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A supply network governance framework: a case study of the South Australian mining industry

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A SUPPLY NETWORK GOVERNANCE FRAMEWORK: A CASE STUDY OF THE SOUTH AUSTRALIAN MINING INDUSTRY

The competitiveness of mining regions largely depends on the performance of the regional supply chains that provide services to mining companies. These local supply chains are often highly intertwined and represent a regional supply network for the industry. Individual companies often use supply chain strategies that are sub-optimal to overall supply network performance. To effectively respond to an uncertain business environment, policy makers and supply chain participants would benefit by a governance framework that would allow to incentivise the formation of supply networks structures enabling effective operations. This paper offers an empirically grounded conceptual framework based on CAS governance principles, which links network governance mechanisms with supply network structure and operational performance to incentivise the formation of adaptive and resilient supply networks in the mining industry.

A mixed method research design and a case study of the South Australian mining sector was used to collect empirical data. Qualitative interviews and network analysis of the SA mining industry regional supply network structure was conducted. The relationships between network parameters were interpreted using CAS theory.

An empirically grounded conceptual framework based on CAS governance principles is developed. The case study revealed that supply chain strategies and governance mechanisms in the SA mining industry have led to the formation of a hierarchical, scale-free structure with low horizontal connectivity which limits the adaptability, responsiveness and resilience of the regional supply network.

The conceptual nature of the proposed framework is one of the acknowledged limitations.

The proposed conceptual framework is an attempt to parameterise the governance of the regional supply networks in the mining industry.

Keywords. Complex Adaptive Systems, CAS, network-centric governance, regional supply networks, supply chain governance, mining industry

1. Introduction

Complex Adaptive Systems (CAS) and complex networks paradigms have gained traction in supply chain management research as useful lenses to address the increasing structural and behavioral complexity and interconnectivity of supply networks (Hollstein, Matiaske, Schnapp, & Schnegg, 2017; Surya D. Pathak, Dilts, & Mahadevan, 2009; Provan & Kenis, 2008). Traditional supply chain management offers engineering and operations management approaches by addressing technical and logistical aspects, while practitioners make their decisions based on hierarchical and linear models of the industrial supply chains (e.g.Nair, Narasimhan, & Choi, 2009; S.D. Pathak, Day, Nair, Sawaya, & Kristal, 2007).

Mining sector and associated supply chains recently have experienced the need for new approaches to deal with the increasing dynamism and complexity (e.g.Figueiredo & Piana, 2016; Knobblock, 2013). Outsourcing of non-core capabilities by mining companies and economy servitisation has significantly increased the interconnectedness and complexity of mining supply chains with more decentralised and flexible structures (Dachs et al., 2014; Scott-kemmis, 2012; Warrian & Mulhern, 2009).

In this paper, an empirically grounded conceptual framework, linking network governance with the emergent structure and operational performance of the regional supply network, is proposed drawing for the case study from the South Australian mining industry supply chains. The framework is based on theoretical assumptions of Complex Adaptive Systems (CAS) and supply network theories to explain how supply network governance leads to emergence of supply network with a particular structure and operational characteristics. Thematic analysis of qualitative interviews with companies and network analysis of their supply chain relationships in the South Australian mining industry were conducted to develop the framework.

The empirical evidence from the case of the SA mining industry demonstrates how supply network structure emerges as a result of the economic interactions of companies and is shaped by formal and informal network governance mechanisms operating in the industry. This structure impacts the operational characteristics of the regional supply network – responsiveness, adaptability and resilience.

The proposed framework offers implications for policy makers and industry practitioners, allowing for better allocation of resources and avoiding sub-optimal decisions in supply chain management. For industry practitioners, the model highlights the need for network centric strategies to be incorporated into supply chain management strategies as opposed to more traditional linear or hierarchical supply chain models. For policy makers, the model highlights the need to incorporate CAS governance principles in developing policies, incentives and coordination mechanisms, enabling formation of interconnected adaptive and flexible regional supply networks. The holonic enterprise model, as one of the possible CA governance approaches, is offered to incentivise the formation of supply networks structures enabling effective operations.

The paper is organised as follows: Section 2 provides a background examining relevant theoretical concepts used as a basis for the development of the proposed conceptual framework; Section 3 describes methodology - research design, data collection and analysis, Section 4 discusses the case study – the South Australian mining industry regional supply network in relations to the proposed framework; and Section 5 concludes the paper.

2. Background

2.1Supply neworks: the current state of knowledge

Increasing product and service complexity, e-business, outsourcing, and globalisation forced scholars and practitioners to adopt a broader view and shift the paradigm from linear to network paradigms in supply chain research (C. Harland, Brenchley, & Walker, 2003). Supply networkis defined as: "[a network] nested within wider inter-organization[al] networks and consists of interconnected entities whose primary purpose is the procurement, use and transformation of resources to provide packages of goods and services" (C. Harland et al., 2003). Supply network structure and behaviour are largely driven by sociotechnical interations among participating firms (T. Choi, J. Dooley, & M. Rungtusanatham, 2001; Nair et al., 2009; S. D. Pathak et al., 2007)

The application network view to supply chain studies developed along three major lines: supply network structure studies, supply network behaviour and performance and supply network governance.

Supply network structure/architecture studies. Supply network structure orarchitecture research focuses mainly on supply network components and their connectivity structure,involving analysis of interactions between network actors (e.g. Borgatti & Li, 2009; Choi & Kim, 2008; Yan, Choi, & Kim, 2009). Recent supply network architecture studies review large scale complex supply networks of major companies and associated suppliers (e.g.Bellamy, Ghosh, & Hora, 2014; Kim, Choi, & Skilton, 2015; Kito, Brintrup, New, & Reed-tsochas, 2014; Luo, Baldwin, Whitney, & Magee, 2012). These studies discussrelationships between network architecture and network performance drawing from analogies of other types of real-world networks, including ecological, biological, social and technological.

