

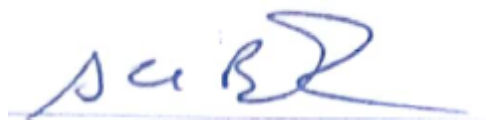
DEVELOPING A DIAGNOSTIC HEURISTIC FOR INTEGRATED SUGARCANE SUPPLY AND PROCESSING SYSTEMS

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in the School of Engineering, University of KwaZulu-Natal

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PREFACE

I, **MDUDUZI I. SHONGWE**, declare that:


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PUBLICATIONS

The following articles, published or under review, form part of the research presented in this thesis.

Chapter 2

Shongwe, MI, Bezuidenhout, CN, Sibomana, MS, Workneh, ST, Bodhanya, S and Dlamini, VV. 2019. Developing a systematic diagnostic model for an integrated agricultural supply and processing system. *Systems* 7(1): 15, doi: 10.3390/systems7010015.

Chapter 3

Shongwe, MI and Bezuidenhout, CN. 2019. A heuristic for the selection of appropriate diagnostic tools in large-scale sugarcane supply systems. *AIMS Agriculture and Food* 4(1): 1-26.

Chapter 4

Shongwe, MI. 2018. A systems thinking approach to investigating complex sugarcane supply and processing systems: integrating rich pictures and Bayesian networks. *Systemic Practice and Action Research* 31(1): 75-85.

Data collection, analyses and discussion of the results for all the above listed articles were conducted in the entirety by MI Shongwe with technical advice from Prof. CN Bezuidenhout, Dr S Bodhanya and Prof. ST Workneh.

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DEDICATION

This work is dedicated to my beloved family especially my wife Vukile and my children Sabusiswa, Uminathi and Luseluhle. Special thanks to the UNISWA Anglican Chapelry, Pastor Dalcy Dlamini and Pastor Wandile Dlamini for all the prayers throughout the journey. I also dedicate this work to my parents Mahhondo Shongwe and Khathazile Phiri for all the sacrifices they had to make for my education.

ABSTRACT

Innovation is a valuable asset that gives supply chains a competitive edge. Moreover, the adoption of innovative research recommendations in agricultural value chains and integrated sugarcane supply and processing systems (ISSPS) in particular has been relatively slow when compared with other industries such as electronics and automotive. The slow adoption is attributed to the complex, multidimensional nature of ISSPS and the perceived lack of a holistic approach when dealing with certain issues. Most of the interventions into ISSPS often view the system as characterised by tame problems hence, the widespread application of traditional operations research approaches. Integrated sugarcane supply and processing systems are, nonetheless, also characterised by wicked problems. Interventions into such contexts should therefore, embrace tame and/or wicked issues. Systemic approaches are important and have in the past identified several system-scale opportunities within ISSPS. Such interventions are multidisciplinary and employ a range of methodologies spanning across paradigms. The large number of methodologies available, however, makes choosing the right method or a combination thereof difficult. In this context, a novel overarching diagnostic heuristic for ISSPS was developed in this research. The heuristic will be used to diagnose relatively small, but pertinent ISSPS constraints and opportunities. The heuristic includes a causal model that determines and ranks linkages between the many domains that govern integrated agricultural supply and processing systems (IASPS) *viz.* biophysical, collaboration, culture, economics, environment, future strategy, information sharing, political forces, and structures. Furthermore, a diagnostic toolkit based on the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) was developed. The toolkit comprises a diagnostic criteria and a suite of systemic tools. The toolkit, in addition, determines the suitability of each tool to diagnose any of the IASPS domains. Overall, the diagnostic criteria include accessibility, interactiveness, transparency, iterativeness, feedback, cause-and-effect logic, and time delays. The tools considered for the toolkit were current reality trees, fuzzy cognitive maps (FCMs), network analysis approaches, rich pictures (RP), stock and flow diagrams, cause and effect diagrams (CEDs), and causal loop diagrams (CLDs). Results from the causal model indicate that collaboration, structure and information sharing had a high direct leverage over the other domains as these were associated with a larger number of linkages. Collaboration and structure further provided dynamic leverage as these were also part of feedback loops. Political forces and the culture domain in contrast, provided low

leverage as these domains were only directly linked to collaboration. It was further revealed that each tool provides a different facet to complexity hence, the need for methodological pluralism. All the tools except RP could be applied, to a certain extent, across both appreciation and analysis criteria. Rich pictures do not have causal analysis capabilities *viz.* cause-and-effect logic, time delays and feedback. Stock and flow diagrams and CLDs conversely, met all criteria. All the diagnostic tools in the toolkit could be used across all the system domains except for FCMs. Fuzzy cognitive maps are explicitly subjective and their contribution lies outside the objective world. Caution should therefore be practiced when FCMs are applied within the biophysical domain. The heuristic is only an aid to decision making. The decision to select a tool or a combination thereof remains with the user(s). Even though the heuristic was demonstrated at Mhlume sugarcane milling area, it is recommended that other areas be considered for future research. The heuristic itself should continuously be updated with criteria, tools and other domain dimensions.

LIST OF ACRONYMS

IASPS:	Integrated Agricultural Supply and Processing System
CEDs:	Cause and Effect Diagrams
CLDs:	Causal Loop Diagrams
CRTs:	Current Reality Trees
FCMs:	Fuzzy Cognitive Maps
ISSPS:	Integrated Sugarcane Supply and Processing Systems
NA:	Network Analysis Approaches
RP:	Rich Pictures
SFDs:	Stock and Flow Diagram
SSM:	Soft Systems methodology
TOC:	Theory of Constraints
UDE:	Undesirable Effects
RSSC	Royal Swaziland Sugar Corporation

TABLE OF CONTENTS

PREFACE.....	ii
PUBLICATIONS.....	iii
ACKNOWLEDGEMENT	iv
DEDICATION.....	v
ABSTRACT.....	vi
LIST OF ACRONYMS	viii
TABLE OF CONTENTS.....	ix
LIST OF FIGURES	xi
LIST OF TABLES	xii
CHAPTER 1: INTRODUCTION	1
1.1 Aim and Objectives.....	2
1.2 Scope of the study	4
1.3 Roadmap of the study.....	4
1.4 List of References.....	5
CHAPTER 2: DEVELOPING A SYSTEMATIC DIAGNOSTIC MODEL FOR AN INTEGRATED AGRICULTURAL SUPPLY AND PROCESSING SYSTEM	9
2.1 Abstract	9
2.2 Introduction	10
2.3 Literature Review	14
2.3.1 Description of IASPS domains	14
2.3.2 Linkages between IASPS domains	17
2.4 Method	22
2.5 Results and Discussion.....	24
2.6 Conclusion and Recommendations	30
2.7 List of References.....	31
CHAPTER 3: A HEURISTIC FOR THE SELECTION OF APPROPRIATE DIAGNOSTIC TOOLS IN INTEGRATED SUGARCANE SUPPLY AND PROCESSING SYSTEMS.....	46

3.1	Abstract	46
3.2	Introduction	47
3.3	An Overview of Multimethodology	51
3.4	Methods.....	54
3.5	Results and Discussion.....	57
3.5.1	Criteria for selecting diagnostic tools	57
3.5.2	Systemic diagnostic tools.....	61
3.5.3	Synthesis	67
3.6	Conclusion and Recommendations	74
3.7	List of References.....	75
CHAPTER 4: A SYSTEMS THINKING APPROACH TO INVESTIGATING COMPLEX SUGARCANE SUPPLY AND PROCESSING SYSTEMS: INTEGRATING RICH PICTURES AND BAYESIAN NETWORKS.....		91
4.1	Abstract	91
4.2	Introduction	92
4.3	Methods.....	93
4.4	Results and Discussion.....	100
4.5	Conclusion and Recommendations	108
4.6	List of References.....	109
CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH		118
5.1	Introduction	118
5.2	Aims and Objectives	118
5.3	Final Comments and Summary Conclusions	119
5.4	Challenges and Future Possibilities.....	120

LIST OF FIGURES

Figure 1.1 The symptom-to-therapy cycle	3
Figure 2.2 A conceptual model of linkages between IASPS domains	18
Figure 2.3 Systematic diagnostic model for IASPS.....	28
Figure 3.1 Stepwise procedure for performing TOPSIS.....	56
Figure 4.1 Map of Swaziland showing the study area	94
Figure 4.2 Rich picture diagram from stakeholder interviews	101
Figure 4.3 A Bayesian model for shredder breakdown at Mhlume sugar factory for the 2013 and 2014 milling season.....	106
Figure 4.4 A Bayesian model for turbine and failure due to chokes at Mhlume sugar factory for the 2013 and 2014 milling season	107

LIST OF TABLES

Table 2.1 Adoption factors associated with supply chains	12
Table 2.2 A meta-analysis of agricultural supply and processing domains.....	26
Table 3.1 The performance of various tools against the diagnostic criteria	68
Table 3.2 Results of TOPSIS based on equal weighting	71
Table 4.1 Profile of interviewed stakeholders	96

CHAPTER 1: INTRODUCTION

Integrated sugarcane supply and processing systems (ISSPS) are complex systems characterised by a large number of autonomous, but mutually interacting stakeholders (Bezuidenhout *et al.*, 2013; Bezuidenhout *et al.*, 2012). As a result, ISSPS face the existence of diverse and often conflicting mental models, values and goals (Bodhanya, 2011; Gerwel *et al.*, 2011). According to Bezuidenhout *et al.* (2013), ISSPS are made up of various system domains that causally interact to regulate the behaviour of the system. This leads to a high degree of complexity and makes ISSPS unpredictable and difficult to manage (Higgins *et al.*, 2010; Archer *et al.*, 2009; Higgins *et al.*, 2007; Pathak *et al.*, 2007). Complexity hampers supply chain performance and contributes to higher costs (Aelker *et al.*, 2013; Serdarasan, 2013; Bozarth *et al.*, 2009). Consequently, there is a strong need to integrate complexity into ISSPS management in order to unlock opportunities and probably improve efficiency, profitability and sustainability (Archer *et al.*, 2009; Higgins *et al.*, 2007).

