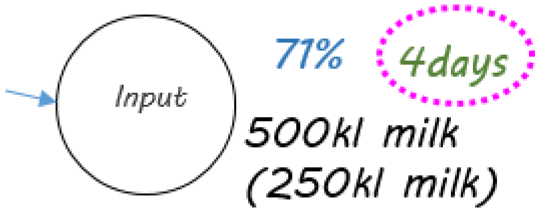


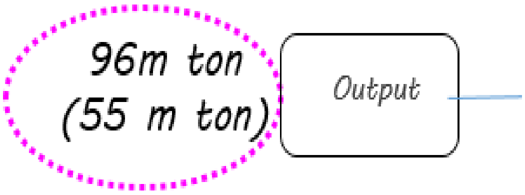
6. For each input identify to the right of the input in black the amount of that product or service that is used by your business. If this input were to be restricted, identify in brackets the minimum amount of product required before your business would be severely disrupted.



7. In BLUE pen, identify the approximate % of your operating expenditure that is spent on this input.

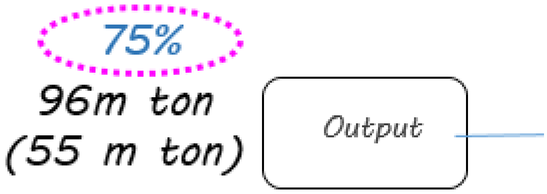
8. In GREEN pen, identify the approximate number of days the business could operate without access to this input during your peak demand period, assuming there is no access to any new suppliers.



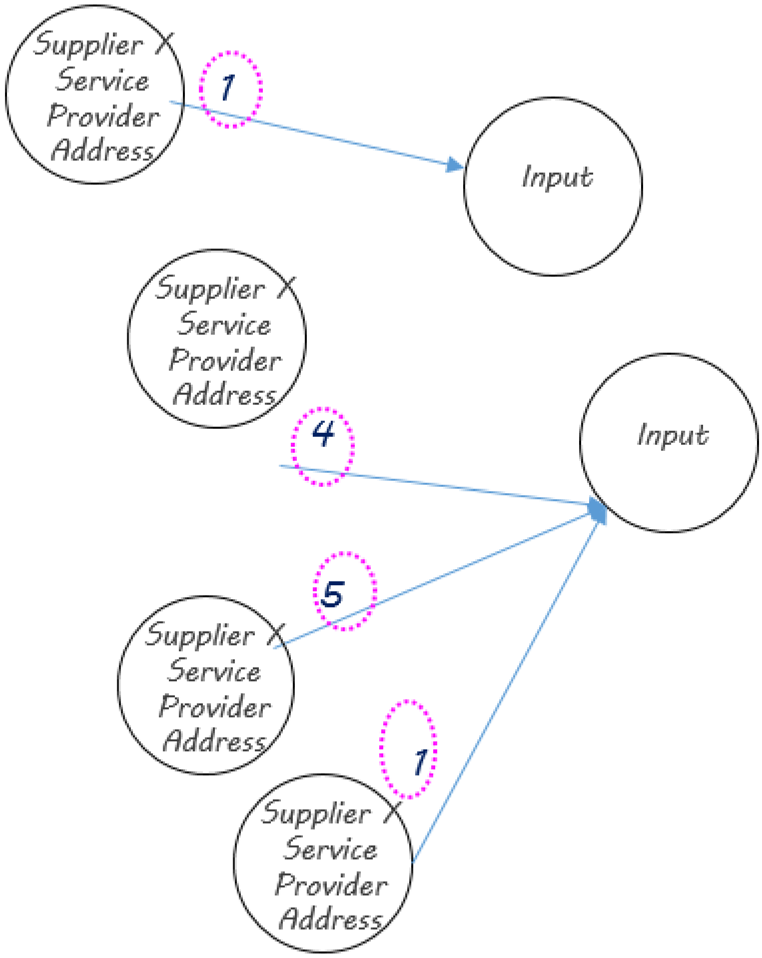


9. For each output identify to the left of the output in black the amount of that product or service that is produced by the business. If this output were to be restricted, identify in brackets the minimum amount required of this product that needs to be sold before the business would be severely disrupted.

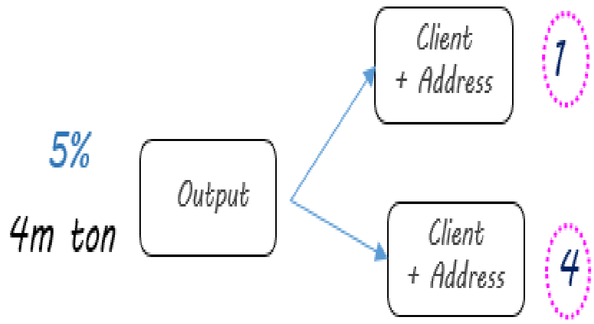
10. In BLUE pen, identify the % of your revenue that is generated from this output.



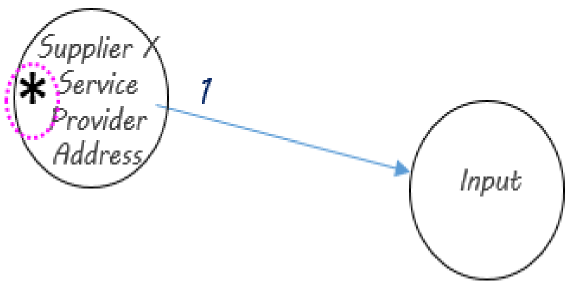
11. For each supplier (or cloud of), place a number next to them which represents how easily you could do business without this supplier. 1 = almost impossible, 5= very easily.



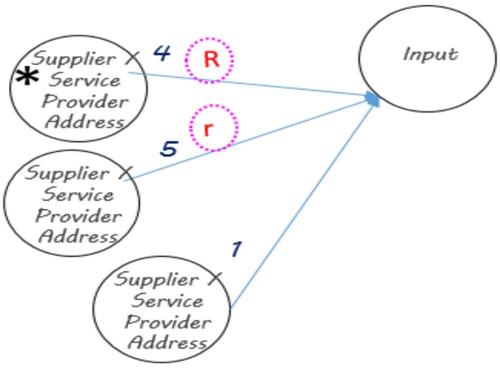
12. For each customer (or cloud of), place a number next to them which represents how easily you could do business without this customer. 1 = almost impossible, 5= very easily.



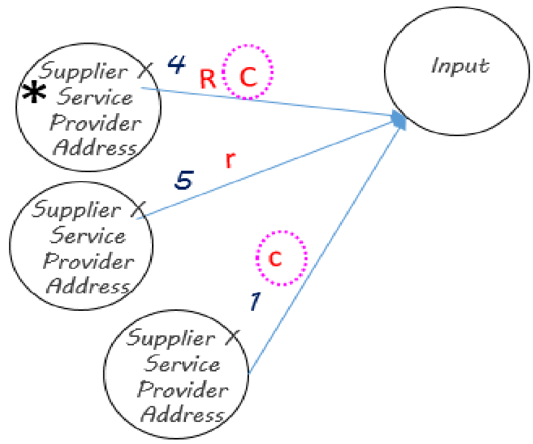
13. Place a star next to any supplier who you perceive to generally be more powerful in the relationship than your business (e.g. they set the price and the requirements).