In spite of the differences in industry contexts, the common structural properties of supply networks are usually identified as determinants of high efficiency, coordination, responsiveness, and adaptability of the supply network (Hearnshaw & Wilson, 2013).Empirical studies of real-world networkshighlight key universal topologies that emerge from self-organising processes, such as small-world and scale-free structures (A. L. Barabási, Albert, & Jeong, 2000; McKelvey, Lichteinstein, & Pierpaolo, 2012; Saavedra, Reed-Tsochas, & Uzzi, 2009).Thestructural properties associted with efficient real-world networks are: 1) short characteristic path length, 2) high clustering coefficient, 3) presence of a power law connectivity distribution, and 4) network modularity, or presence of communities (e.g.A.-L. Barabási & Bonabeau, 2003; Hearnshaw & Wilson, 2013; Newman, 2003). Short average path length in the supply network is a sign of responsiveness and ease of information diffusion. High density, characterised by high clustering coefficient, or the number of connected triads, is a sign of well coordinated, flexible and adaptive networks(Bellamy et al., 2014; Hearnshaw & Wilson, 2013; Thadakamalla, Raghavan, Kumara, & Albert, 2004). For example,Saavedra et al. (2009) found comparable patterns of degree distribution, nestedness and modularity in ecological and organisational networks. Bar-Yam (2007)using data on information flows related to product developmentactivities proved thatstatistical properties of complex networks structures show similar patterns with other types of real-world networks such as biological, social and technological: 1) small-world property that allows to rapidly react to changes; 2) power-law in-degree and out-degree distribution ensures resilience to random attacks; and 3) modular structure is a sign of an adaptive network. Small-world network topology is a trait of responsive, well connected and resilient network, which shorten average path length and high clustering coefficient.The high share of the largest connected component of a supply network is associated with network integration, robustness and resilience (Thadakamalla et al., 2004). Modularity or decomposability contributes to network resilience and ability to adapt to changing environment, by being able to restructure and reorganise intself in response to environmental shifts (Thadakamalla et al., 2004).

Supply network governance studies. *Network governance* is defined as "…a select, persistent, and structured set of autonomous firms (as well as nonprofit agencies) engaged in creating products or services based on implicit and open-ended contracts to adapt to environmental contingencies and to coordinate and safeguard exchanges. These contracts are socially- not legally-binding…" (C. H. Jones, William S.Borgatti, Stephen P., Jones, Hesterly, & Borgatti, 1997, p. 914). The network governance reflects interactions, coordination and hybrid types of governance, focused on self-organisation of independent actors involved in complex relations and continuing interactions of network membersKeating, Katina, & Bradley, 2015).

Formal and informal mechnisms of network-governance are identified in the literature. Formal govenance is referred to as a set of standards, processes and contracts utilised in the industry that guide firms behaviour in supply chains, while informal mechanisms involve social norms, values, culture, trust, and power (Pilbeam, Alvarez, & Wilson, 2012). Organisation science literature discusses system level informal mechanisms of network governance, referring to such drivers as trust, reputation, macro-culture, collective sanctions, and restricted access (Grandori & Soda, 1995; C. Jones, Hesterly, & Borgatti, 1997; Provan & Kenis, 2008).

Supply network governance and policy studies originated from organisational studies literature examining mechanisms operating in neworks,which allow for leveraging and improving supply network performance(Grandori & Soda, 1995; C. H. Jones, William S.Borgatti, Stephen P. et al., 1997; Provan, 1993). Network governance refers to the set of instruments that coordinate participating organizations to deliver collective outcomes and mechanisms of reaching and implementing decisions cooperatively as opposed to coordination mechanisms based on hierarchy or market regulations (Hollstein et al., 2017). Supply network governance strategy focuses on the interorganisational and relational aspects of the supply chains and also seeks improvements of the overall supply chain system rather than individual firms (C. M. Harland & Knight, 2001).

Supply network behaviour and performance studies discuss behaviour and key operational characteristics of supply networks –ability to respond effectively to changing market conditions, being reconfigurable, adaptive, and resilient (Surana, Kumara, Greaves, & Raghavan, 2005). Additional characteristics of complex networks, such as nestedness (Brintrup, Barros, & Tiwari, 2015; Kito et al., 2014), hierarchy (Luo et al., 2012), and self-organisation (Nair et al., 2009) were investigated in relation to supply chain performance characteristics. In these studies, statistical characteristics of collective behaviour of supply network agents are identified (e.g.T. Y. Choi, K. J. Dooley, & M. Rungtusanatham, 2001; Fredriksson & Wänström, 2014; Jimmy Gandhi, Gorod, & Sauser, 2012; Nair et al., 2009; S. Pathak, Dilts, & Biswas, 2007).

From methodology perspective, studies that use CAS frameworks to understand supply networks behaviour and operational characteristics mainly apply simulation and modelling techniques (e.g.Brintrup et al., 2015; Nair et al., 2009; S. D. Pathak et al., 2007) and network analysis methodologies (e.g.Bellamy et al., 2014; Kito et al., 2014; Luo et al., 2012; Saavedra et al., 2009). There are also a number of conceptual theoretical studies (e.g. T. Y. Choi et al., 2001; Surana et al., 2005).

Thus, supply network literature developed around three major themes: supply network architecture or structure, supply network policy and governance, and supply network dynamics and performance. However, there are significantly fewer studies that would investigate relationships between network structure, behaviour and governance supply network studies (e.g. Pilbeam et al., 2012). While separately these domains are well developed with extensive empirical evidence (for more details seeBellamy & Basole, 2013; Hollstein et al., 2017; Pilbeam et al., 2012), a considerably smaller number of empirical frameworks is available that would apply CAS view to examine how these parameters are related. There is also a scarcity of empirical studies that would investigate, micro-level mechanisms in supply networks in relation to macro-level architecture of supply networks (Luo et al., 2012).

Complex adaptive systems (CAS) view bridges this gap by explaining how the structure or architecture of the supply network emerges as a result of collective behaviour of individual agents and implications for the systemic properties of the supply network as a whole. CAS theory viewes supply network as a system, relating these parameters to networks emergent behaviour being a function of self-organistion of individual agents and mechnisms operation in the system.