Complexity is considered an important factor influencing the adoption of technologies in ISSPS (Bezuidenhout and Bodhanya, 2010; Higgins *et al.*, 2010; Archer *et al.*, 2009). According to Bezuidenhout and Bodhanya (2010), the adoption of innovative technologies in agricultural value systems especially ISSPS have been relatively slow when compared with other industries such as electronics and automotive. Higgins *et al.* (2010) attributed the slow adoption to the presence of complexity. Most research interventions in ISSPS view the system as characterised by tame problems. This is seen from the widespread application of traditional operations research approaches within the system. Traditional operations research views problem contexts as being linear and disregard linkages between components (Hester and Adams, 2017; Alberts *et al.*, 2011). Integrated sugarcane supply and processing systems are complex socio-technical systems and interventions within these systems should simultaneously consider interactions between hard and soft issues (Siriram, 2012; Bezuidenhout and Bodhanya, 2010; Higgins *et al.*, 2010). Systemic interventions enable improvement through incremental adjustments (Singh and Singh, 2015; Grossbart and Agrawal, 2012; Gerwel *et al.*, 2011).

Bezuidenhout and Bodhanya (2010) noted that most research in ISSPS is long-term focused, aimed at making “large and permanent” system changes. It is for this reason that various

researchers advocate for short-term focused *in situ* opportunistic solutions within ISSPS (Sanjika *et al.*, 2012; Bezuidenhout and Baier, 2011; Gerwel *et al.*, 2011). Such an approach is common in the field of medicine, especially pharmaceuticals and therapy. This approach, however, calls for the knowledge of the overall “health” of the system before any changes can take place (Childerhouse and Towill, 2011; Banomyong and Supatn, 2011; Chow *et al.*, 2008). Diagnosing issues in complex systems can, however, be more challenging due to systems’ multi-dimensionality (Gonzalez-Garcia *et al.*, 2012). The matter is further complicated by the fact that most of the diagnostic tools available are only tailored to deal with specific areas and commonly, within single paradigms (Howick and Ackermann, 2011; Mingers and White, 2010; Zawedde *et al.*, 2010). Even those tools that are able to diagnose multiple dimensions often give less attention to the integrated nature of the problem context (Schut *et al.*, 2015). A comprehensive diagnosis process is thus, more possible through the use of a combination of tools, a concept widely referred to as multimethodology (Bezuidenhout *et al.*, 2014; Franco and Lord, 2011).

1.1 Aim and Objectives

In line with the continuous improvement philosophy of incremental changes (Singh and Singh, 2015), this study aims to develop and test a novel overarching diagnostic heuristic for complex ISSPS that could be used to diagnose relatively small, but pertinent, system constraints and opportunities. In essence, the heuristic, largely based on the medical symptom-to-therapy cycle, could provide short-term focused *in situ* opportunistic solutions while making small, incremental changes. As with the symptom-to-therapy cycle, the heuristic will determine causal linkages between different ISSPS domains and also provide a toolkit that will be used to diagnose issues in one or more of these domains. Figure 1.1 illustrates the use of the symptom-to-therapy cycle in practice (Zhu, 2010; Speyerer and Zeller, 2004). In the example a patient visits a doctor’s office with two symptoms *viz.* irritability and headache. Based on the symptoms the medical practitioner, using a well-defined nomenclature, hypothesises that this is a fever syndrome. From the nomenclature, the doctor knows that fever syndrome is characterised by high temperature, cough and nasal congestion. To accept or reject the hypotheses, various diagnostic tools are selected from the toolkit to conduct small experiments or assessments.

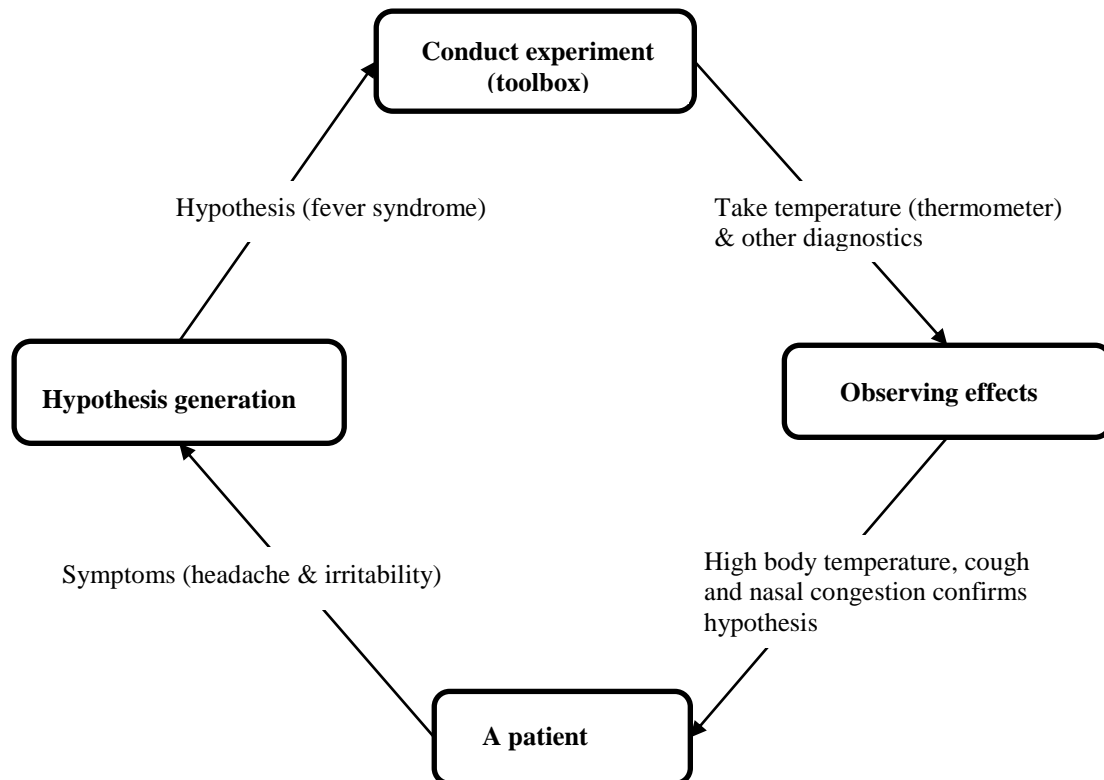


Figure 1.1 The symptom-to-therapy cycle (Zhu, 2010)

Since complex systems are characterised by ill-defined problems, problem definition (symptoms) involves multiple perspectives (Franco and Montibeller, 2010). This therefore demands a negotiated problem-definition phase (Mehmood, 2015). Tools for diagnosing complex issues should therefore, not only determine causality but also appreciate different worldviews. This means that instead of having a toolbox after “hypothesis generation” (refer to Figure 1.1), complex systems also require a set of tools before “hypothesis generation” to facilitate a shared problem-definition.

To the researcher’s knowledge, this is the first comprehensive diagnostic heuristic in any integrated agricultural supply and processing system (IASPS) in the world. The heuristic offers a basis for the construction of comprehensive methodologies and provides a mechanism to objectively select, use and commission diagnostic tools. Although the focus is on sugarcane systems, the attributes of ISSPS make the heuristic a relatively general approach to IASPS. It is therefore envisaged that the heuristic could also be transferable to other agricultural

industries, including the large number of new and rapidly developing bio-fuel and bio-refinery supply systems. The objectives of the study were to:

1. identify ISSPS domains and determine linkages between these domains,
2. identify a suite of complimenting diagnostic tools that would assist in establishing an in-depth understanding of the complexities in ISSPS in terms of the many domains that govern the system,
3. demonstrate the heuristic by conducting a case study in a sugarcane milling area, and
4. make recommendations on the systematic diagnosis philosophy within ISSPS.

1.2 Scope of the study

It is important to note that the ISSPS as defined in this study refer to the segment between sugarcane growing and raw sugar production. This includes components of cultivation, harvesting, transport and milling. The ISSPS up to the point of raw sugar is driven by a wide range of biophysical push factors such as pest and diseases, unpredictable weather, and fluctuating qualities. Post-milling the supply chain drivers change significantly as the product (raw sugar) becomes biologically stable and also becomes the responsibility of one firm. The supply chain downstream as such is driven by the market-related forces rather than biophysical push factors. Research on ISSPS is even more important given that ISSPS include multiple stakeholders with different (and sometimes conflicting) objective.