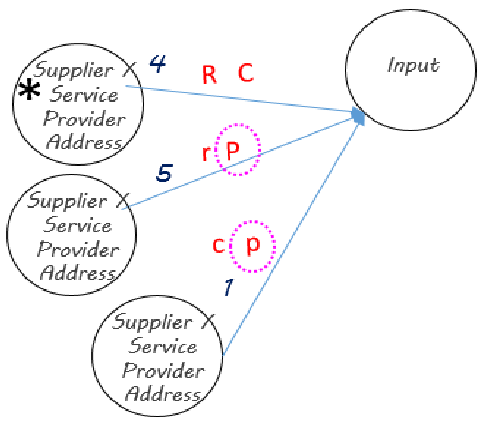
14. Using a RED pen, for each supplier (or cloud of), indicate how reliable you consider this supplier to be. Use a capital R for a very reliable supplier, a lower case r for a moderately reliable supplier, or leave it blank if this supplier is not considered to be reliable at all.



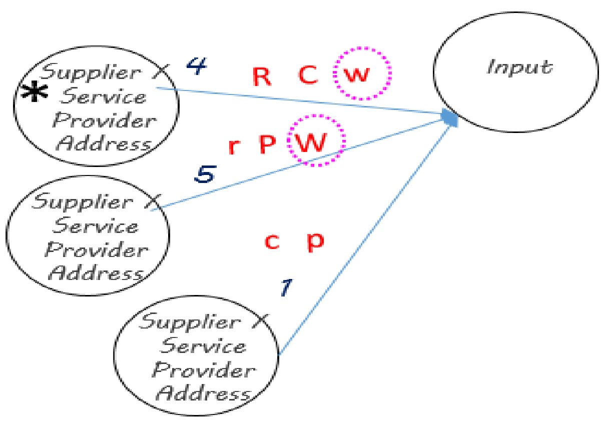
15. Using a RED pen, in a similar fashion indicate how frequently you communicate with this supplier. Use a capital C for very frequent communication, a lower case to represent a moderate level of communication and leave it blank if there is none, or very irregular, direct communication between your business and this supplier.



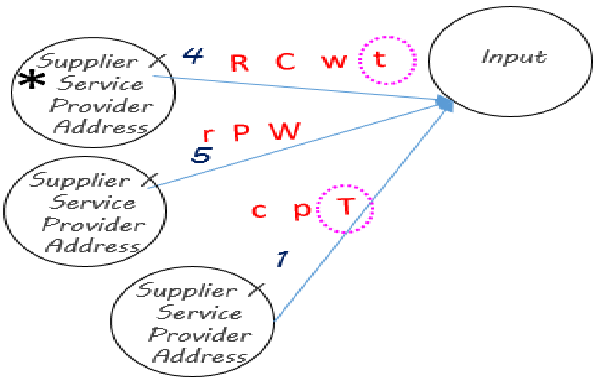
16. Using a RED pen, in a similar fashion indicate if there are personal professional relationships between staff at your business and staff at this supplier. Use a capital P for close personal relationship, a lower case p to represent a loose personal relationship and leave it blank if there is no personal relationship between your business and this supplier.



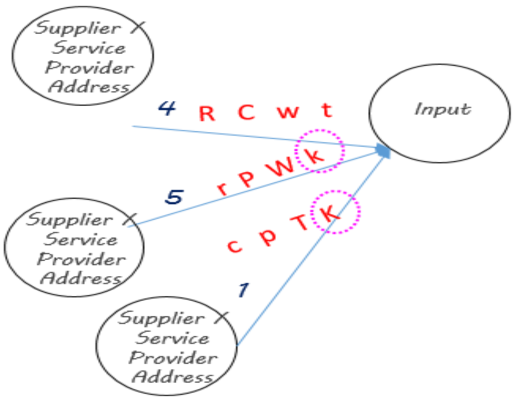
17. Using a RED pen, in a similar fashion indicate to what degree the supplier would be willing to compensate to help your business during a difficult time. Use a capital W for those with a high willingness to compensate, a lower case w to represent those with a moderate willingness to compensate and leave it blank if this supplier will not be willing to compensate you in an emergency.

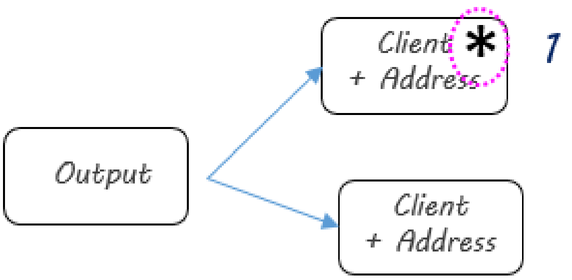


18. Using a RED pen, in a similar fashion indicate the level of transparency you have up and down this supplier's supply chain, ie are you well aware of whom their suppliers and customers are. Use a capital T for those with a high transparency, a lower case t to represent those with a moderate transparency and leave it blank if this supplier is not transparent at all.

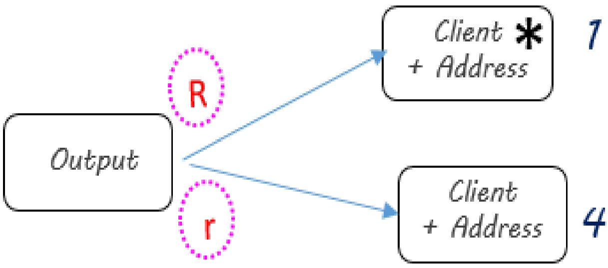


19. Using a RED pen in a similar fashion indicate the extent that the business relationships with this supplier are maintained through cultural connections e.g. Iwi, Chinese community etc. Use a capital K where there are strong cultural connections between your business and this supplier, a lowercase k where there are moderate cultural connections and leave blank if there are no cultural connections between your business and this supplier.

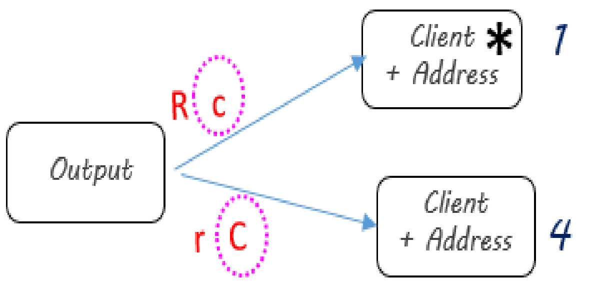




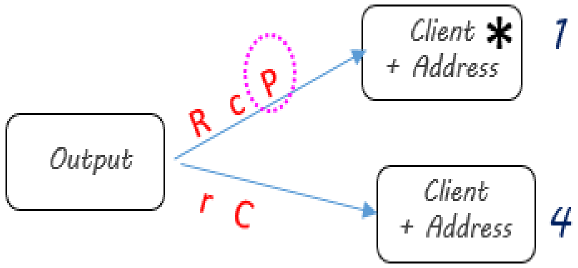
20. Place a star next to any customer who you perceive to generally be more powerful in the relationship than your business.



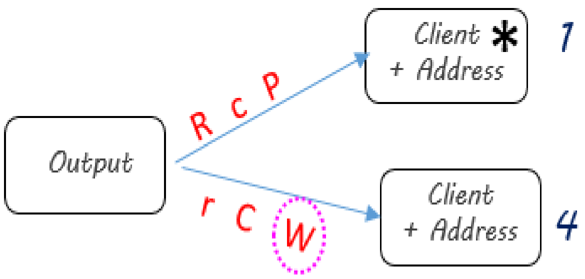
21. Using a RED pen, for each customer (or cloud of), indicate how reliable you consider this party to be. Use a capital R for a very reliable customer, a lower case r for a moderately reliable customer, or leave it blank if this customer is not reliable at all.