2.2 Application of Complex Adaptive Systems view in supply network research

Supply networks, increasingly recognised to be Complex Adaptive Systems (CAS) that emerge as collective entities from exchange interactions of multiple autonomous firms engaged in economic exchange relationships, constantly co-evolve with and adapt to changing business environment.

The seminal works of T. Choi et al. (2001) and Surana et al. (2005) acknowledged the need for CAS approaches in supply chain management to enable system-level optimization. CAS view is particularly useful for explaining how simple micro-level interactions, strategies and behaviour lead to emergence of networks as collective aggregate outcomes at the macro-level

(S. D. Pathak et al., 2007). The effectiveness and efficiency of supply networks as CAS is a non-linear function of individual agents behavior, supply network topology and multiple forces acting in the system, guiding collective self-organised dynamics of firms participating in the network. Four parameters of the supply network as CAS that matter for supply network performance were suggested: organisational entities exhibiting adaptivity; a topology with interconnectivity between multiple supply chains; self-organising and emergent system performance; and an external environment that coevolves with the system(S. D. Pathak et al., 2007).

Choi et al. (2001) defined supply networks as CAS driven by internal mechanisms and co-evolving with environment. CAS agents and agency, self-organisation and emergence, dimensionality and connectivity are parts of the internal mechanism that drive the co-evolution of supply networks and environment over time.

Agency as a key characteristic of the CAS is defined as ability of agents to intervene meaningfully in the course of events (Choi et. Al., 2001). The agents are independent and autonomous and act according to *schema* – values, believes and mental models shared among supply network participants. For example, long-term relationships with suppliers is part of schema that supply chain managers follow when making decisionson puchasing (T. Choi et al., 2001). In supply network literature, *schema* can be associated with the informal network governance mechanisms – relationships based on trust and reputation, norms and values of supply network participants (Hollstein et al., 2017).

Self-organisation and emergence is another fundamental quality of CASresulting from simultaneous action of agents in the system, which produce macro-level structure and properties. Supply network structure and functional characteristics are a product of self-organisation processes. For example, winning contract with large mining operatorsand contractors in the region is highly desirable for local suppliers. Such behavior results in the emergence of ‘preferential attachment’ mechanism in the supply networkformation, when the most connected companiesbecome the most desirable partners growing the number of supply chain connections. This type of a mechanism drives formation of a scale-free network structure.

Dimensionality is a CAS property, characterised by the degrees of freedom an agent may have in the system representing formal mechanisms of network governance – standards, rules and regulations. The *fitness* of an individual company as a CAS agentis thus defined by its compliance to environment and quality standards as well as conractual regulations.

CAS functional and operational performance is influenced by the interconnectedness among CAS agents, which emerges as a result of frequent interactions among agents, guided by forces and mechanisms operating in the supply network (T. Choi et al., 2001; Nair et al., 2009; Surana et al., 2005). *Connectivity* among agents is a critical property ofsupply network, which defines its performance – adaptability, responsiveness and resilience to external shocks.

Therefore, the CAS view in supply network interrelates *supply network governance* with *structure* and *performance* through the notions of *agency and schema*, *self-organisation* and *emergence*, *connectivity*, and *dimensionality.*

Despite the well developed field of application of CAS theory in supply network context, there are multiple calls from scholars for more empirical studies with the analysis of complex supply network structures from various industries (e.g.Bezuidenhout, Bodhanya, Sanjika, Sibomana, & Boote, 2012; Brintrup et al., 2015), testing CAS principles of supply network governance to be investigated in various industry contexts (e.g.Nair et al., 2009; Surana et al., 2005), and developing methods that involve visualisation and analysis complex real-world supply networks to inform decision-making given the increasing amount of data (e.g.Bellamy & Basole, 2013; Galaskiewicz, 2011).

This paper attempts to address calls from previous researchers for empirical evidence of CAS principles applied to real world supply networks by proposing anempirically grounded conceptual framework which uses CAS view to explain the relationships and interplay among supply network parameters – supply network governance with emergent supply network structure and performance. The proposed framework draws on the case of the South Australian mining industry to explain how regional supply network structure emerges as a result of self-organisationprocesses,which has implications for network performance.

3. Methodology and methods

3.1 Research design

The research design, including theoretical and practical approaches data to collection and analysis, was dictated by the need: (a) to develop a conceptual framework by exploring the case of SA mining industry supply networks governance, supply network structure and performance and (b) to draw theoretical inference and implications for policy and practice.

As a research philosophy, pragmatism was adopted in this study, giving freedom to researcher to select the most appropriate ontology, epistemology and methodology for a case. Pragmatic research philosophy, which is suitable for investigation of a phenomenon in a natural context with the partnership between researcher and practitioners, guided this research (Bryman & Braun, 2012). The conceptual framework developed as a result aimed at assisting practitioners and policy makers in devising better strategies to enhance regional supply network performance.

The exploratory case study research design was adopted since the topic is highly complex and the boundaries between phenomenon and environment are unclear (Yin, 2012). Furthermore, this research focuses on why the phenomenon emerges, which is also addressed by the case study approach. These arguments led to the selection of an exploratory qualitative case study design, allowing for "…finding out 'what is happening; to seek new insights; to ask questions and to assess phenomena in a new light'… (Robson 2002:59).

The case of South Australian resource sector has been selected for a number of reasons. Firstly, mining industry and related services sector make a significant contribution to exports and the gross state product in South Australia, with the largest open-pit mine Olympic Dam operated by PHB Billiton, one of the leading world operators. South Australian economy is significantly affected by large-scale mining projects, being the key source of market demand for local technology and services suppliers. The mining services supply sector is ranked 17th based on its contribution to South Australia's Gross State Product and 19th in terms of taxes (Department of State Development, 2015). Secondly, the development of efficient and competitive local supply chains in the mining sector is one of the top priorities for the South Australian government. Mining equipment and technology services sector presently contributes $2.4 billion to the Gross State Product of South Australia. It further employs 17,830 full-time employees (FTE). Finally, this case is unique due to the current restructuring of regional supply chains, which is taking place in the mining sector as a result of the worldwide downturn in commodity prices.