1.3 Roadmap of the study

The thesis is written in an article format with three articles appearing as Chapter 2, 3 and 4. Chapter 1 is the Introduction and Chapter 5 contains the Conclusion and Recommendations for Future Research. Chapter 2 provides a meta-analysis conceptual causal model where the main IASPS domains were identified and causal interdependencies between the domains determined. Chapter 3 develops a diagnostic toolkit (heuristic) for the selection of appropriate tools in large-scale ISSPS that is based on multimethodology and the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS). An inventory of diagnostic tools is presented where each tool's application and limitations within ISSPS domains are outlined. Diagnostic criteria are thereafter developed and the performance of the diagnostic tools against the criteria determined. Chapter 4 reports on a multi-methodological case study that

was conducted at Mhlume sugarcane milling area where rich picture diagrams were used in tandem with Bayesian networks.

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CHAPTER 2: DEVELOPING A SYSTEMATIC DIAGNOSTIC MODEL FOR AN INTEGRATED AGRICULTURAL SUPPLY AND PROCESSING SYSTEM

2.1 Abstract

Despite all the innovative research on technologies, technology adoption in integrated agricultural supply and processing systems (IASPS) remains a challenge. This is attributed to the complex nature of IASPS and the continued lack of a holistic view towards some of the interventions into the system. Integrated agricultural supply and processing systems are characterised by multiple domains and numerous stakeholders. Under such contexts, the sums of local optimisations do not always translate to an overall system solution. As a consequence, a systems thinking approach is required to unlock and understand the adoption process. This research developed a systematic diagnostic model for IASPS that determines, ranks and compares linkages between the many IASPS domains *viz.* biophysical, collaboration, culture, economics, environment, future strategy, information sharing, political forces, and structure. It is envisaged that the model could be used to locate high leverage intervention points within IASPS. The model could also be used as a diagnosis tool to make predictions about the systems' behaviour. A meta-analysis was conducted to provide a quantitative review of empirical research on linkages between the IASPS domains and to examine relevant design and contextual factors. Results show that collaboration, structure and information sharing had a high direct leverage over the other domains as these were associated with a larger number of linkages. Collaboration and structure in addition, provided dynamic leverage as these domains were part of feedback loops. In terms of the potency of relationships, collaboration was highly correlated to culture compared to its other correlations *viz.* information sharing, coercive power and transaction costs. The broad nature of some of the domains, however, mean that correlations should be treated with caution as various constructs within each domain may have different effects.

Keywords: *adoption; linkages; meta-analysis; supply systems*

2.2 Introduction

Technology adoption offers organisations the potential to improve performance (Talukder *et al.*, 2008). Wu and Chen (2006) are of the view that innovation is a valuable asset that gives supply chains a competitive edge. The adoption of innovations in supply chains increases productivity and the quality of service (Prahalad and Mashelkar, 2010). Ham and Johnston (2007) allude to the fact that inter-organisational supply chain innovations increase the level of cross organisational interoperability and integration. However, despite the obvious benefits and effort towards innovation, the performance gains are often obstructed by low adoption (Meyer-Larsen *et al.*, 2014).

The adoption of technologies in integrated agricultural supply and processing systems (IASPS) is no exception as non-adoption is widely reported despite all the potential benefits (Higgins *et al.*, 2007; Le Gal *et al.*, 2009; Bezuidenhout *et al.*, 2013). According to McCown (2002), the adoption of technologies in IASPS and in particular, integrated sugarcane supply and processing systems (ISSPS), has been relatively slow especially, when compared to other industries such as electronics and automotive. Higgins *et al.* (2010) attribute this slow adoption of technologies to complexity. Agricultural systems are complex mainly due to the presence of many stakeholders on top of the multiple domains that constitute the system (Bezuidenhout *et al.*, 2013; Schut *et al.*, 2015). Complex systems such as these are characterised by non-linear interactions and the presence of many feedback loops. Solutions to such contexts, as a consequence, rely on the interactions between the many dimensions than on each component in isolation (Shongwe, 2008; Bezuidenhout and Baier, 2011). A systems thinking approach is therefore required to unlock and understand the adoption of technologies in IASPS. System thinking offers a way to describe and understand interactions between components, their patterns and processes. Bezuidenhout and Baier (2011) posit that technology adoption in IASPS is more possible when all system domains are considered simultaneously.

A range of models have been used to determine the adoption of technologies and among the mostly used is Rogers's (1995) diffusion of innovation framework (DOI) and Davis's (1989) technology acceptance model (TAM). The DOI identifies five characteristics of technological innovations *viz.* relative advantage, compatibility, complexity, triability, and observability. These factors, as stated by Hsu *et al.* (2006), can explain 49-87% of the variance in adoption

rates. The TAM on the other hand, identifies two critical factors that determine adoption *viz.* perceived usefulness and ease of use. The DOI and TAM are, however, primarily based on an individual's acceptance behaviour.

Adoption of technologies by organisations is different to that by individuals as it involves multiple decision makers. The application of DOI and TAM in such contexts is thus insufficient. Tornatzky and Fleischer's (1990) technology, organisation and environment context (TOE) model is a widely accepted adoption model at organisational level. According to Tornatzky and Fleischer (1990), an organisation's decision to adopt does not only lie with the characteristics of the technology itself but also with the organisational capabilities and the environmental context. Organisational context refers to the characteristics and resources of the entity. More broadly, organisational factors such as structure (Ali and Kumar, 2011), strategy (So and Sun, 2010), culture (Lee *et al.*, 2013), and economics (Lin, 2014) have all been studied to establish their role in the adoption of technologies. The environmental context represents the setting within which an organisation operates.

Technology adoption in supply chains introduces other dimensions to those of organisations. Since supply chain initiatives often impact on operational routines and relational structures there is an obvious need to also consider inter-organisational factors (Ham and Johnston, 2007). According to Wu (2013), inter-organisational interactions induce uncertainty. Institutional theory posits that organisational changes are not only driven by intra-organisational and technological criteria but also by pressure to conform. Institutional theory as stated by Suddaby *et al.* (2013), is based on the assumption that organisations sharing the same environment become isomorphic with each other. As a consequence, institutional theory is widely applied in inter-organisational adoption research, whether in isolation or in combination with other factors and/or models. Table 2.1 shows some adoption factors that have been studied across supply and processing systems.

Table 2.1 Adoption factors associated with supply chains

Researchers	Adoption factors									
	Physical	Collaboration	Culture	Economics	Environment	Strategy	Information sharing	Power	Structures	History
Chatterjee <i>et al.</i> (2002)			•			•			•	
Hsu <i>et al.</i> (2006)				•	•			•		
Seymour <i>et al.</i> (2008)	•		•	•	•	•	•		•	
Chong <i>et al.</i> (2009)		•		•			•			
Ranganathan and Jha (2005)					•		•		•	
Pang and Bunker (2007)		•			•			•		
Johnston and Gregor (2000)	•	•	•	•	•			•		
Patterson <i>et al.</i> (2003)				•	•			•	•	•
Matopoulos <i>et al.</i> (2009)		•				•		•	•	
Bezuidenhout <i>et al.</i> (2013)	•	•	•	•	•	•	•	•	•	•
Schut <i>et al.</i> (2014)	•		•	•				•	•	

As indicated in Table 2.1, different supply chain adoption issues often align with different and/or a combinations of factors or domains. Johnston and Gregor, (2000) and Patterson *et al.* (2003) provide a more general list of factors that affect the adoption of technologies in supply chains. Seymour *et al.* (2008) considered factors that were empirically identified to affect a container supply chain. Schut *et al.* (2014) and Bezuidenhout *et al.* (2013) factors were conceptualised from an agricultural systems view. Also clear from Table 2.1 is that various factors have been studied and amongst the most researched are physical factors, collaboration, culture, economics, strategy, information sharing, power, structures, environment, and history. The history domain is nonetheless not common among researchers and Bezuidenhout and Bodhanya (2010) argue that even its description lacks consistency.

The “factor approach” (TOE model and institutional factors), however, is static and tends to view adopters as being passive (Zhang and Dhaliwal, 2009). Kurnia and Johnston (2002) argue that these models do not capture the complex and dynamic nature of inter-organisational linkages introduced at the adoption stage. In this context a process-based approach is widely proposed (Lyytinen and Damsgaard, 2011; Kurnia and Johnston, 2002; Johnston and Gregor, 2000). A processual approach views system’s behaviour as being emergent and accordingly captures the interplay of interactions between an individual firm, the industry and the environment it operates in (Ali *et al.*, 2010).

Various researchers have identified numerous linkages between some of the supply systems adoption factors. Defee and Stank (2005) studied interdependence between strategy, environmental uncertainty and supply chain structure. A study by Abosag (2006) explored linkages between economics, culture, information sharing, and collaboration. Kang *et al.* (2004) studied interdependence between power, collaboration, culture, and communication. In this context, this research developed a systematic model that explores and compares the inter-linkages between the many IASPS adoption domains *viz.* biophysical, collaboration, culture, economics, environment, future strategy, information sharing, political forces, and supply chain structure. Knowledge of these inter-linkages is important given that technological adoption in supply chains requires a comprehensive approach. It is vital to have a diagnostic model within which to work and from which testable hypotheses could be drawn. The model could be used to locate high leverage intervention points within IASPS. Assuming the “hypothesis generation phase” of the symptom-to-therapy (refer to Section 2.4) the model could further be used to make predictions about the IASPS behaviour. To the researcher’s

knowledge, there are currently no studies that have comprehensively considered the inter-linkages between all of these IASPS domains within a single intervention. The use of the model is therefore expected to improve the efficiency of systemic diagnosis of issues within IASPS.

This article is organised into five sections. The first section reviews literature on linkages between IASPS domains and develops a conceptual model. Section 2.4 describes the Method undertaken whilst a section on Results and Discussion follows thereafter. Lastly, Conclusion and Recommendations are presented.