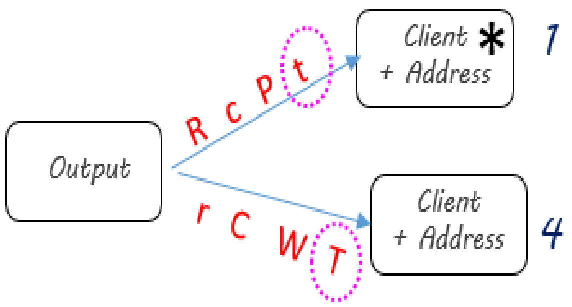
22. Using a RED pen, in a similar fashion indicate how frequently you communicate with this customer. Use a capital C for very frequent communication, a lower case c to represent a moderate level of communication and leave it blank if there is no direct communication between your business and this customer.



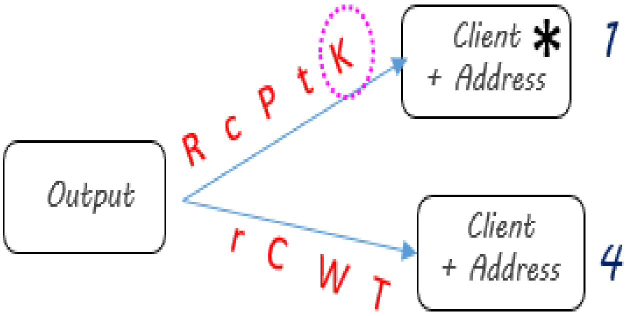
23. Using a RED pen, in a similar fashion indicate if you have a personal relationship with this customer. Use a capital P for close personal relationship, a lower case p to represent a loose personal relationship and leave it blank if there is no personal relationship between your business and this customer.



24. Using a RED pen, indicate the level of willingness this customer will have to compensate you if you were unable to meet your usual order to them. Use a capital W for those with a high willingness to compensate, a lower case w to represent those with a moderate willingness to compensate and leave it blank if this customer will not be willing to compensate you in an emergency.

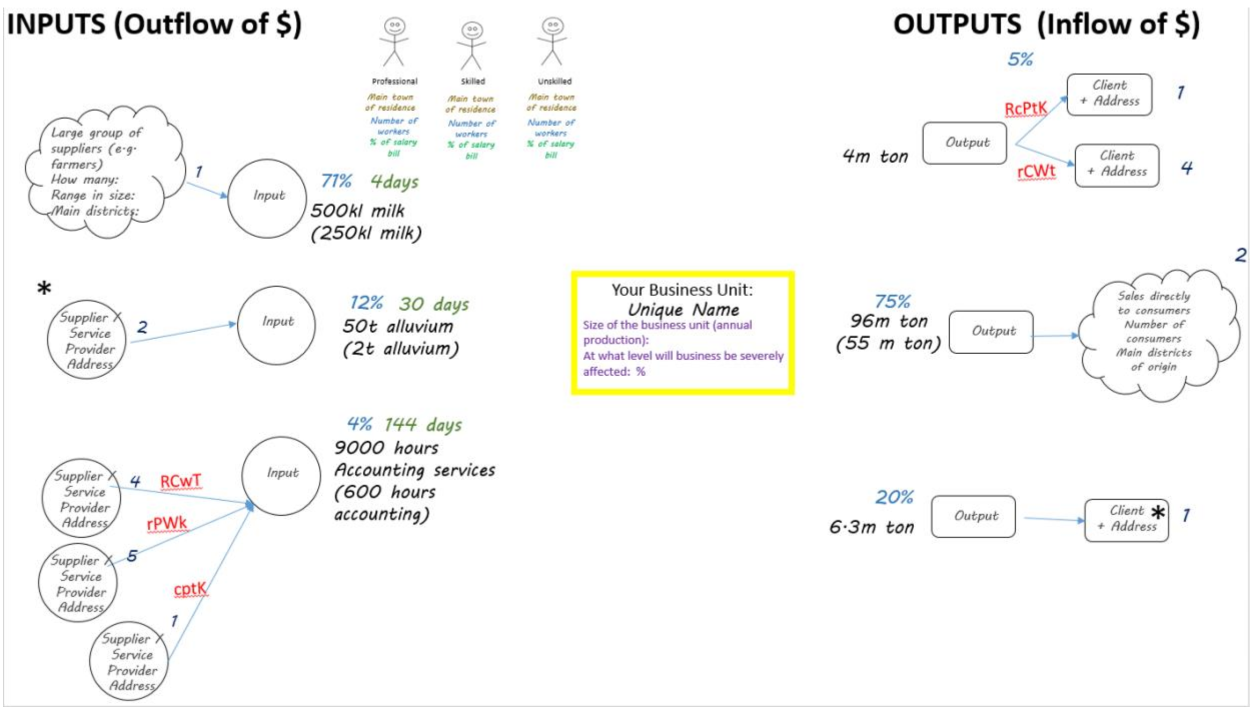


25. Using a RED pen, in a similar fashion indicate the level of transparency you have up and down this customer's supply chain, e.g. are you able to clearly see who their suppliers and customers are. Use a capital T for those with a high transparency, a lower case t to represent those with a moderate transparency and leave it blank if this customer is not transparent at all.



26. Using a RED pen in a similar fashion indicate the extent that the business relationships with this customer are maintained through cultural connections e.g. Iwi, Chinese community etc. Use a capital K where there are strong cultural connections between your business and this customer, a lowercase k where there are moderate cultural connections and leave blank if there are no cultural connections between your business and this customer.

27. Your map at this stage should look similar to this



Appendix 5: Ethical considerations based on Massey University's Code of Conduct

(University, 2017)

Respect for persons

Great care were taken to ensure proper communication and behaviours during the interviews to minimise the potential for participants to feel offended or uncomfortable.

Minimisation of harm to participants, the researcher, institutions, and Massey University

Structured interviews were conducted in the most comfortable environment for interviewees. A risk mitigation plan was put in place, including first aid training, safety compliance, and appropriate interview scheduling. Since managers represent their organisations, care was taken to ensure that existing relationships at both personal and organisational levels would not be negatively impacted. The relationships between firms and research organisations including Scion and Massey University received equal attention. Every effort was taken to safeguard the reputation of these institutions during the course of the research.

Informed and voluntary consent

This study was designed to ensure that all participants were clearly informed of the purpose of the project and that they had at least two chances to confirm their consent. Before the interviews, they were invited to provide a verbal agreement before issuing a written approval to participate. During the interviews, participants were asked to re-confirm their willingness to participate and were assured that they could withdraw at any stage if they chose.

Respect for privacy and confidentiality

This study addressed the concerns over privacy and confidentiality through several ways. Firstly, during data collection, interviewees could request for the audio recording of the interview to be switched off or for the researcher to stop taking notes if they were about to discuss confidential or sensitive information. All electronic documents and information from the interviews were stored on the project system with protection passwords. Secondly, during the data processing and analysis stage, the identities of all interviewees and their companies were removed and coded into anonymous pseudonyms like A001, and were referred to at highly generic levels such as their industry. Only the project team of Scion, the researcher, and her supervisors know the real identities of the participants. Node labels from network visualisation were suppressed unless there was a need to highlight or explain some phenomena observed. In these cases, nodes were shown only by their pre-determined codes and their categories. Finally, data destruction also ensured the privacy of participants and protected the confidential nature of their contributions. All paper notes and electronic files were destroyed once the findings were written up.

Avoidance of unnecessary deception

At the beginning of each interview, participants were clearly informed of the objectives, processes, and ethics of this study. Following each interview, verbatim records of participant responses were examined without an attempt on the part of the researcher to either change the collected data or to create false data. During the analysis stage, the researcher closely consulted with her supervisor to ensure that her interpretations of the data were balanced and that no chunks of data were omitted, either accidentally or on purpose.

Avoidance of conflict of interest

The researcher has no commercial relationships with the organisations involved or power relationships with the participants. There were no potential conflicts of interest within the participating organisations either.