Mixed methods research design was adopted, including quantitative analysis of the regional supply network structure as well as qualitative analysis of the interviews and secondary sources to get insights into network governance mechanisms and network performance. The research design ensured methodological triangulation and source triangulation. Analyst triangulation was ensured by engaging two researches in the interpretation of findings (Saunders, 2011).

3.2 Data collection

The data collection took place from November 2015 till August 2016, including qualitative interviews and mapping supply chain connections in the regional supply network of SA, complemented by secondary data collection (see Figure 1). The study was conducted in collaboration with the mining industry associations as well as assisted by researchers in getting access to multiple secondary sources, including industry and government reports and Industry Capability Network (ICN)[1] industry database.

<<Insert Figure 1 about here>>

Selecting interview participants. Thirty-eight semi-structured in-depth interviews were conducted with supply chain managers and top-level managers of mining operators, regional service suppliers of various tiers in the mining supply chain and industry associations, seeking insights into network governance mechanisms and network performance in the South Australian mining sector. Exploratory and open-ended nature of the research enquiry required participant selection based on snowball sampling. The major criteria for selecting interview participants were: (a) the company should be located in South Australia, (b) the company's major source of income should come from the mining sector. In addition, industry associations and industry consultants were interviewed and provided expert-checking of the interview data summary. The cases of supplier companies were diverse in terms of size, capability base and years of operation in the SA mining sector supply chains. The list of interviewed companies and organisations presented in Table 1.<<Insert Table 1 about here>>

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Qualitative data collection. Interviews were digitally recorded and transcribed using a third party organisation. The respondents were informed that their participation was voluntary and their responses would be recorded. The first interviews were open ended with the intention to better understand the operations in mining industry supply chains in South Australia as well

[1] Industry Capability Network (ICN) is an independent organisation financially supported by Australian, New Zealand, state and territory governments. ICN database contains information about 70,000 companies supplying services across Australia and their supply chain connections. https://gateway.icn.org.au/

as challenges and opportunities faced by the company during current downturn in commodity prices. The particular emphasis was made on the nature of companies ‘relationships with customers, suppliers and other organizations, certification and compliance to industry standards, and companies’ strategies to sustain and grow business in the SA mining sector. The mining companies, EPCM providers and industry association leaders were asked to give a ‘big picture’ insight into processes and operational characteristics of the SA mining industry supply chains. In addition, mining companies and EPCM providers were asked about their supply chain strategies, particularly their engagement of local suppliers. Despite diversity of backgrounds of the interview participants, the interviews allowed to reach data saturation.

3.3 Data analysis

Qualitative data analysis. Qualitative interview findings were interpreted through the CAS theoretical lens, with the particular attention to CAS agents and agency, schema, dimensionality, and self-organisation and emergence. These mechanisms were discussed in relation to supply network governance, network structure and performance. Thematic analysis and coding was then undertaken assisted with NVIVO 11 software. *A priory* themes included CAS agency (companies’ strategies and behaviour), CAS schema (informal network governance), CAS dimensionality (formal network governance), CAS self-organisation and emergence (mechanisms leading to emergence of particular supply network structures (small world, scale-free, modularity, core-periphery) and CAS performance (supply network responsiveness, adaptability and resilience). Multiple secondary sources such as industry, government and consultancy reports were used in analysis to supplement and triangulate interview data.

Network Analysis was conducted to reconstruct and identify structural patterns in the SA mining industry supply network. The ICN database was used to identify SA firms supplying services to mining industry and operating in South Australia. The criteria applied to mining services suppliers selection were: (a) the company should be located in South Australia, (b) the company indicated mining sector as a major source of income. The information about companies’ names, capabilities and major clients was extracted. The clients were represented by mining, oil and gas and processing companies, Tier 1 suppliers to mining companies – original equipment manufacturers (OEMs) and Engineering, Procurement and Construction Management (EPCM) providers, Tier 2 suppliers to mining companies, supplying to Tier 1, and Tier 3 - suppliers to mining companies, supplying to Tier 2.

To reconstruct the structure of SA mining industry supply network, an adjacency matrix was created based on individual supplier-customer relationships. The adjacency matrix was imported into UCINET 6 software to calculate centrality measures and analyse supply network structure. The Polinode web-service[2] was used to visualize the regional supply network structure. The resulting dataset consisted of 2,455 firms, with 489 clients and 1,966 supplier companies with a total of 6,683 connections. Structural characteristics of the regional network – average degree, network density, average path length, clustering coefficient, and largest connected component were measured.

4. Results and discussion

4.1 The empirically grounded conceptual framework based on CAS principles

As a result of application of CAS principles to gain a broader understanding of supply networks based on empirical case study of the South Australian mining industry supply networks,the proposed conceptual framework was developed (see Figure 2). The conceptual framework recognizes regional mining industry supply network as a CAS. Mining companies, EPCM providers, and local technology and services suppliers represent *CAS agents* connected through supplier-customer relationships operating in South Australian mining region.

The conceptual framework interrelates supply network governance mechanisms with suply network structure and functional characteristics - by means of CAS mechanisms – agency, schema, dimensionality, connectivity, emergence and self-organisation.

<<Insert Figure 2 about here>>

4.2 CAS dimensionality - formal network governance mechanisms: standards, contracts and network organizations

Formal network governance mechanisms define dimensionality of CAS agents as ‘degrees of freedom’ that suppliers have in the regional supply network. These include conventional organization of the mining industry supply chains based on tiered procurement, industry standards and the system of taxes and regulations imposing constraints on agents.

[2]https://www.polinode.com/

Typical organisation of the mining industry supply chain

A typical mining company establishes supply chains to procure the major stages of a mining project: exploration, project management, construction, operation, and rehabilitation. Mining project requires inputs from a diverse range of industries from specialised services, such as drilling and blasting to more general, including design, engineering and IT. These companies are broadly defined as Mining Equipment and Technology Services. The top ten services in the present profile of SA mining services suppliers include: EPCM / EPC/ Engineering mining related services (geological, construction, engineering, electrical, etc.), consultancy, research and technology development, manufacturing of equipment, consumables, human resources management and education, training provider, dealer/distributor or re-seller of equipment and parts, information and communications technology and services, transport, logistics and infrastructure, and other professional services, such as legal and accounting (Austmine, 2015).