2.3 Literature Review

This section reviews literature on linkages between nine IASPS adoption domains. The nine domains considered in the research are the biophysical domain, collaboration, culture, economics, environment, future strategy, information sharing, structure, and political forces. The first section (2.3.1) describes these domains in detail and identifies their key antecedents, consequences and barriers. Section 2.3.2 identifies interdependencies between the domains and develops relevant research hypotheses.

2.3.1 Description of IASPS domains

The biophysical domain refers to the network structure of physical equipment and processes used to enable value adding in the supply and processing system. It includes raw materials, work-in-process inventory and finished products. Christopher (2011) identified capacity utilisation, asset turn and synchronisation as the precursors for effective material handling. The state of inventory and logistics in a supply chain depends on coordination. An efficient physical flow system guarantees on-time delivery which in turn, ensures that inventory levels (and costs) are kept minimal. Sugarcane supply synchronisation is considered critical within ISSPS as this promotes capacity utilisation, mitigates material handling risks, minimise stockpiling, and reduces sugarcane deterioration (Bezuidenhout and Bodhanya, 2010).

Collaboration is an act where two or more independent supply chain members work mutually together to arrange and execute operations with more prominent accomplishment than when

acting in isolation (Sridharan and Simatupang, 2013). Kumar *et al.* (2017) describe collaboration as inter-firm linkages where supply chain members share information, resources and risk to accomplish mutual objectives. The key antecedents to supply chain collaboration are information sharing, decision synchronisation and incentive alignment (Hudnurkar *et al.*, 2014; Naspetti *et al.*, 2011). Collaboration is often defined by trust, commitment, cooperation, and coordination (Martins *et al.*, 2017; Wilding and Humphries, 2009). According to Weaver (2012), collaboration marks the final phase of the C3 model (coordination, cooperation and collaboration), meaning that it requires coordination and cooperation as prerequisites.

Supply chain culture describes a pattern of shared values, beliefs, assumptions, and behaviours among supply chain partners (Cao *et al.*, 2015). Culture facilitates inter-organisational learning and is often viewed as a direct precursor to trust and commitment (Saenz *et al.*, 2012). According to Schein (2010), culture manifests itself at three levels viz. artefacts, espoused values and underlying assumptions. Artefacts are the visible aspects and consist of the physical and social settings. Values represent conscious, affective desires whilst assumptions embody an unconscious aspect.

The economic domain describes activities that progressively create value for a supply chain. These are the activities that determine costs and affect profits. The aim of a value chain is to deliver maximum value through value-added products and services. Accordingly, Bezuidenhout and Bodhanya (2010) posit that value chains generate profit, prevent value loss and distribute benefits. The economic domain, however, is constrained by market access and orientation, infrastructure and institutional barriers (Trienekens, 2011). In the South African sugarcane supply chain, Bezuidenhout and Bodhanya (2010) identified four common value chain strategies viz. economies of scale, co-products, cost of growing and harvesting, and sugar markets.

The environment domain as used in this study defines the context within which a supply chain exists. This is a multi-dimensional world that comprises both macro and micro factors. The multi-dimensionality of the environmental domain brings about uncertainty into a supply chain. According to Terjesen *et al.* (2012), as the environment becomes less munificent supply chains are subjected to greater uncertainties. Environmental uncertainty as a consequence, gives rise to adaptation and evaluation challenges (Samsami *et al.*, 2015). Environmental uncertainty is thus the main driver for seeking flexibility (Zhang, 2001). Scott

and Davis (2015) classify environmental uncertainty into two *viz.* complexity and dynamism. Environmental dynamism is the rate of change and turnover in the environment. Complexity on the other hand, represents the diversity of and/or interdependence between environmental factors that a supply chain has to cope with.

Future strategy is the blueprint for supply chain activities. Strategy monitors the environment for threats and opportunities. Hence, it determines supply chain's goals and configurations (Ambe, 2012). There are two generic supply chain strategies, *viz.* lean and agile. A lean strategy focuses on increasing efficiency through the elimination of waste. Agile strategies in contrast, are founded on structures that are capable of competing in highly dynamic and unpredictable environments (Khan *et al.*, 2009). There are four concepts inherent to agility *viz.* flexibility, responsiveness, competency and speed (Ambe, 2012; Yeganegi and Azar, 2012). According to Amir (2011), agile supply chains are network-based, information-driven and integrated. Most agricultural systems, however, are characterised by both lean and agile principles (Bezuidenhout, 2010; Kaasgari *et al.*, 2017). Integrated sugarcane supply and processing systems for example, require lean principles to adapt to a commodity-type market downstream whilst upstream the system requires agile strategies to deal with multiple stakeholders and high production risks (Bezuidenhout, 2010).

Information sharing is the extent to which critical and proprietary information is communicated between supply chain partners (Hudnurkar *et al.*, 2014). Information sharing describes the act of capturing and dissemination. Restricted information flow not only obstructs the ability to prepare for sudden changes but impedes adaptation to environmental changes (Hatala and Lutta, 2009). Information sharing is described as the heart (Lotfi *et al.*, 2013) and nerve centre (Chopra, 2018) of supply chain collaboration. According to Maghsoudi and Pazirandeh (2016), information sharing increases the visibility of key performance and process data. Khurana *et al.* (2011) recognises four broad barriers to information sharing *viz.* managerial, technological, individual characteristics and socio-cultural factors.

Supply chain structure describes the tasks, authority and coordination mechanisms across the distinct parts that form a supply chain (Rong *et al.*, 2011; Awaysheh and Klassen, 2010). There are many structural dimensions proposed in literature (Daft *et al.*, 2010), but the mostly used dimensions in supply systems are integration and communication (Koc Baban, 2013).

Integration is the alignment and coordination of processes and functions across a supply chain. Stevens and Johnson (2016) recognise three forms of supply chain integration *viz.* information integration, coordination and organisational linkages.

Political behaviour defines those actions that influence resources within a supply chain but are not part of one's formal role (Latif *et al.*, 2011). Political forces are an important aspect of deciding "what does or does not get done" (Checkland and Poulter, 2006). Accordingly, politically-oriented behaviour manifests itself through the exercise of power as power serves as a mechanism for achieving compliance (Handley and Benton, 2012). According to Maloni and Benton (2000), power is either mediated or non-mediated. Mediated power describes those bases that are deliberately engaged to guide response e.g. reward power, coercive and legitimate power. In contrast, non-mediated power defines those forms that are more relational and positive in orientation e.g. expert and referent power. Power is also conceptualised from a resource-dependency perspective where supply chain partners are viewed as interdependent entities seeking to manage uncertainty (Zhang and Huo, 2013). Another approach to power is derived from transaction cost economics where partnerships are motivated by self interests driven by economic gains (Turkkantos, 2014).

2.3.2 Linkages between IASPS domains

A conceptual model showing interdependencies between the various IASPS domains described in Section 2.3.1 is given in Figure 2.1. The conceptual model is based on a thorough literature review where linkages between the domains were identified, informing the formulation of several hypotheses.