Social and cultural sensitivity

The data collection team were required to be sensitive and responsive to each participant. The interviews were scheduled so as not to clash with religious events, social gatherings, or holidays. Several pilots were undertaken to test how appropriate and easy to understand the questionnaire was in the context of rural settings. The final interview materials were based on consultation with experts to avoid any confusion or possibility of misunderstandings.

Justice

Respondents were selected purely on the basis of their roles without any discriminations made in terms of their profiles and backgrounds. All participants were given clear and consistent information regarding the estimated timeframe and expectations of the project so as to ensure that participants could make an informed decision.

Appendix 6: Data analysis approach (detailed)

Figure 13 illustrates a full data analysis approach that is outlined in Section 3.5. This appendix provides some details of the SNA metrics, tools, and techniques applied. A thorough account of their formal definitions can be referred from Wasserman and Faust (1994). Instructions and application examples, particularly those of UCINET package, can be found in the tutorials of Borgatti et al. (2013); Hanneman and Riddle (2005).

Network data analysis approach		
Level of analysis	**Type of analysis**	**SNA metrics, tools, techniques**
Network	Network configuration	Degree centralisation
	Network cohesion	Average degree
		Density
		Connectedness
		Average distance
		Diameter
Group	Cohesiveness	Triad census
		Cliques
		K-plexes
		K-cores
	Connectivity	Lambda sets
Node	Individual contribution	Centrality measures
	Fragile spots	Block and cutpoints
		Fragmentation centrality
All	Simulation	Information diffusion
		Disruption
Relation type: Transaction-based Flow type: Information Software: UCINET 6 package (UCINET, NetDraw, KeyPlayer)		

Figure 13 - A full data analysis approach in this thesis

A-6.1. Network-level analysis

Table 25 presents the metrics and indices selected to perform the network-level analysis. Network configuration involves network centralisation (Kim et al., 2015) that implies the authority and decision implementation process (Kim et al., 2011). The centralisation level may indicate the degrees of flexibility and responsiveness. In this research, it is measured by a degree centralisation index that serves to capture the dominance of central actors in terms of their influential scope in the current network (Borgatti et al., 2013; Freeman, 1978). This metric is the ratio of the actual sum of differences in degree centrality between the central actors and the others. The ratio ranges from 0 to 1, changing from a circle to a star network shape respectively. Real networks often have this index falling between these two extremes (Freeman, 1978).

Table 25 - Summary of metrics and indices used in the network-level analysis

Network properties & characteristics	**Metrics/ Indices**	**Explanation**	**Agility aspects**
Network configuration – Network centralisation	Degree centralisation	The extent to which a network is organised around specific central actors, based on degree centrality indicators	Flexibility Responsiveness
Network cohesion – Direct connections	Average degree	Average number of ties each actor has	Capacity to receive and transmit information and resources
	Density	The probability that two random actors in the network has a tie	
Network cohesion – Reachability	Connectedness	The proportion of pairs of actors that can reach each other by any means	Accessibility
	Fragmentation	The reverse measure of connectedness	
Network cohesion – Path length	Average distance	Average smallest number of connection steps among pairs of reachable actors	Speed and quality of exchanged information and resource Speed of responses
	Diameter	The number of connection steps between two farthest actors in the network	

Among the various network cohesion measures available in the extant SNA literature and softwares, three main types of metrics are applied in this research. Direct connections are hypothesised to relate to the capacity to receive and push information flows of either a single organisation via average degree or a whole network via density metrics. Reachability can be measured by connectedness and fragmentation. The extent to which the network is well connected indicates the possibility that every organisation is able to access relevant information and necessary resources. The metrics of overall path length include average distance and diameter, which determine the speed and quality of exchanged flows.

A-6.2. Group-level analysis

The group-level analysis seeks for cohesive subgroups and regions to study tie strength, connectivity, and similarities – characteristics of linkages and interactions among organisations embedded in such network locations. This is not only to allow the estimation of agility distribution but also to identify the roles of entities. The examination of cohesiveness starts from triads, since this unit of analysis is arguably the most sensible to study small social structures in the SNA literature (Easley & Kleinberg, 2010; Scott, 2013; Scott & Carrington, 2011). A triad can be regarded as the smallest subgroup in this research. The subgroup size is then expanded, and varying criteria are applied to uncover the network.

a. Triad census analysis

A triad census analysis is conducted to examine triad configuration as summarised in Table 26. While triad configurations of type 1 and type 2 may say little about the network's agility, those of types 3 and type 4 may have implications for the network. Triads of type 3 indicate a possibility of triadic closure. Theoretically, these "structural holes" can help the involved organisations to capture new opportunities (Burt, 2015), which may then contribute to the overall agility. Meanwhile, triads of type 4 are tightly knit subgroups in which all three actors are directly connected to each other (Hanneman & Riddle, 2005). Such complete subgraphs indicate a possibly higher degree of cooperation that enables higher agility levels.

Table 26 - Illustrative summary of a triad census analysis to the research network

Type of triad configuration	Description	Meaning/ Implication to the research network
1	No dyads have ties	No economic exchange ties between any two organisations
2	Only one mutual dyad	Only one economic exchange tie between two out of any three organisations
3	Two mutual dyads	Structural holes; possibility of capturing new opportunities
4	Three mutual dyads	Complete subgraphs; possibility of stronger cooperation

b. Cliques – cohesive subgroups based on complete mutuality

A clique approach is taken as a generalised way to examine tightly knit subgroups. In SNA literature, a clique formally refers to a maximal complete subgraph wherein every node is directly connected to each other. No other nodes can be added into such a subgroup without changing this property (Hanneman & Riddle, 2005; Wasserman & Faust, 1994). This method has a strict criterion. It requires complete mutuality among members, and hence, results in highly cohesive and robust subgroups. Removing a certain node does not greatly affect the overall connectivity of the remaining members, although the clique structure may be broken by this removal (Borgatti, Everett, & Shirey, 1990; Seidman & Foster, 1978).

Identifying cliques is just the starting point from which secondary analysis uncovers clique structures as well as the roles of organisations in network agility. As Borgatti et al. (2013) suggest, a combination of two common methods -- analysing clique overlap and bimodal techniques -- can maximise the benefit of clique analyses. This thesis follows this line of suggestion as summarised in Table 27.

Table 27 - Summary of approaches for secondary analysis of cliques in this thesis – adapted and abridged from Borgatti et al. (2013)

Method	Focus of examination	Expected outcomes	Meaning/ Implications
Analysing clique overlap	Clique-by-clique overlap	The number of cliques that a certain clique is indirectly connected to via common members as intermediaries	Positions and overlapping structure of cliques in the network
	Clique co-membership	Frequency of being together in the same clique of each pair of organisations in the network	A measure of association indicating strength of ties between each pair of organisations
Bimodal	Clique participation	Chances of participation in/ being identified with a clique of a given organisation	Potential brokering role of organisations

In terms of clique overlap analysis, a focus on how cliques overlap can reveal positions and an overall pattern of connections among cliques in the network being examined. This may then suggest how well information flows across such subgroups. Furthermore, a closer look at clique co-membership can uncover potentially strong links that may be ignored or which are unfeasible to identify by conventional methods. This may also provide complementary findings pertaining to the strength of ties from an SNA perspective in comparison to conventional measures of SC relationships such as reliability, frequency of communication, and personal intimacy.