Consequently, regional supply network forms around resource-extractive activity in proximity to mining sites supporting mining operations. A typical mining industry supply chain is hierarchically organized according to the 'tiered procurement' strategy (see Figure 3).

<<Insert Figure 3 about here>>

Tier 1 subcontractors receive opportunities directly from resource companies. These companies are mainly represented by major internationally operating engineering procurement and construction management companies (EPCMs), and more rarely by large original equipment manufacturers (OEMs). The interviewed representatives of mining companies comment:

...Typically, they'll [mining companies] outsource the risk of construction to a bigger specialist player. That might be EPC, or that might just be a contractor. They go to Theiss "Build me a mine." If they're bigger then they go to Bechtel and Fluor, or someone to do the construction as well as the program management...

...When you contract with these guys [EPCM providers], you have to pass to them a lot of risk, and they will manage this risk though their own workforce because they have more control over quality, output...

Tier 2 subcontractors to a mining project receive opportunities from Tier 1. Tier 2 suppliers are mainly represented by the companies subcontracted by EPCMs to undertake specific aspects of design, management or installation of a mining project, including engineering design, civil construction, electrical engineering, water or tailings management, and environmental. The interviewee from an electrical company explains supply chain organization in the mining sector:

…That builder, or the EPCM contractor, will manage or break up the project into smaller packages, and manage those smaller packages. We in the electrical business rarely get to be at that higher level, because we're just one part of the services that are provided…

Tier 2 suppliers can be OEMs, or component manufacturers servicing OEMs with particular types of equipment or processes, representing a wide spectrum of standard and specialised component manufacturers. Tier 3 suppliers receive opportunities from Tier 1 and Tier 2 subcontractors, supplying large work packages in key areas or specialist providers of technology, equipment or services. They have experience in working on major projects and have the capacity to bid for major projects. Tier 4 suppliers receive opportunities from Tier 2 and Tier 3. They are usually suppliers of niche products, lacking the systems and project management capabilities of higher tiers. A supply chain consultant working with mining operators in SA said that lower tier suppliers cannot get direct contracts with mining companies due to lack of capabilities and experience of working with large-scale projects:

…They [mining operators] can go to these other smaller companies, but there's a fair bit of risk going with those smaller suppliers in their capability of delivery…

Industry standards. Mining equipment and technology services suppliers must comply with the industry standards, including quality management and occupational health and safety regulations. To be able to tender for a project, suppliers must pass pre-qualification process. An interviewee from an EPCM provider company explains that supplier pre-qualification is a part of quality and occupational health and safety systems:

…We have a quality system and a health and safety system, which means that we have to pre-qualify contractors that we deal with. We have to understand this in our chain as well. Part of the pre-qualification is understanding, who's going to do the work. That's part of our health and safety and QA system…

This is often a barrier for many SA METS providers seeking to get work in the mining sector, since certification process is time consuming and requires significant investments. However, the typical statements from the EPCM providers regarding certification of local service providers were:

…Didn't have the systems and understanding in place, so they were unable to deliver good product consistently and they failed to deal with varied requirements – they were good in delivering standard service but could not deal with slight variation, they fell apart.

…They did not know how to price, how to deliver it as it is slightly different sub-contracting outside their core team – they struggled with quality control…

Often local suppliers sub-contract to another certified company with accredited quality management and health and safety systems, which takes risks for the mining project execution. A medium size electrical company provider acknowledges that being a sub-contractor to an EPCM provider, since project and risk are managed by higher tier contractor and the company only have to deliver service:

...That builder, or the EPCM contractor, will manage or break up the project into smaller packages, and manage those smaller packages. We in the electrical business rarely get to be at that higher level, because we're just one part of the services that are provided…

They're [EPCM contractors] very much in the spotlight and there's less to manage. If you're doing lots and lots of smaller projects, and dealing with lots and lots of builders and customers, yeah you don't have to take your eye off it too long, something can happen..."

Complicated industry specifications are another major barrier for service providers to enter and sustain business in the industry. The detailed and prescriptive nature of mining project specifications is challenging to comprehend and comply, leaving almost no room for innovative solutions. An interviewee from a small size innovative company providing automation solutions across a range of industries in SA, interstate and overseas mentions that his company find it hard to tender for projects in the mining sector due to cumbersome documentation and prescriptive specifications:

…Because when you're first trying to first tender to a company like BHP, to get your head around 2,000 pages of specifications and all the little traps that you couldn't caught out by, having missed some small aspect of their specification. It doesn't mean that the system doesn't work, it just means that it's not exactly the same as what they asked for. They might then make you go and spend a lot of money to rectify it. It is a little bit of a barrier to entry, I suppose...

Regulations and taxes

Royalties and other taxes push mining companies to reduce costs, which impacts procurement arrangements and decision-making. Interviewees from several local supplier firms consider South Australia a somewhat overregulated and high cost environment:

"…The challenge for South Australia now is quite significant. We are a high cost state, where government burden is considerable…"

"…South Australia would be the most over-governed state… It hits business everywhere. In time, in delays…"

To summarise, supply network formal governance mechanisms in the SA mining industry, that is CAS dimensionality define the rules the regional suppliers must follow to build and maintain connections in the regional supply network. These are hierarchical tiered structure of the mining supply chain, industry standards and specifications, government regulation, and taxes.

4.3 CAS schema – informal mechanisms of network governance

CAS schema is represented by informal governance mechanisms- shared values, norms and culture in the regional supply network.