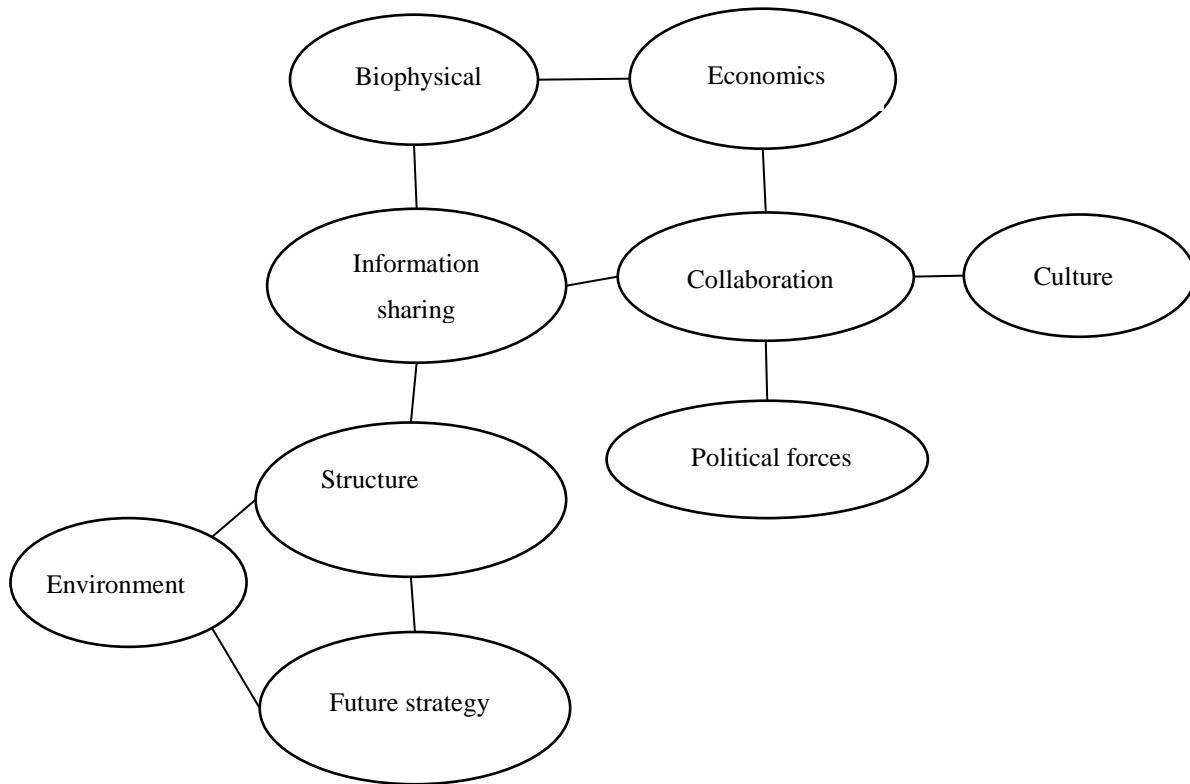


Figure 2.2 A conceptual model of linkages between IASPS domains

Several researchers advocate for the adoption of the structure-strategy-performance paradigm within the supply chain context (Borella *et al.*, 2017; Juttner and Christopher, 2013; Defee and Stank, 2005). The structure-strategy-performance paradigm (SSP) posits that a firm's strategy drives its structure and performance. Furthermore, the SSP put forward that the structure-strategy relationship is contingent to external environmental factors. According to Effendi and Arifin (2010), the relationship between structure and strategy relationship is inextricably reciprocal. Consequently, structure should be compatible with strategy otherwise strategy formulation and implementation will be constrained. Agile supply chains require coordination and integration of functions across supply chain members (Lu and Ramamurthy, 2011). According to Tse *et al.* (2016), agility moderates the effect of integration on performance. Empirical findings from a multi-case study by Ngai *et al.* (2011) show a correlation between supply chain integration and agility. Similarly, Cagliano *et al.* (2006) found an association between integration and a lean supply chain strategy. Henceforth, it is hypothesised that,

H1: Supply chain structure is correlated to supply chain strategy

Supply chain integration leads to timely and accurate information sharing (Lu and Ramamurthy, 2011; Mansoori *et al.*, 2014). According to Amu and Ozuru (2014), the integration-information sharing relationship is reciprocal as information sharing is also a prerequisite for external integration. Consequently, integration improves communication channels between supply chain partners (Yang *et al.*, 2015). Findings by Sahin and Robinson (2005) show a positive correlation between logistics integration and information sharing. Mansoori *et al.* (2014) found a strong association between information sharing and supply chain integration. It is therefore hypothesised that:

H2: Supply chain structure is correlated to information sharing

The environment is either exogenous to the SSP or have a direct relationship (Xu *et al.*, 2010; Merschmann and Thonemann, 2011). According to Decheng and Yu (2013), environmental uncertainty is positively correlated to supply chain integration. Integration, through improved responsiveness, mitigates the impact of environmental uncertainty on performance (Boon-itt and Wong, 2011). Accordingly, Salvato and Vassolo (2018) posit that dynamic environments are mostly associated with higher levels of integration. A study by Chi *et al.* (2009) found a positive relationship between environmental dynamism and supply chain structures. It is hypothesised that:

H3: The environmental domain is associated to supply chain structure

As partly proposed by the SSP debate, sustainable competitive advantage is achieved through a fit between the environment and both the structure and supply chain strategy (Boon-itt and Wong, 2011; Merschmann and Thonemann, 2011). More so, highly uncertain environments are mostly characterised by agile strategies whilst lean strategies are common among low uncertainty environments (Sebastiao and Golicic, 2008). Ambe (2012) points out that the agile strategy is more appropriate in turbulent environments as it responds quickest to dynamic conditions. In contrast, lean strategies perform better in stable, predictable environments (Duarte and Machado, 2011). Empirical evidence by Gligor *et al.* (2015) shows a positive association between agility and customer uncertainty. It is therefore hypothesised that:

H4: The environmental domain is correlated to strategy

Various researchers have studied the effect of supply chain collaboration on firm performance and, in general, concluded that higher levels of collaboration leads to better firm performances

(Cao and Zhang, 2011; Flynn *et al.*, 2010; Duffy and Fearne, 2004). Improved cooperation and coordination improves on-time delivery and greater responsiveness (Richey *et al.*, 2012). Supply chain collaboration helps partners to share risks and to reduce transaction costs (Cao and Zhang, 2011). According to Jiang *et al.* (2013), trust is a substitute for contracts. Trust reduces relational risk and as a consequence, decreases transaction costs (Hong, 2015). Dyer and Chu (2003) are of the view that in conditions of high trust, transacting partners spend less time on *ex-ante* contracting because they are confident that partners will not be opportunistic. In their study, Zaheer *et al.* (1998) found a negative relationship between inter-organisational trust and negotiation costs. A study by Um and Kim (2018) found that the collaboration-transaction cost relationship is moderated by contractual and relational governance mechanisms. A shared sense of identity motivates partners to be attached to shared values and to seek the best interests of the transaction. Similarly, contracts allow parties to work as promised and restrict opportunism.

According to Simatupang and Sridharan (2008), the need for decision synchronisation in supply chains lies with the potential increase in “collective pay-off” in terms of overall profits and lower costs. Accordingly, Pol and Inamdar (2012) state that vendor managed inventory (VMI) reduces inventory buffers and the need for extra capacity. Through VMI, adds Sandberg (2007), suppliers are able to coordinate transport and make more efficient route planning. Findings by Irungu and Wanjau (2011) show that VMI promotes faster inventory turns and inventory flow by reducing carrying costs, inventory holding and product spoilage. In the ISSPS grower consortiums are touted as a transaction cost reduction strategy (Sartorius *et al.*, 2003). On this basis, it is hypothesised that,

H5: Collaboration is correlated to the economics domain

Cooperation and trust are reciprocal processes depending on and fostering each other (Abdulkadiroglu and Bagwell, 2013). Soosay and Hyland (2015) state that trust, cooperation and commitment are a dynamic process where partners constantly evaluate their decisions whether or not to continue with a particular relationship. A study by Hardman *et al.* (2002) on the South African apple value chain found that trust leads to cooperation and in turn, commitment. Masuku and Kirsten (2004) came to the same conclusion on a study on ISSPS. A lack of trust, however, is a “common obstacle” to information sharing (Li and Lin, 2006). Conversely, high levels of trust reduce the fear of information disclosure (Lotfi *et al.*, 2013).

Zand's (1972) dynamic trust model views the trust-information sharing relationship as a reinforcing spiral. When a relationship is based on mistrust, this spiral deteriorates into decreased information sharing and subsequently, reduced trust (Li, 2015). A study by Nyaga *et al.* (2010) found trust to be positively correlated to information sharing. Kim and Lee (2006) discovered an increase in information sharing capabilities as a consequence of increased trust levels. It is therefore hypothesised that,

H6: Collaboration is positive association to information sharing

The value of stock in ISSPS is often outweighed by rapid sugarcane deterioration hence, stockpiling only occurs on the basis of inconsistent supply and demand. Moreover, downstream inventory performance is often positively related to an increase in market share, sales and profit (Capkun *et al.*, 2009; Iakovou *et al.*, 2010). Empirical findings by Shah and Shin (2007) show that inventory levels have a direct link to financial performance. A study by Agus and Hajinoor (2012) found a positive correlation between inventory control and both return on sales and profitability. Research conducted on sugar manufacturing firms by Lwiki *et al.* (2013) concluded that there is a correlation between inventory control and return on equity. It is therefore hypothesised that,

H7: The biophysical domain is correlated to the economic domain

According to Kaipia *et al.* (2017), information sharing leads to improved inventory management, higher sales and to a better understanding of demand. Srinivasan and Swink (2015) are of the view that information sharing enables supply chain members to plan properly and avoid inventory bottlenecks. The sharing of inventory information improves order replenishment, safety stock placement and trans-shipment. In vendor managed systems, suppliers are continuously updated on inventory levels and sales data via electronic data interchange systems (EDI) and replenishments are often automatically generated once the inventory drops below certain levels. It is thus hypothesised that,

H8: information sharing is correlated to the biophysical domain

Culture is a direct precursor to trust and commitment (Saenz *et al.*, 2012). According to Zhang *et al.* (2009), the relationship between trust and shared values is reciprocal with shared values helping to create a relationship built on trust, and trust serving to maintain and express those shared values. Accordingly, Morgan and Hunt (1994) note that when exchange partners share values, they become more committed to a relationship. Based on the notion that culture

promotes behavioural consistency, Bouachouch and Mamad (2014) argue that culture facilitates coordination. Empirical findings from Urbancova (2012) show that culture affect both cooperation and trust. Henceforth, H9 is proposed:

H9: Culture is positively correlated to collaboration

According to Belaya and Hanf (2012), coercive power is negatively correlated to collaboration. Leonidou *et al.* (2008) state that the continuous use of coercive power between partners degrades trust. Empirical research by Maloni and Benton (2000) show a negative relationship between coercive power and cooperation. Another study by Cheng *et al.* (2008) found that the coercive bases of power increase conflict. It is therefore hypothesised that,

H10: Political forces are inversely related to collaboration

2.4 Method

The research adopts the “hypothesis generation” phase of the medical symptom-to-therapy cycle (Speyer and Zeller, 2004; Zhu, 2010). The symptom-to-therapy cycle refers to a process a patient undergoes in a medical facility from the point when he/she enters a medical practitioners’ office with certain symptoms to the point where a root cause to the symptoms is identified. Based on the symptoms, the practitioner uses a well-defined nomenclature to guide “hypothesis generation”. For example, in a patient that shows irritability and headache (symptoms) the practitioner may hypothesise a fever syndrome. From the nomenclature, the medical practitioner knows that fever is characterised by high temperature, cough and nasal congestion hence, to accept or reject the hypothesis certain tools are used to conduct assessments. A model that identifies and analyses linkages between IASPS domains was as such developed in this study. In line with the “hypothesis generation” phase, the model developed a “well-defined” nomenclature that ranks the influence of each domain within any of the identified linkage(s).