Within a clique, all member organisations are equal since they are all graph theoretically identical (Wasserman & Faust, 1994). However, their roles differ across cliques. This thesis seeks for the oranisations which potentially play a brokering role in disseminating information. This leads to the clique participation analysis on the assumption that the greater the possibility of being identified with certain cliques, the more potential an actor has to be an important broker. Among alternative ways of examining clique participation under the bimodal method, 2-mode data matrix in NetDraw is applied thanks to the visualisation function (Borgatti et al., 2013).

c. K-plexes and k-cores – cohesive subgroups based on adjacency of members

The strict criterion of complete mutuality among members restricts the number and the size of cohesive subgroups found in networks. Therefore, more relaxed approaches have been introduced in the SNA literature to examine groups of similar cohesiveness (Wasserman & Faust, 1994). This research uses two available approaches based on the adjacency of subgroup members: *k*-plexes and *k*-cores. A *k*-plex is a cohesive subgroup in which each actor can lack ties to no more than *k* group members. In contrast to *k*-plexes, a *k*-core requires each actor to connect with at least other *k* members. It is difficult to break down either a *k*-plex or a *k*-core by only affecting one individual. Accordingly, *k*-plexes and *k*-cores are robust subgroups (Borgatti et al., 2013; Hanneman & Riddle, 2005; Wasserman & Faust, 1994).

In the *k*-plex analysis, '*k*' represents the maximum number of ties that are allowed to be missing whereas 'n' equates to the minimum number of entities in a cohesive subgroup (Wasserman & Faust, 1994). This thesis studies *k*-plexes in two main scenarios: (1) *k*=2 and the value of n ranges from three to ten, and (2) *k*=3 and the value of n ranges from four to twelve. These scenarios give more options of cohesive subgroups wherein agility can be relatively evaluated and evidenced. As *k*-plexes draw attention to overlaps and co-presence (Hanneman & Riddle, 2005), this research looks for common members of *k*-plexes found in the above scenarios. These common members are also brokers of information flows. Their roles are then compared with or justified against those identified in the clique analysis and other measures at node level.

Following a normal procedure, the discovery of *k*-cores in the research network starts from *k*=1 and continues until increasing *k* does not reveal any subset of actors satisfying the criterion. In this thesis, *k*-cores are regarded as network regions rather than subgroups or groups. This is because *k*-cores analysis usually results in larger subsets of actors than the above approaches of cohesive subgroups. There is no further analysis of co-members between *k*-core regions because such regions do not partially overlap. Indeed, *k*-core regions are disjoint sets of nodes of the graph (Borgatti et al., 1990). In other words, the regions of smaller value *k* contain the areas of bigger value *k*.

d. Lambda sets – cohesive subgroups based on comparison of relative strength

An alternative approach to uncover network subgroups is comparing the relative strength between ties within a group and ties to outsiders. Of the various methods available, this study adopts the Lambda set approach proposed by Borgatti et al. (1990) to examine relatively cohesive and robust groups in terms of connectivity between group members. Lambda is the value indicating the level of line connectivity between actors. This value is proved to be equal to the number of independent paths, or alternative routes, linking anyone to any other (Borgatti et al., 1990; Wasserman & Faust, 1994). A lambda set consists of actors who have more edge-independent paths connecting them to each other than to outsiders. Because of this property, a lambda set is robust, relatively cohesive, and difficult to crack (Hanneman & Riddle, 2005). The larger the lambda value, the greater number of independent paths for each pair of actors, yet the smaller the size of the group containing this pair. Like *k*-cores, lambda sets disjoint at a given lambda value rather than overlap (Borgatti et al., 1990). Therefore, the analysis of co-membership is not applicable.

A-6.3. Node-level analysis

The node-level analysis highlights variances in actors' connections and defines which entities may impact the network agility directly or indirectly. An entity is important thanks to its popularity, its potential influence, or simply its graph-theoretical position. The measures and tools applied for this analysis are as follows.

a. Individual contribution by centrality measures

Eigenvector centrality measure

The eigenvector centrality measure is used to evaluate the popularity of individuals. Like degree centrality, this measure also counts the number of neighbours an actor has but then weights each neighbour by its own centrality (Borgatti et al., 2013; Hanneman & Riddle, 2005; Wasserman & Faust, 1994). The higher an individual scores, the more popular it is. Within the network being studied, the highly popular organisations exchange economic benefits with the entities who are themselves well-connected. In the context of information flows, they are highly visible. Their operational activities are likely to be known by both direct and indirect contacts. The higher their popularity, the greater their potential to receive and transmit information. Therefore, they may contribute to the agility of their network by enhancing visibility aspects, especially transparency, and the potential scope of exchanged information.

Beta centrality measure

The potential influence of an actor on all other organisations is quantified by Bonacich power or the so-called beta centrality measure. The beta parameter determines the extent to which long walks of influence are counted in networks. Theoretically, the smaller and closer to 0 a beta value is, the less the longer walks are counted in measuring the amount of influence (Bonacich, 1987). In other words, a given actor tends to influence others by direct channels if the beta value moves towards 0 and by indirect connections if it becomes almost infinite. There are no theories or common practices that determine the ideal beta value in the literature. Instead, such determinations are shaped by the objectives of the research at hand (Borgatti et al., 2013). However, the current questions and purpose of this study do not focus on whether long paths or short paths matter. Therefore, in this study, the beta value is set to be automatically determined by UCINET 6.

Closeness centrality measure

The graph-theoretical proximity of a given node apparently impacts its potential to receive quality information at the earliest time (Hanneman & Riddle, 2005). This is calculated and presented by the normalised closeness centrality. The measure is first calculated by a sum of geodesic distance – length of the shortest path – from a given node to all others. The value is then normalised to have a maximum of 100%. The higher the normalised score, the closer the individual is to others, and the more potential that entity has to receive information quickly and with higher levels of accuracy (Borgatti et al., 2013).

Betweenness centrality measure

Betweenness centrality measures the frequency in which a given actor stands between two other entities. It counts how many times all the shortest paths from one entity to the other go through a given actor (Hanneman & Riddle, 2005). In this study, this measure can indicate the brokerage role of actors in addition to their co-membership in the analysis of subgroups. The actors with a high betweenness value can facilitate information exchanges, yet at the same time, may be a potential threat to network operations if disruptions happen. In either case, they impact overall network agility.

b. Fragile spots by fragility analysis

Some organisations warrant attention as they potentially pose a threat to the network structure, which may impact the overall network agility negatively. There are two common lenses through which to examine the degree of damage caused: maximum component counts and network fragmentation (Borgatti, 2006; Borgatti et al., 2013). Maximum component counts allow the analysis to occur at node level whereas network fragmentation is typically used for analysis at network level. This study adopts both lenses. The lens of maximum component counts holds that fragile organisations are graph theoretically key 'weak' points, or cut-points by SNA terminologies (Hanneman & Riddle, 2005; Wasserman & Faust, 1994). If they are removed, the network is divided into unconnected parts which are deemed blocks or vulnerable parts. The extent to which an actor has an impact on the fragility of the network can be quantified by the fragmentation centrality measure derived from the network fragmentation lens. Specifically, this measure calculates the difference in the network fragmentation scores before and after a given actor is removed (Borgatti et al., 2013).

A-6.4. Simulation analysis

The simulation analysis is conducted to identify key actors in terms of information diffusion and SC disruptions which equally impact on overall network agility. These key actors are then reviewed with those found by centrality measures to either reconfirm or complement the views on individual importance. In addition, co-membership status from the analysis of subgroups and self-evaluation in non-network data are used for further explanations and for supplementing information where applicable.

The simulation is run to examine scenarios of diffusion and disruptions through two approaches. On the one hand, with the naïve approach, the top list of centrality measures is selected. The reach capacity is calculated for information diffusion whereas the severe consequence on network fragmentation is evaluated for unexpected events. On the other hand, the use of KeyPlayer programme follows the work of Borgatti (2006) who proposes to identify or redefine the key players of the network through combinatorial optimisation. By default, this programme sets the algorithm to a greedy algorithm.