Shared norms and values

Regional suppliers operate and build their client base by understanding customer values, organisational culture and problems. Regional suppliers acknowledge the role of sharing values and culture with the client organisations:

"… I just like to know about the company's philosophies, values, the internal culture, if you like, of an organization…"

Regional supplier say that on-going relationships and long-term engagement with the customer is key for maintaining work in the mining sector:

"…I would say, probably about 80% of our business is repeat business, from existing clients, so we do tend to build those longer-term relationships…"

"…It's all about long term customers. There's nothing short term outlook in what we do…"

The need for flexibility and responsiveness to the customer needs make social aspect of supplier-buyer relationships important. Although relationships are based on commercial transactions they are sustained through social relationships between individuals. Long-term view ensures that personal links formed through supply chain relationships between companies are maintained for long time after people leave. Thus, informal social networks are formed, which underpin connectivity of the regional supply network. The general manager of the small-size SA branch of a multinational company supplying filtration solutions operating in SA for more than 40 years and business development manager from medium size environmental services acknowledge the role of social networks in building supply chain connections:

"…It just makes it very tedious that you've got maybe seven, eight, nine years of history with one person so you understand their site, you understand, you've worked with each other for a long time so you know how each other thinks…"

"…Some of those customers leave. They may have been retired, or they'll apply for another job to another company, and then they'll ring me and say, "Hey, Pete. Come over, I'm working for …" wherever…"

Trust and reputation

Trust and reputation in the SA resource sector are major relational assets. Even being formally compliant with the industry standards, local firms should be known as trusted providers and have referrals to get work in the mining sector. All the interview participants acknowledged the role of trust in building supply chain connections and getting new clients:

"…Executing them [projects] well and then building up that relationship. I think industry is still very relationship-based…"

Newcomer firms interested in entering the industry find it hard to 'get foot in the door', without being known as reputable suppliers. Interviewed companies highlighted particular importance of social networks in South Australia. Social bonds between people created over a lifetime are tightly intertwined with industrial connections, therefore confirming the interpenetration of boundaries of professional, social and supply networks. The principle "who you know" in the industry has been highlighted by several respondents. The comments from small size health and safety education and medium size electrical service providers are presented below:

"… Adelaide is a network city. Sydney is different. Sydney let's get on with the business, not so worried about the relationship…"

"… Unfortunately, it's a bit like this that you got a relationship with somebody then you're more than likely to get the work than somebody else who sees it. They might still go out to tender. If you got the relationship then the chances of getting the job are very high. So in terms of … its just a fact of life. It's who you know…"

Local business ownersare concerned about building their personal brand and reputation to maintain work continuity and get referrals. Doing favors for customers is part of relationship and trust building through providing expertise and advice to customer's problem. The companies build reputation by working on previous projects, maintaining relationships with the main customers and developing a basis for referrals. An interviewee from the successful engineering and project management local company, which see the downturn more as opportunity that threat, highlights the role of trust and reputation built through 'looking after customers'.

…I take a lot of pride looking after my customers, I do. Because they will then trust me later on when they do need something from our company…You've got your range of previous contacts you've worked with over the years. It certainly puts you in good stead. You've either got a solid reputation or you've got a bad reputation…

Collaboration and information sharing

Low level of collaboration among local suppliers was evident from the interviews, which impedes formation of horizontal supply chain linkages in the regional supply network. Local companies are guarded about building alliances and partnerships since they struggle to establish clear legal frameworks for sharing work and associated risks and profit as well as are concerned with technology being copied by former partners, preferring sub-contractual relationships. Most of the interviewed local companies say they are not interested entering collaborative relationships with their supply chain partners:

"…Yeah, you're paying them for a service [sub-contracting]. It lessens the risk, but also it's more money that's going out of your business. You could be losing out any profit out of that area [joint-ventures, alliances, partnerships]. You lose control over the section of work to a degree…"

"…It's really just very close working relationships. We don't try to have cross ownership or anything like that. We have looked at quite closely, but it's not a particularly beneficial relationship for any of us…"

"... You do two, three projects with them. They think, we can do that, so they'll buy the plant and equipment and all of a sudden, you're not doing that work anymore. They're self-performing..."

Local suppliers also report opportunistic behavior in the industry. Some companies collect market information and ask for solutions from METS suppliers. Suppliers become more guarded about the information they provide to clients. The comments on the lack of trust, which precludes suppliers from entering collaborative relationships, are made by the representatives of the engineering and software development companies:

... You don't want to give away too much, because the customer could use that and give the information to the competitor... but sometimes on a tender this could be the difference. You gotta disclose if it's a real innovation that's gonna save money... I would think you would disclose it if it was a good idea. You know that you run the risk of them using that information and sharing it with others…

"…A lot of people do come to us and sometimes we'll embrace it fully, other times we'll think, get part way through and say this is a waste of time. All their doing is picking our brains and then just going go out to the cheapest price, or whatever. We've become very guarded…"

4.4 CAS agency–companies strategies and behaviour

Agency. Procurement strategies of mining companies and Tier 1 EPCM providers as well as business strategies of local suppliers define probability of formation or dissolution of supply chain connections.

At this time, due to downturn in the mining commodity prices, mining companies optimize their supply chains and search for cost effective innovative solutions. This has led to increased competition of local suppliers with overseas and interstate companies. The supply chain consultant company working with the major operators in SA comments that lower suppliers struggle to sustain their business:

"…Basically what happens is the lower [down the supply chain] you get, the harder it is, it's a sad situation for this country, because then the local guys don't have that work data. What they are getting is they're getting the crumbs and virtually no income. They're virtually working for wages…"

A small size forth tier civil contractor expressed his concerns associated with increased amount of contracts being awarded by local mining operators to interstate competitors:

"…People have their clients that they break into the market, break into that section. Especially up around the [processing plant] with us on a couple of jobs up there that we tendered for. They were happy for us to tender. But they were sort of running the job anyhow, so it was, I think, difficult for us to get in on there..."

"…with regards to the job at [mining site], [Tier 2 contractor] got the job. However, they outsourced their concrete works to a Melbourne company…."