The study used meta-analysis for hypotheses testing (developed in Section 2.3) and to determine and compare the strength of the various inter-linkages. Most of the research on the inter-linkages is drawn from multiple disciplines. Furthermore, research under such contexts is often operationalised differently. Meta-analysis therefore, provided a systematic statistical analysis of the different independent studies. Results from a meta-analysis are better than those from single studies because meta-analysis integrates diverse sets of population. This

increases precision around the overall mean effect and reduces sampling error (Schmidt and Hunter, 2014). Meta-analysis as used in this study allowed the researcher to explore a comprehensive research model that have not been examined in individual primary studies (Chan and Arvey, 2012; Zimmerman, 2008).

The outcome of a meta-analysis addresses three key issues *viz.* central tendency, variability and prediction. Central tendency describes the effect size and the confidence levels and/or significant levels drawn around the average effect size. There are many effect sizes available and amongst them Pearson's correlation coefficient, Cohen's *d* coefficient and the odds ratio. This research, however, adopts the Schmidt and Hunter (2014) random-effects meta-analysis method. This is effectively a weighted mean of raw correlation coefficients. Variability is described by the heterogeneity tests or the comparison of effect sizes and significance levels. Heterogeneity tests ascertain whether the included effect sizes belong to the same population or not (Field and Gillett, 2010). Lastly, prediction issues refer to the availability of moderator variables within the sample. Moderator variables explain variability around the results.

Peer-reviewed articles published between the years 2000 and 2015 were consulted for this research. Although the emphasis was on agricultural supply chains, articles from other supply systems were considered for hypothesis 10. This was due to a shortage of empirical studies specific to IASPS (not enough to warrant meta-analysis) for this particular hypothesis. The collaboration-political force relationship in this research therefore, is viewed from a domain perspective rather than the meta-analysis of articles specific to IASPS. The search for relevant articles began with a keyword search using the domains and/or domain dimensions. Academic search engines including Web of Science, EBSCO and ProQuest were used to identify relevant empirical studies. A manual search of journals was also conducted. In other cases, snowballing was employed. To be considered in the meta-analysis articles had to report on an effective size statistic on a relationship between any of the domains. Since the Pearson correlation coefficient (*r*) served as the effect size metric, studies that reported other metrics (e.g. F-test and t-test) were converted to *r* using appropriate formulas (Borenstein *et al.*, 2009). After a thorough "sifting" exercise, one hundred and thirty five studies were included in the meta-analysis.

Each effect size was corrected for sources of error (sampling error, attenuation and reliability) using a weighted average reliability value of the sampled studies (Le *et al.*, 2016). Corrected

correlation coefficients (r_c) for each hypothesis were subsequently computed. Lastly, Cochran's Q-tests and credibility intervals (CV) were computed for each hypothesis to quantify heterogeneity. A Q-test is interpreted as a comparison of between-study to within-study variance. A null hypothesis in a Q-test assumes that all studies come from the same population. A significant Q-test therefore indicates that effect sizes are heterogeneous (Pereira *et al.*, 2010).

Schmidt and Hunter (2014) discourage the use of the Q-test in isolation especially when the number of studies considered is less than six and/or when the average sample size is less than thirty. It is argued that at such values, the Q-test tend to accept the null hypothesis even though with an unknown type II error rate (Kock, 2009). When the number of studies is large, the Q-test tends to reject the null hypothesis (Schmidt and Hunter, 2014). The sample sizes in this research ranged from 4 to 1174. Hence, a Q-test may not have been sufficiently able to accurately reflect heterogeneity. Credibility intervals were therefore computed alongside the Q-test. Credibility intervals provide an estimate of variability in the distribution of the correlation values. They are constructed from a posterior distribution of effect sizes after the correction for error. According to Geyskens *et al.* (2009), a large credibility interval or that which includes zero assumes heterogeneity and indicates the presence of moderators.

2.5 Results and Discussion

The open nature of some of the IASPS domains meant that it was difficult to cover all domain dimensions within the meta-analysis. It is for this reason that only a few dimensions from each domain were selected for the study. Dimensions as used in this article refer to the various constructs or forms that make up a domain, for example, structure can be formalisation, centralisation, complexity, and/or integration. Table 2.2 shows results from the meta-analysis and as indicated the r_c were ranked according to Cohen's (1992) correlation threshold scale (SE). According to Cohen (1992), correlations between 0.10 and 0.3 are regarded as small (S). Accordingly, correlations between 0.30 and 0.50 are categorised as medium (M) whilst those above 0.50 are considered large (L). In support of the threshold values, Cohen (1992) argued that correlations of 0.1, 0.3 and 0.5 explain 1%, 9% and 25% of variance, respectively. The SE further suggests that any correlation smaller than 0.10 is trivial. Most researchers, however, are critical of the SE and many argue that the effectiveness of any intervention can only be interpreted within the context of a research domain that is

being evaluated (Aarts *et al.*, 2014; Lakens, 2013; Baguley, 2009). Also indicated in Table 2.2 is the number of independent samples consulted (k) and the overall sample size (N).

Table 2.2 A meta-analysis of agricultural supply and processing domains

Hypothesis	k	N	r_o	r_c	SE	95% CV		$Q (p < 0.05)$
						Upper	Lower	
H1 (Structure-strategy) ¹	10	1914	0.321	0.322	M	0.374	0.272	8.84
H2 (Structure-information sharing) ²	10	2298	0.643	0.594	L	0.669	0.519	9.85
H3 (Structure-environment) ³	11	1894	0.062	0.054	Trivial	0.069	0.038	14.51
H4 (Strategy-environment) ⁴	15	2514	0.310	0.295	S	0.350	0.239	11.81
H5 (Collaboration-economics) ⁵	11	2935	-0.103	-0.145	S	-0.207	-0.019	9.27
H6 (Collaboration-information sharing)	21	6810	0.530	0.468	M	0.540	0.396	15.00
H7 (Biophysical-economic) ⁶	10	382	0.822	0.728	L	0.837	0.618	10.78
H8 (Information sharing-biophysical) ⁷	11	2029	0.336	0.372	M	0.434	0.309	8.68
H9 (Culture-collaboration)	17	4776	0.595	0.545	L	0.619	0.469	20.07
H10 (Political forces-collaboration) ⁸	19	4283	-0.671	-0.313	M	-0.133	-0.494	4.41*

¹ Integration-agile strategy

² Integration-information sharing

³ Integration-environmental uncertainty

⁴ Flexibility-environmental uncertainty

⁵ Trust-transaction costs

⁶ Inventory control-return on sales

⁷ Inventory levels-information sharing

⁸ Trust-mediated power

The Q-test was statistically insignificant ($p < 0.05$) for all hypotheses except H10 (political forces-collaboration), indicating that the effect sizes were homogeneous. This was further supported by the computed credibility intervals as all the values (hypothesis 1 to hypothesis 9) excluded zero. According to Harlow *et al.* (2016), significant effect sizes have credibility values on the same side of zero. The statistically significant Q-test for hypothesis 10 indicates heterogeneity. Furthermore, the CV for H10 was fairly wide (-0.133- -0.494) suggesting that moderators may exist. According to various researchers, the relationship between trust and coercive power is moderated by commitment (Jain *et al.*, 2014; Teimouri *et al.*, 2015). A study by Jain *et al.* (2014) found that the effect of coercive power on trust decreases with an increase in affective commitment.

According to Cohen's (1992) SE (refer to Table 2.2), hypothesis 2, 7, and 9 were large whilst hypothesis 1, 6, 8 and 10 were categorised as medium. Hypothesis 3 was classified as trivial. This research uses Cohen (1992) classification only as a guide and as such, does not view hypothesis 3 as insubstantial. This is in line with Durlak's (2009) argument that the practical importance of an effect size only depends on its relative costs and benefits. Still on Cohen's (1992) SE, the strategy-environment and the collaboration-economics average effect sizes were classified as small. According to Hale (2011), a stronger correlation increases the predictive value of an interaction hence is the case for hypothesis 2, 7 and 9. This implies that the knowledge of either factor can be used to predict the value of the other. Referring to Figure 2.2, information sharing is seen to be more predictive of structure ($r_c = 0.594$) compared to collaboration ($r_c = 0.468$) and the biophysical domain ($r_c = 0.373$). In case information sharing is viewed as a constraint, the model (Figure 2.2) indicates that decision-makers should first consider the role of directly-linked domains. Based on potency, the decision-makers should consider the role of structure, collaboration and the biophysical domain, respectively.