Appendix 7: Business size based on employment numbers

The size of businesses in New Zealand is usually classified based on headcounts of employees. This research adopted this common practice but slightly adjusted it and named the ranges to better describe the state of enterprises in the rural area being researched. Specifically, the size ranges from micro, with fewer than 6 employees, to global with at least 100 employed, as summarised in the following table.

Table 28 – Classification of business size of the interviewed businesses based on headcounts

Business size	**Employment size**
Micro	0 – 5 employees
Small	6 – 19 employees
Medium	20 – 49 employees
Large	50 – 99 employees
Global	From 100 and above employees

Appendix 8: Procedure of resizing the agriculture network from the fully extracted version

<u>Step 1:</u> Consolidate the profile of interviewed agri-businesses, based on main outputs

The 24 interviewed agri-businesses comprised:

- 14 farms – cattle-based
- 1 nursery
- 1 beekeeper
- 4 firms providing farming services
- 2 marketers, processors, and exporters of red meat products
- 1 processor, retailer, and wholesaler
- 1 supplier of farm inputs

<u>Step 2:</u> Draw an agriculture supply chain map based on the collected data

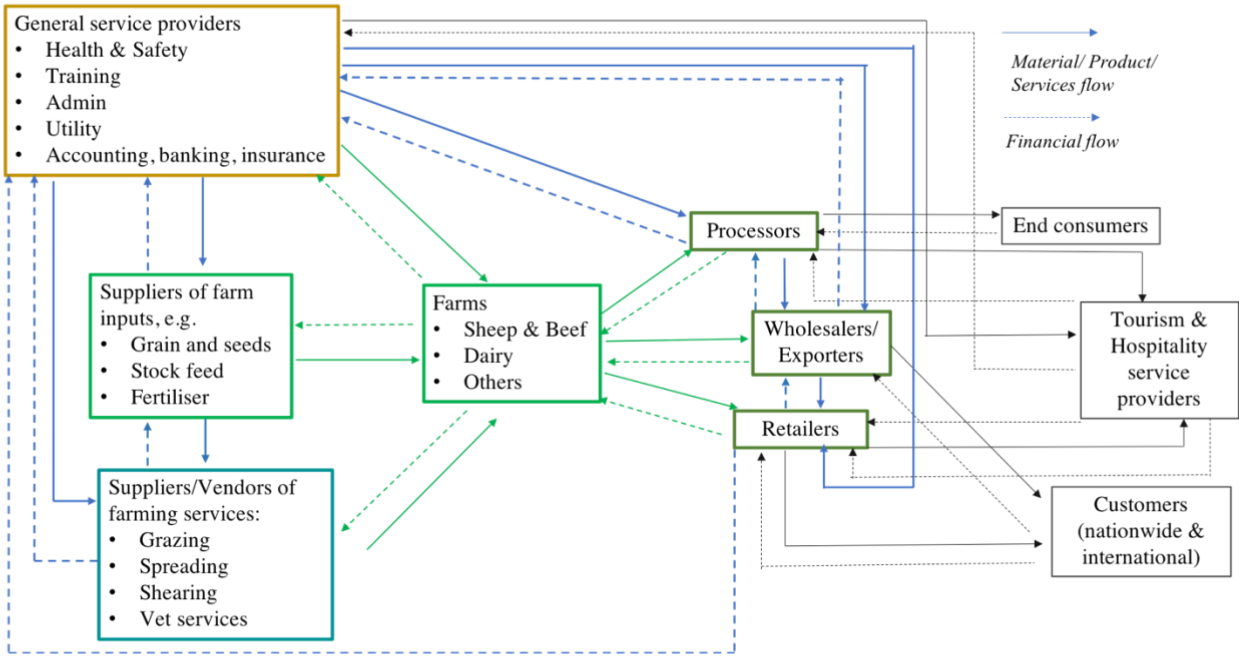


Figure 14 - Agriculture supply chain map from the collected data of this thesis

<u>Step 3:</u> The following agribusinesses were chosen to resize the agriculture network in order to establish a fair comparison with the tourism and hospitality network. Based on the supply chain map, at least one representative was chosen for each type of organisation involved in a typical SC. As the farms in the researched area were dominated by those that were cattle-related, this was reflected in the business nature of the organisations interviewed. These cattle-related farms were filtered so that there was a good mix of business size based on headcounts.

Table 29 - List of chosen agribusinesses for resizing the original agriculture network

ID	Type of businesses	Reason for being chosen	Business size
B045	Marketers, processors, and exporters of red meat products	Randomly picked between two businesses	
B035	Processor, retailer and wholesaler	The only one interviewed	
B047	Supplier of farm inputs	The only one interviewed	
B003	Firm providing farming services	Shearing	
B007		Spreading	
B046		Vet	
B036	Farm	The only pig farm interviewed	Employment size: L
B033		Specialising in dairy	Employment size: S
B042		Sheep, Beef, Dairy, Deer	Employment size: S
B016		Culinary produce	Employment size: XS
B009		Sheep, Beef & Honey	Employment size: XS
B014		Sheep & Dairy	Employment size: XS
B015		Sheep, Beef & Dairy	Employment size: XS
B018		Beef and Dairy	Employment size: XS
B039		Sheep & Beef	Employment size: XS

Appendix 9: List of shared members of k-plexes in the two networks

Agriculture network		Tourism and Hospitality network	
Org. ID	**Number of 2 k-plexes containing a minimum of 5 entities that are joined by these organisations**	**Org. ID**	**Number of 2 k-plexes containing a minimum of 5 entities that are joined by these organisations**
B003	11	B003	5
B041	9	A005	4
B042	8	A242	4
A005	5	B041	4
A242	5	B042	4
A379	5	A379	2
B020	5	B009	2
B009	2		
B010	2		

Agriculture network		Tourism and Hospitality network	
Org. ID	**Number of 3 k-plexes containing a minimum of 6 entities that are joined by these organisations**	**Org. ID**	**Number of 3 k-plexes containing a minimum of 6 entities that are joined by these organisations**
B046	464	B046	423
B042	461	A193	387
A242	439	A242	387
A193	423	B042	346
B041	372	A343	342
A343	370	B039	263
B015	305	B041	255
B009	298	B009	251
B039	276	B037	237
B037	253	B015	229
B018	214	B018	213
B047	182	B047	172
A230	103	A230	90
B045	102	B014	90
B014	99	B045	89
B003	95	B038	88
B038	88	A167	63
A167	68	B008	56
B008	68	B003	39
B043	59	B033	38

Appendix 10: Results of examining the lambda sets in both subset networks

Table 30 - Summary of robust groups with edge connectivity from level 11 in the agriculture network

Line connectivity levels	22	19	18	16	15	14	13	12	11
	B041	B041	B041	B041	B041	B041	B041	B041	B041
	B042	B042	B042	B042	B042	B042	B042	B042	B042
		A242	A242	A242	A242	A242	A242	A242	A242
		B009	B009	B009	B009	B009	B009	B009	B009
		B015	B015	B015	B015	B015	B015	B015	B015
		B033	B033	B033	B033	B033	B033	B033	B033
			B037	B037	B037	B037	B037	B037	B037
				B039	B039	B039	B039	B039	B039
				B003	B003	B003	B003	B003	B003
					B035	B035	B035	B035	B035
					B040	B040	B040	B040	B040
					B046	B046	B046	B046	B046
						B018	B018	B018	B018
							A193	A193	A193
								A343	A343
								B008	B008
								B038	B038
									B014
									B043

Table 31 - Summary of robust groups with edge connectivity from level 11 in the tourism & hospitality network