Mining companies and Tier1 EPCM providers establish lists of preferred suppliers, with whom they work on a regular basis. This does not contribute to flexibility and adaptability of the regional supply networks. Furthermore, many tier one suppliers working directly with the mining companies do not work with the local suppliers. Such strategies reduce connectivity of the regional supply network. For example, an interviewee from a tier one pipe and fitting supplier explains that the company operates through the Approved Manufacturer List, which contains only suppliers from overseas.

"…We have an AML, which is an Approved Manufacturers List. So this business does not buy from anyone who is not on that list… All of these suppliers have been audited and approved by this business… So we buy products from China, Europe, India, all over the place. Thailand. We don't buy anything local, no…"

However, the majority of Tier 1 service consider local suppliers for inclusion into the preferred suppliers' lists. The interviewee from an EPCM company explains how the company builds the list of service providers through networking and operating in the industry.

"…As we network and connect with good providers, we add them to our database. Through industry associations, connections, working on projects. Often will be working within a company like BHP, and all of our competitors. All of our competitors are working on other projects there and other providers that we would want to work with are also there as well. Just from operating in industry…"

At the same time, as a result of the downturn in mining sector, several Tier 1 service providers exited the industry, which increased opportunities for local firms to offer cheaper solutions. An interviewee from a local medium size engineering and project management company has a positive outlook in relation to downturn, commenting on increased amount of work and ability to move up in the supply chain becoming direct Tier 1 service provider to mining companies:

"…That's why at mining companies now, that's why we really fit in to what's going on, because even in the past, the tier 1s are very expensive as you know… Now the people that are sick of paying big dollars… all the sudden they're all dropping off and we get busier and busier…"

Regional suppliers holding a competitive position in the industry define their '*fitness*' – propensity to form and maintain linkages in the regional resource supply network. Strategic focus of the mining services supplier determines positioning of the company in the tier structure of the regional supply chain, number and diversity of supply chain connections.

Local suppliers comment on various strategies they adopted to sustain business through the downturn, including development of innovative solutions and new services:

"…Where we think if we could come up with a good solution for that problem there's likely to be a market there…"

"…Because we service a lot of different customers and a lot of different industry sectors we get exposed to a lot of different opportunities as well. We like to think that we're a fairly dynamic organization, and we're always looking to try to differentiate ourselves in doing things innovatively…"

Suppliers expand customer base by organizing educational sessions for customers and joining industry associations. Successful small-size regional drilling company and filtering solutions provider comment on finding new ways to promote their businesses, through industry associations and potential supply chain partners, through running information and training sessions with the potential clients:

"…Making contact with geologists and managers directly to promote ourselves. Join appropriate bodies in the sector to learn and to promote business…"

"…We've had to diversify our own operational and our profile footprint to the market, by doing things such as client sessions, luncheons, breakfasts, educational type things. Not a "salesy thing", but just educating the market…"

Many large size local suppliers acknowledged the need to develop capabilities to be able to move up in the mining industry supply chain's tiered procurement structure. The engineering and project management company representative says:

"…Well I think that always been the aim - the higher up the food chain you can get, the more control you've got over your projects and obviously you're dealing directly with the client, rather through a second, or third party…"

Accordingly, as informal network governance mechanisms, agency and schema also shape self-organisation processes. In addition, companies' strategies and probability of formation of new ties in the regional supply network influence its structural characteristics.

4.5Analysis of supply network structure in relation to performance characteristics

Regional supply network emerges as a result of supply chain connections among individual firms operating in the South Australian mining sector. The analysis of the SA mining industry supply network was performed to assess overall interconnectivity and identify structural patterns of self-organisation, having implication for network performance Figure 4).

<<Insert Figure 4 about here>>

Network parameters presented in Table 2 were compared with the Toyota supply network, which is considered to have excellent operational characteristics – responsiveness, adaptability and resilience (Kito et al., 2014).

<<Insert Table 2 about here>>

Scale-free and small-world structures

The network was analysed for presence of commonly discovered structural patterns of self-organisation using established methods for complex networks analysis[3].The analysis revealed that SA regional supply network exhibits a scale-free structure with several highly connected ‘hubs’- key clients in the SA mining region. The BHP Billiton was the largest hub with 342 regional connections, and six additional highly-interconnected hubs with more than 100supply chain connections were represented by two major mining operators, including an oil & gas operator and two EPCM providers (in Figure 4, the larger size nodes are those with a greater number of connections). Node average degree in the network is 5.380.

Such a structure has an impact on networks’ functional characteristics. According to previous studies (Hearnshaw & Wilson, 2013; Thadakamalla et al., 2004), scale-free networks are resilient to random attacks with minimal cascading risk effect. This means that exit of

[3]The procedures of identification scale-free and small-world structure are explained in detail in (Statsenko, Ireland, & Gorod, 2016)

random customer companies in the region will not significantly impact the whole supply chain network unless one or more hubs are affected, which has been confirmed by the interviews about the current situation in the SA mining industry. Despite many mining operations stopped in the region and followed by exit of several EPCM providers, the regional supply network keeps functioning.

Distinctive core and periphery confirm the presence of a hierarchical structure. Dominance of international corporations at the higher tiers of the mining supply chain and high barriers to entry in the mining supply chains make it difficult for those in the periphery to form new supply chain connections.

Network density – connectivity.The SA resource supply network density is 0.001084, which is comparable to the density of Toyota supply network (0.00115), identified by Kito et al. (2014). *Clustering coefficient* in the SA supply network is 0.028 and almost twice lower than in Toyota supply network - 0.0647.The average path length is 4.11 (this is about twice the number if comparing with the Toyota supply network - 2.28). This indicates that any firm in the network can reach another one within four steps. This does not allow to infer efficient information flows and overall coordination of the regional supply network.

Average path length and clustering coefficient do not permit asserting the presence of a ‘small-world’ structure in the regional supply networks. In the supply chain context, a ‘small-world’ structure is a sign of responsive and agile supply chains, even though supply chain managers may only know their immediate Tier 1 partner. A small world property is a sign of efficient, responsive and resilient network, as it has been identified in Toyota supply network (Kito et al., 2014). On the other hand, SA mining industry supply network has a hierarchical structure with low horizontal connectivity. This is supported by the interview data – companies report low horizontal collaboration and reluctance to entering supply chain partnerships and alliances. The SA resource sector’s regional supply network has yet to improve its cohesiveness and interconnectivity.