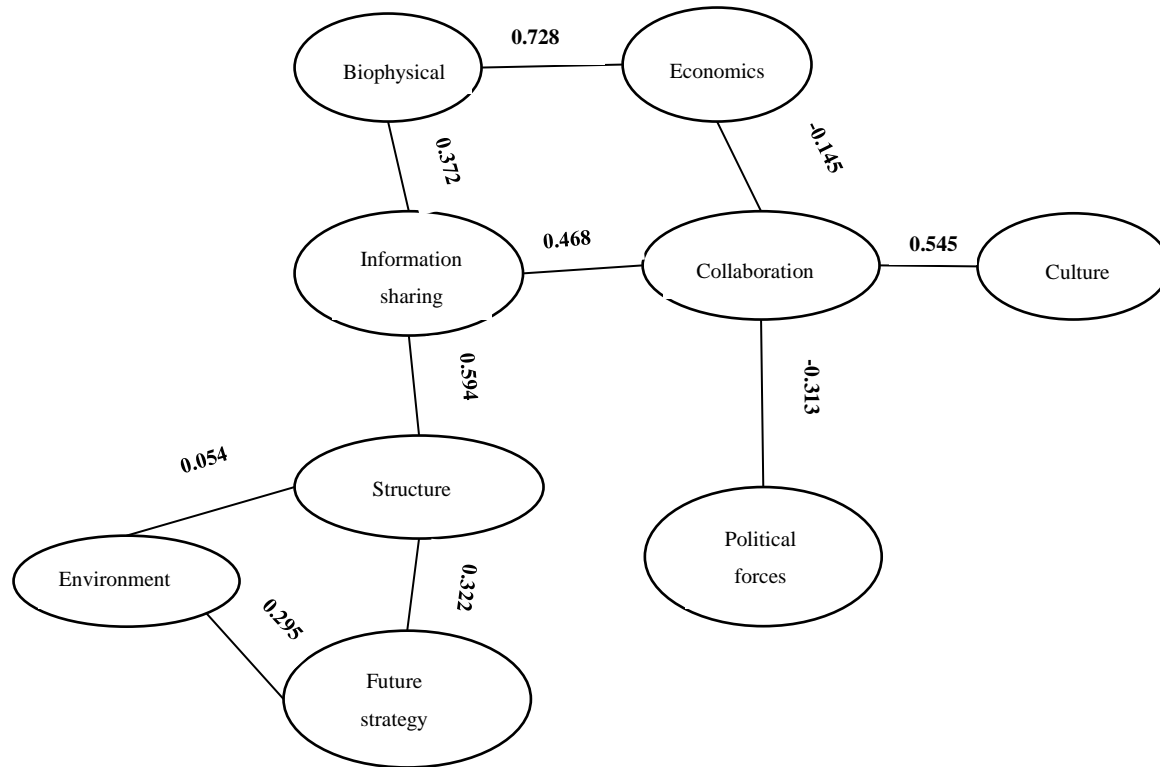


Figure 2.3 Systematic diagnostic model for IASPS

The information sharing “versus” structure and collaboration correlation values are comparable with the findings of Kalyar *et al.* (2013) who found legal protection ($r = 0.463$) and trust ($r = 0.444$) to be most predictive of information sharing. Based on potency, collaboration was found to be strongly correlated to culture ($r_c = 0.545$) compared to information sharing ($r_c = 0.468$), coercive power ($r_c = -0.313$) and transaction costs ($r_c = -0.145$). These findings are consistent with those of Fawcett *et al.* (2008) that found culture and information sharing to be the most potent barriers to supply chain collaboration. Diagnostically, a low supply chain collaboration index may imply the overuse of coercive power, mismatched values, problems with information sharing and/or higher transaction costs.

Referring to Figure 2.2, it is clear that collaboration, information sharing and structure are the most central domains directly influencing four (culture, economics, information sharing, and politics), three (biophysical, collaboration and structure) and three (environment, information sharing and strategy) domains, respectively. This means that these domains hold a relatively higher direct leverage in IASPS. Furthermore, the relationship between structure, environment

and strategy forms a feedback loop (positive feedback loop considering the domain constructs considered in the meta-analysis). Feedback loops can either be positive or negative. Positive loops are self-reinforcing whilst negative loops exhibit a goal-seeking behaviour. According to Nguyen and Bosch (2013), feedback loops are an important source of dynamic leverage. Dynamic leverage focuses on cause-and-effect relationships that feedback over time (Meadows, 2008). Dynamic leverage as such, minimises the amount of initial effort required to set a system moving and the amount of maintenance forces required to keep feedback structures in place. For example, external integration (strategy) could be used to leverage (dynamic) environmental uncertainty. With higher levels of integration, supply chain partners obtain more current and accurate information especially on order requirements as well as their variation (Barrat, 2004). This allows tight coordination and ensures that supply chain partners are more flexible (strategy) to environmental changes. Information sharing, collaboration, economics and the biophysical domain also form a feedback loop. Collaboration could be used, for example, to leverage issues in the biophysical domain. An increase in trust in the supply chain increases the level of information sharing and by so doing, inventory data become more accessible which improves coordination and consequently, reduces transactional costs. The loops in Figure 2.2 imply that any intervention into IASPS should strive to simultaneously consider collaboration, information sharing and structural implications as these have a higher leverage (direct and dynamic).

The high leverage position of information sharing within IASPS is visible from Figure 2.2. Through information sharing, structure links strategic factors (environment and strategy) to operational domains (collaboration and biophysical). Information sharing further affects both feedback loops on the model (Figure 2.2). Moreover, the relationship between information sharing and the collaboration-economics-biophysical loop provides higher leverage compared to that with the structure-strategy-environment loop. As indicated, information sharing forms part of the collaboration-economics-biophysical loop whilst it acts as an exogenous factor towards the structure-strategy-environment loop, only directly affecting structure. These findings support Lotfi *et al.*'s (2013) argument that information sharing is at the heart of supply chain management. Although important, the influence of culture and political forces on the overall domains provide low leverage. As indicated in Figure 2.2, culture and political forces were only linked to the collaboration domain. Moreover, the correlation between culture and collaboration

was large especially when compared to economics (small), political forces (medium) and information sharing (medium).

After obtaining the meta-analysis results as indicated in Table 2.2, funnel plots (not shown here) were created to investigate the presence of publication bias. Publication bias arises when certain studies are published whilst others are excluded. According to Ahmed *et al.* (2012), research findings that are statistically significant have a higher chance of being published compared to non-significant research. The bias often leads to a non-representative database that overestimates the true effect size (Lakens, 2013). After visual inspection of each funnel plot, it was concluded that no meaningful publication bias existed in this research.

2.6 Conclusion and Recommendations

The adoption of technologies in IASPS is comparatively slow given the investment and potential benefits. The slow adoption is largely attributed to the complex nature of IASPS especially the linkages between the various domains that constitute the system *viz.* biophysical, collaboration, culture, economics, environment, strategy, information sharing, structure and politics. In this study a systematic model that determines and evaluates the interdependencies between these domains was developed. The model acts as a decision support mechanism to detect leverage intervention opportunities and also as a tool to make predictions about the system's behaviour.

The research found that collaboration, information sharing and supply chain structure had a higher direct leverage within IASPS as these were directly associated with a larger number of linkages. Collaboration and structure in addition, provided dynamic leverage as these formed part of feedback loops. The Q test results from the meta-analysis were insignificant except for the relationship between political forces and collaboration which showed heterogeneity. This was because the relationship between trust (collaboration) and coercive power (political forces) is moderated by commitment. In terms of potency, culture had a higher mean effect size compared to the other domains that were correlated to collaboration *viz.* information sharing, political forces and economics. Similarly, structure was more predictive of information sharing compared to collaboration and the biophysical domain.

Owing to the broad nature of some of the IASPS domains, the mean effect sizes (direction and magnitude) should be treated with caution as various constructs within each domain can have different effects within the same relationship. For example transaction costs and return on sale (economic domain) are negatively and positively correlated to collaboration, respectively. To a certain extent, the model can be extended to other socio-technical systems, especially those of similar domains. The limitation of the study, however, was that the articles considered for the meta-analysis were sourced from different industries, national conditions and economic environments. All these factors could have introduced bias. The aggregated results from the meta-analysis nonetheless, provided robust conclusions as these were derived from large samples to even out the possible errors. The correlation between the collaboration and the political force (H10) was, however, computed from a sample that included articles from outside IASPS. Hence, the correlation value is more general than specific to IASPS. It is as such, recommended that a meta-analysis of Hypothesis 10 that is specific to IASPS be conducted in the future. It is further recommended that for future studies the model be updated with linkages from other domain dimensions as these will provide a more holistic diagnosis.

2.7 List of References

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CHAPTER 3: A HEURISTIC FOR THE SELECTION OF APPROPRIATE DIAGNOSTIC TOOLS IN INTEGRATED SUGARCANE SUPPLY AND PROCESSING SYSTEMS

3.1 Abstract

Holistic diagnostic sugarcane supply chain studies are critical and have in the past identified several system-scale opportunities. Such studies are multidisciplinary and employ a range of methodologies. Most of these methodologies nonetheless, are only tailored to surface a few facets of problem complexity. Even those methodologies that cover multiple dimensions, more often, give less attention to the integrated nature of some of the problem contexts. A comprehensive view is therefore, more possible only through a combination of various methodological approaches. The large number of methodologies available, however, makes it difficult to choose a right method or a combination thereof. A heuristic for the selection of diagnostic tools in integrated sugarcane supply and processing systems (ISSPS) was therefore, developed in this research. Systemic diagnostic criteria were developed to serve as a foundation for tool comparison. The performance of various diagnostic tools on the criteria was thereafter tested. The performance matrix served as an input into the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) to prioritise and select preferred tool(s). Each tool's suitability to diagnose any of the many ISSPS domains was further established. The criteria were accessibility, interactiveness, transparency, iterativeness, feedback, cause-and-effect logic, and time delays. The tools considered were current reality trees (CRTs), fuzzy cognitive maps (FCMs), network analysis approaches (NA), rich pictures (RP), stock and flow diagrams (SFDs), cause and effect diagrams, and causal loop diagrams. Causal loop diagrams, SFDs, NA and FCMs were the only tools in the heuristic that captured feedback. Rich pictures and CRTs were the most accessible and interactive, respectively. All the tools in the heuristic could be applied across all the ISSPS domains except for FCMs which should be applied with caution within a biophysical domain as these tools are explicitly subjective. Sensitivity analysis of the TOPSIS model indicated that SFDs were the most sensitive to criteria weights whilst NA were the least sensitive. It is recommended that the heuristic be demonstrated in an actual ISSPS. It is further

recommended that the heuristic should be continuously updated with criteria and other diagnostic tools.