Line connectivity levels	**17**	**16**	**15**	**14**	**12**	**11**
	A242	A242	A242	A242	A242	A242
	B042	B042	B042	B042	B042	B042
		B035	B035	B035	B035	B035
			B046	B046	B046	B046
				B009	B009	B009
				B019	B019	B019
				B041	B041	B041
					A193	A193
					B033	B033
					B038	B038
						A343
						B015
						B018
						B039

Appendix 11: Simulation results of information diffusion within two steps run by KeyPlayer

Table 32 - Detailed list of 5 optimal actors to diffuse information in each network within 2 steps

Network A (Agriculture)		**Network T&H (Tourism and Hospitality)**	
Option	**List of 5 optimal actors**	**Option**	**List of 5 optimal actors**
1	A193, A242, A364, A379, B042	1	A002, A193, B017, B035, B049
2	A193, A242, A364, A438, B042	2	A011, A193, B017, B035, B049
3	A193, A242, A364, B009, B015	3	A122, A193, B017, B035, B049
4	A193, A242, A364, B009, B041	4	A123, A193, B017, B035, B049
5	A193, A242, A364, B009, B042	5	A193, A225, B017, B035, B049
6	A242, A364, A438, B016, B042	6	A193, A265, B017, B035, B049
7	A242, A364, B009, B015, B016	7	A193, A313, B017, B035, B049
8	A242, A364, B009, B016, B041	8	A193, A340, B017, B035, B049
9	A242, A364, B009, B016, B042	9	A193, A407, B017, B035, B049
Highest reach capacity: 98.70%		10	A193, A408, B017, B035, B049
		11	A193, A427, B017, B035, B049
		12	A193, A433, B017, B035, B049
		13	A193, A445, B017, B035, B049
		14	A193, B017, B021, B035, B049
		Highest reach capacity: 94.33%	

Table 33 - Summary of options for seeding groups to diffuse information within 2 steps

	Network A (Agriculture)		**Network T&H (Tourism and Hospitality)**	
Number of optimal actors	**Highest reach capacity**	**Number of options**	**Highest reach capacity**	**Number of options**
6	100%	40	98%	52
8	100%	99	100%	87

Appendix 12: Simulating illustration of information diffusion

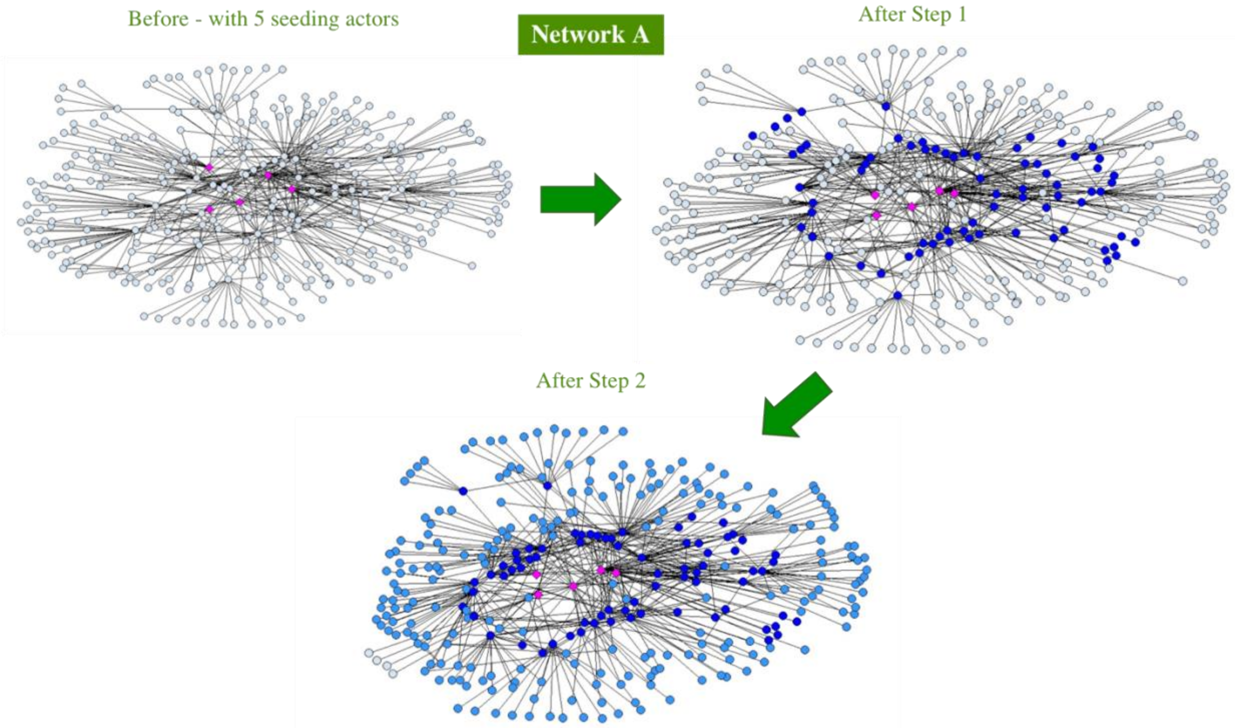


Figure 15 –Information diffusion process within two steps of one seeding group identified by KeyPlayer programme in Network A

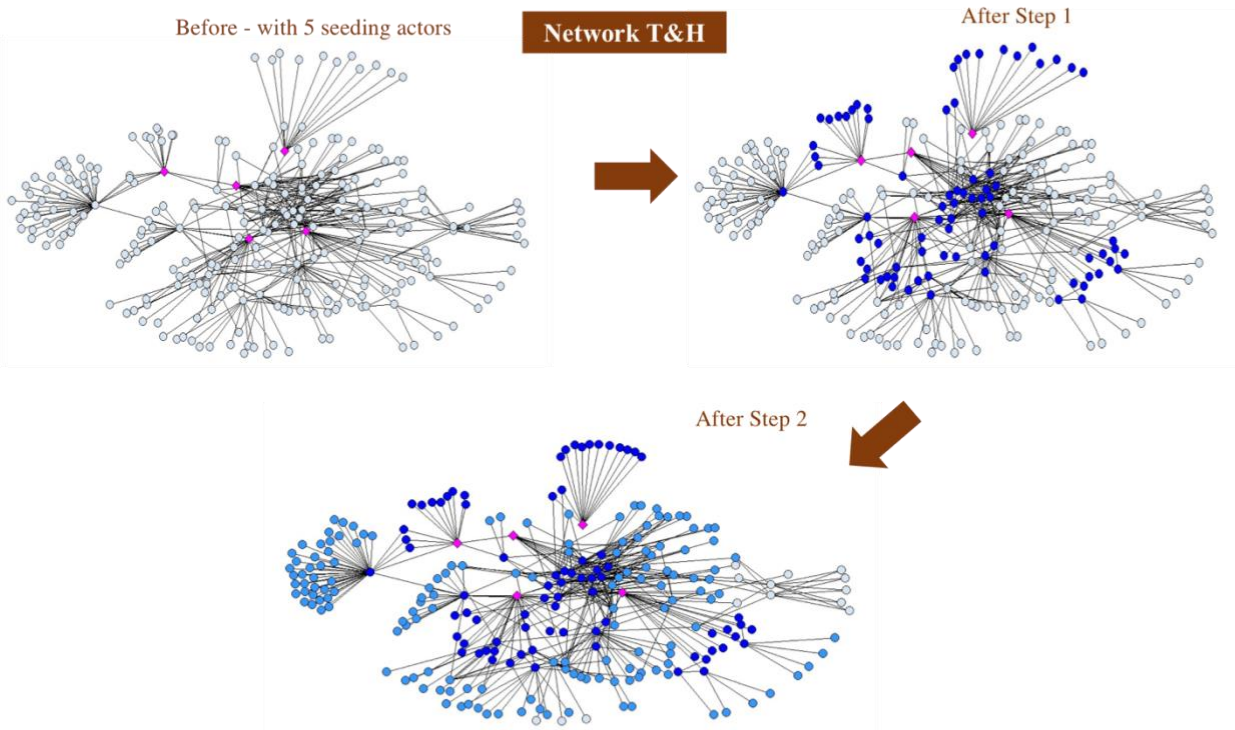


Figure 16 - Information diffusion process within two steps of one seeding group identified by KeyPlayer programme in Network T&H