The largest connected component in the network unites 99.5% companies, which can be interpreted as all firms operating in the SA resource sector are indirectly connected through supplier-buyer relationships. Seventeen sub-networks clustered around hub companies were identified. The two largest sub-networks of regional METS suppliers, surrounding mining hub BHP Billiton as well as of Santos and Rio Tinto, are exhibited Figure 5a and Figure 5b.

<<Insert Figure 5 about here>>

Fifteen peripheral segments loosely connected with the network core were identified. Densely connected sub-networks may represent 'clusters' or "cohesive subgroups" – a particular business group of companies, sharing similar informal mechanisms of network governance: macroculture, norms and values (Uzzi, 1996). Presence of embedded communities or sub-networks are signs of cohesive and resilient networks as claimed by scholars (Hearnshaw & Wilson, 2013; Saavedra et al., 2009; Thadakamalla et al., 2004). According to Thadakamalla et al. (2004), modularity and presence of sub-networks is seen as a sign of network resilience and ability to adapt to changing environment by being able to restructure and reorganise itself in response to environmental shifts.

The case of the SA mining industry supply network revealed that governance mechanisms currently operating in the industry impede formation of flexible and adaptive regional supply network structures. Industry pre-qualification standards and prescriptive nature of project packages act as constraining factors for local suppliers to enter and sustain business in mining supply chains. The industry supply network is dominated by large operators and first tier companies performing role of hubs in the region with a distinctive core-periphery structure. This shows a connectivity gap between local lower tier suppliers and companies representing the core of the regional supply network. Low horizontal connectivity among peripheral low tier suppliers as a result of low trust and collaboration led to emergence of hierarchical, scale-free regional supply network topology. While mining industry leaders and SA government have a vision for improving performance of local industry supply chains, there is a need for involvement of mining companies and coordinated effort to develop working strategies in the sector. Furthermore, it is clearly time for a paradigm shift among supply chain practitioners and business owners to leverage change in traditionally formed supply chain management practices.

One of the possible CAS governance approaches could be applied to facilitate transition from hierarchical to net-centric organisation based on open systems standards (Keating, Katina, & Bradley, 2015). The holonic enterprise model is a useful paradigm to guided restructuring of the regional supply chains towards more flexible and adaptive structures with high degree of self-organisation(Ulieru, Brennan, & Walker, 2002). The holonic enterprise model uses principles of distributed enterprise system architecture, viewing supply chain agents as holons. The notion of holons was introduced by Smuts (1926) and later further developed by Koestler (1964). Holons are referred to as identifiable parts of a CAS, having a unique identity and being made up of subordinate parts that can act as an independent whole, where parts cooperateto achieve the objective of the holarchy. The principles of governance of the multi-layered holonic structure include a shift '…from the closed system philosophy of the traditional supply chain management to the open system philosophy governing a collaborative cluster of partners devoted to the same goal…" (Ulieru et al., 2002, p. 549).

The suppliers and mining companies could be seen as holons at the lower level of a greater holarchy. The communities or sub-networks formed around client companies and their shared suppliers can be governed as holons at the medium level of holarchy. Finally, the entire SA mining supply network can be perceived as a holon at the highest level(Ulieru et al., 2002). At the company level, this require development and implementation of relevant systems and at the network level, coordinating bodies have to develop integrated standards to orchestrate cooperation of suppliers at all levels of holarchy. The strategy of implementing the open-systems approach to the resource regional supply networks should involve: 1) identification of stakeholders and their role in the system (network administrative organisations that could be regional industry hubs, industry associations and policy makers); 2) development of open-system standards, including communication strategies and interfaces, templates, ICT platforms, and shared resource pools; and 3) implementation of network governance enabling infrastructure at the company level to ensure interoperability.

5. Conclusion

The proposed framework extends existing supply chain management literature and practice by applying CAS principles to link network governance mechanisms with the emergent self-organising structure of the supply network and its operational characteristics. The proposed empirically grounded conceptual model is a first step towards a new vision for policy makers and supply chain managers in the mining industry, moving from hierarchical and linear to net-centric view of supply chain management.

Practical implications. The proposed conceptual framework draws attention of the policy-makers and supply chain participants towards the net-centric structure of industrial supply chains. The framework highlights the need for incorporating CAS governance mechanisms to improve operational performance, agility and responsiveness of the regional supply chains. It is suggested that strategies and approaches that focus on regional supply network connectivity associated with more effective flexible structures, lead to improved operational performance. In regard to mining companies, it is important to change supply management strategies based on prescriptive hierarchical approaches to create space for lean innovative solutions from lower tier small suppliers. Mining operators and EPCM providers should be more actively engaged in the programs being undertaken under state government supervision aimed at building collaborative relationships across supply chain tiers. For local firms, operating in the mining industry supply network, there is a need for incorporating systems and strategies of network-centric governance in supply chain management practices. The unification and integration of industry standards is vital for the reduction of certification costs that are a barrier to entry for local firms to build more connections in the regional supply chains. Platforms and associated policies for data sharing and collaboration across regional supply chains would encourage formation of horizontal links. Industry associations can play an integrating and facilitating role in the formation of alliances and partnerships among local suppliers, providing suppliers with the legal advice. A purposeful focused effort on increasing connectivity on the regional supply network from policy makers and industry stakeholders is required. Visualisation of the network structure can be used as a dashboard for monitoring interconnectivity and performance of the regional supply network that could be tracked on a regular basis.

The main limitation of the proposed framework is limited generalisability of findings since data are drawn from a single case study. Empirical evidence from other mining regions and other successful industries is needed to investigate the impact of CAS mechanisms on supply network structures and performance. As a part of future research, the proposed conceptual framework will be used as an initial condition for modeling and simulation of regional supply networks. Modeling and simulation of the SA mining industry will be implemented to evaluate possible network configurations and associated performance characteristics.

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