Appendix 13: Simulation results of supply chain disruption run by KeyPlayer

Table 34 – Sets of most fragile spots of each network identified by KeyPlayer programme

No.	Set of the most fragile actors in	
	Network A (Agriculture)	**Network T&H (Tourism and Hospitality)**
Set 1: 8 most risky organisations		
1	B010	B017
2	B015	B019
3	B019	B021
4	B035	B025
5	B036	B032
6	B037	B035
7	B040	B036
8	B049	B049
Set 2 : 14 most risky organisations		
1	A193	B008
2	B003	B012
3	B008	B017
4	B010	B019
5	B015	B021
6	B016	B022
7	B019	B025
8	B033	B026
9	B035	B032
10	B037	B033
11	B040	B035
12	B042	B038
13	B041	B042
14	B043	B049

Appendix 14: Simulating illustration of SC disruptions

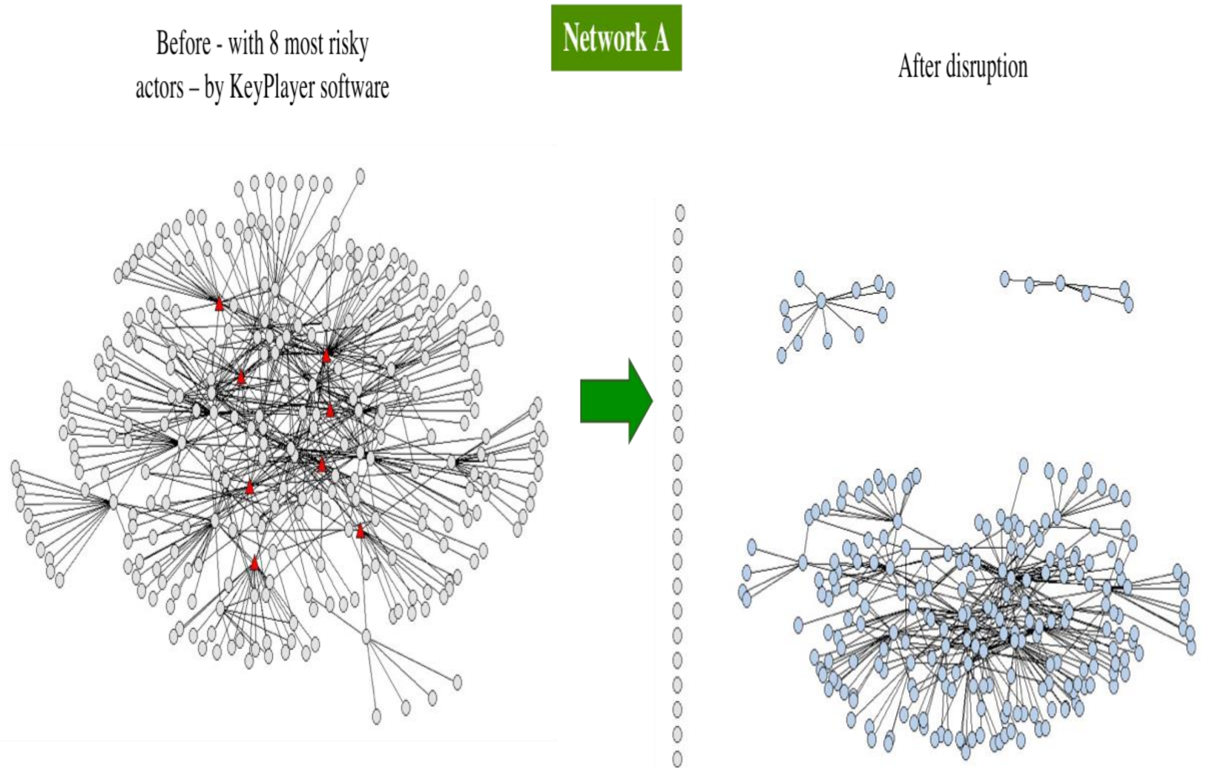


Figure 17 – Network changes if removing 8 most risky nodes identified by KeyPlayer programme in Network A

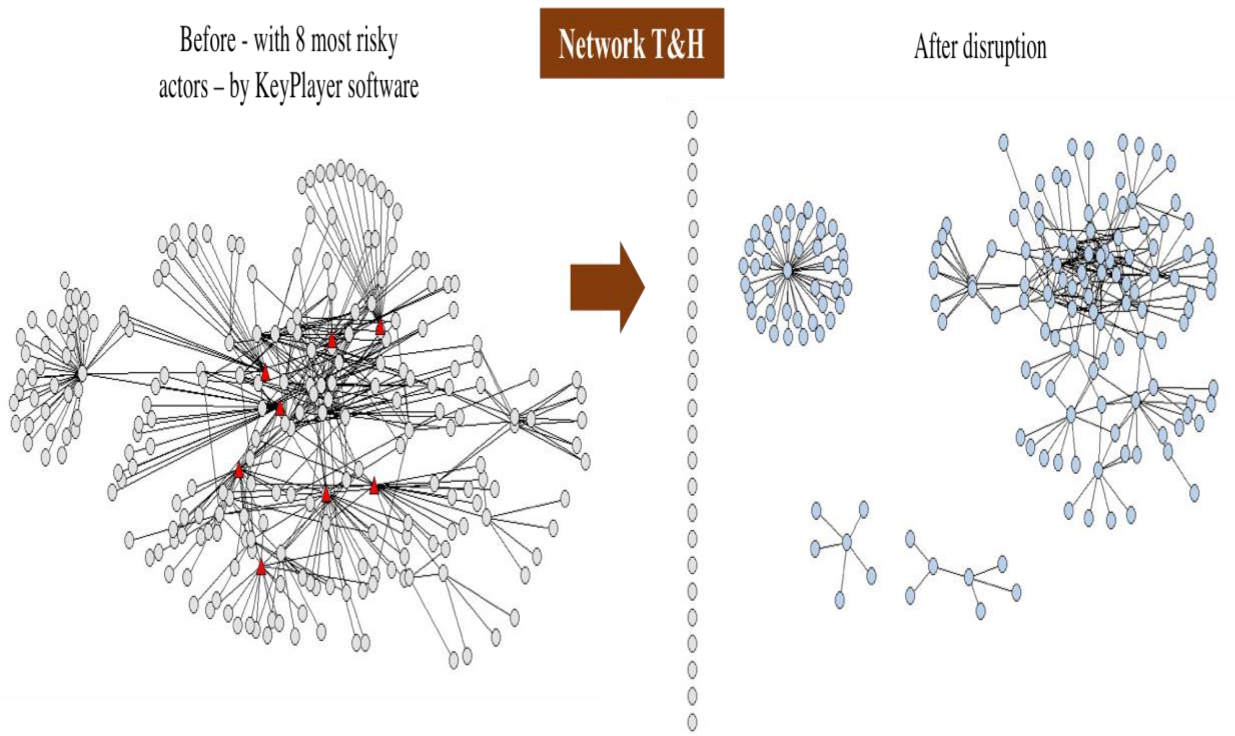


Figure 18 - Network changes if removing 8 most risky nodes identified by KeyPlayer programme in Network T&H