Keywords: *complexity; criteria; diagnosis; multimethodology; sugarcane supply systems*

3.2 Introduction

Integrated sugarcane supply and processing systems (ISSPS) are complex systems characterised by multiple stakeholders with various, often conflicting objectives (Gerwel-Proches and Bodhanya, 2015; Sanjika and Bezuidenhout 2015; Shongwe, 2018). Furthermore, these systems contain several domains that causally interact to regulate behaviour (Bezuidenhout *et al.*, 2013; Bezuidenhout and Baier, 2011). As a consequence, ISSPS exhibit several complex systems characteristics *viz.* non-linearity, feedback, delays, constant change, counterintuitive behaviour, emergence, and trade-offs (Bezuidenhout *et al.*, 2012). Similar to many other industries, the sugar industry is mature, well established and systems are relatively efficient. However, due to a range of complexities significant inefficiencies remain present, such as vehicle over-fleeting (Giles *et al.*, 2008), unnecessary risk averse behaviour (Bezuidenhout, 2008) and problematic forecasting and planning (Kadwa *et al.*, 2012). Many of these inefficiencies are attributed to economics, collaboration issues, system governance and misaligned stakeholder objectives.

To make sense of complex systems it is important to recognise that most issues do not exist in isolation, but are imbedded within complex interrelationships and interdependencies between system elements. Holistic sugarcane supply chain research has been an important contributor to the industry and has in the past identified several system-scale opportunities (Higgins *et al.*, 2007; Le Gal *et al.*, 2008). Such research is mostly multidisciplinary and employs a range of research methodologies, such as interviews, questionnaires, stakeholder workshops, statistical data analysis, analysis of economics and modelling. A “one size fits all” approach to optimising all the systems at the same time, however, is unlikely (Higgins *et al.*, 2007). Bezuidenhout and Baier (2011) argue that even though the fundamentals of sugarcane supply chains are the same, each mill area exhibits a number of relatively unique combination of issues, which need to be contextualised at the local level. Complex systems theory presents valuable universal laws such

as Ashby's law (Ashby, 1958) and the Theory of Constraints (Goldratt, 1990), to help unlock such localised opportunities. Ashby (1958) posits that the precise measure of complexity is variety. Through the Law of Requisite Variety, Ashby (1958) argues that the variety of a system which regulates has to be at least equal to the variety of the system it is regulating. Goldratt (1990) Theory of Constraints on the other hand, is premised on the assumption that within any complex system exist a certain constraint, or a few. Goldratt (1990) argues that the Theory of Constraints makes it possible to identify such constraint(s) for improvement purposes.

According to Lichtenstein and Plowman (2009), system improvements are likely to occur through an evolutionary small step-by-step approach as opposed to a complete top-down restructuring and system overhaul. This guided self-organisation notion is supported by amongst others, Helbing (2013) who claim that modern systems have a high degree of connectivity which makes these systems unpredictable, rigid and slow to change. Within a rigid and complex system it becomes difficult to follow standard optimisation-based research strategies. In fact, it often takes a significant amount of time to prioritise the importance of different issues that seem to negatively affect the overall system. Researchers can find themselves entangled in a web of unstructured, interconnected and multidisciplinary issues, which restricts the opportunity to apply unbiased scientific methodologies.

In this context, a heuristic research approach helps the researcher to fast track progress and to select appropriate research methodologies that appear promising. Heuristics are problem solving strategies designed to arrive at satisfactory solutions with a modest amount of effort (Albar and Jetter, 2009). Gigerenzer and Gaissmaier (2011) provide a review of heuristics and define the term as a strategy "with the goal of making decisions more quickly, frugally, and/or accurately than more complex methods". Heuristics reduce the cognitive burden associated with complex decision making and offer decision-makers an opportunity to examine only a few signals and/or alternative choices before reaching a conclusion (Shah and Oppenheimer, 2008; Dietrich, 2010). Gigerenzer and Gaissmaier (2011) argue that many researchers, including Einstein, extensively used and supported heuristic research approaches. Given the background, this article develops an overarching diagnostic heuristic for ISSPS aimed at diagnosing relatively small but pertinent, *in situ* constraints and opportunities. Contrary to most research in ISSPS which focuses on long-

term issues (Gerwel *et al.*, 2011), the proposed heuristic advocates for short-term focused solutions with an aim of making small, incremental changes. An integrated sugarcane supply and processing system as defined in this research refers to the physical flow of sugarcane between growing, harvesting, transport, as well as the processing components.

According to Childerhouse and Towill (2011), the health of a supply chain should be evaluated before making any interventions into the system. Determining the “overall health” of the system implies a systematic process that considers all components that constitute the supply chain hence, diagnosis is critical for continuous improvement (Yatskovskaya *et al.* 2018; Singh and Singh, 2015; van Dyk and Pretorius, 2014). The term “diagnosis” refers to identification and investigation of the cause and nature of a condition, situation or a problem. Supply chain diagnosis is thus, a structured examination of issues within a supply system in order to identify improvement opportunities (Simon *et al.*, 2015). Poor diagnosis remains a huge challenge within agricultural supply systems (Schut *et al.*, 2015). Various researchers attribute the low adoption of technologies in agricultural systems to misdiagnosis of issues (Higgins *et al.*, 2007; Higgins *et al.*, 2010; Schut *et al.*, 2014). Although literature provides many examples of diagnostic tools and applications within ISSPS, these tools, however, are largely tailored to deal with specific problem areas and mostly, within certain paradigms (Mingers and Brocklesby, 1997; Mingers, 2003; Zawedde *et al.*, 2010). Even those tools that are able to diagnose issues in multiple paradigms and/or dimensions, more often give less attention to the integrated nature of some problems (Schut *et al.*, 2015). A comprehensive view is therefore more possible only through the use of a combination of tools, a concept widely referred to as multimethodology.

The large number of diagnostic tools available further makes it difficult to choose the best tool or a combination thereof, an obvious gap to developing criteria for accurate comparison of tools. The objectives of the research were therefore, to develop criteria against which diagnostic tools could be evaluated and also to compare the performance of different tools against such criteria. The broad nature of ISSPS (multiple domains), however, indicates that not all tools can be applied across all ISSPS domains. Depending on the domain(s), each tool can (to a certain extent) be applicable or not applicable. This research further seeks to capture the diagnostic suitability of each tool against the domains. The heuristic will provide a mechanism to

objectively compare, select, use, and/or commission various systemic diagnostic tools. Although the focus is on sugarcane systems, the attributes of ISSPS make the heuristic a relatively general approach to integrated agricultural systems. It is therefore envisaged that the heuristic is also transferable to other agricultural industries, including the large number of new and rapidly developing bio-fuel and bio-refinery supply systems.

An integrated sugarcane supply and processing system as conceptualised in this study is a sum of nine domains *viz.* biophysical, collaboration, culture, economics, environment, future strategy, information sharing, political forces, and structures (Bezuidenhout and Bodhanya, 2010; Bezuidenhout *et al.*, 2013; Schut *et al.*, 2015). The biophysical domain describes the physical equipment and processes involved in an ISSPS. These include raw material, work-in-process inventory, and finished products. Collaboration in contrast, describes an act where two or more independent supply chain members mutually work together to achieve more benefits than when acting in isolation (Kumar *et al.*, 2017; Sridharan and Simatupang, 2013). According to Wilding and Humphries (2009), supply chain collaboration is defined by the level of trust, commitment, cooperation, and coordination. Culture is defined as a pattern of shared values, beliefs, assumptions, and behaviour (Schein, 2004).

The environment describes the context within which a supply chain exists. The environment is thus multi-dimensional consisting of macro and micro factors (Koumparoulis, 2013). Conversely, supply chain strategy is the intelligence function that monitors the environment for threats and opportunities (Shoushtari *et al.*, 2011). The economic domain describes all activities that progressively create value for the supply chain. Economic factors determine the success and profitability of ISSPS as they affect capital availability, cost and demand (Koumparoulis, 2013). Structure refers to the distribution of tasks and responsibilities within supply chains (Teixeira *et al.*, 2012). Issues of power within a supply system are described by political forces. Lastly, information sharing describes the extent to which critical and proprietary information is communicated between supply chain partners (Mafini *et al.*, 2016).

The article is structured into five sections. The first section provides an overview of the practice of multimethodology outlining its applications, strengths and weaknesses. Methods undertaken

to conduct the study are described in Section 3.4. Results and Discussion are presented in Section 3.5 followed by a section on Conclusion and Recommendations.

3.3 An Overview of Multimethodology

Multimethodology is a form of methodological pluralism that describes the creative combination of different methodologies, or parts thereof, within a single intervention (Green and Hardman, 2013). It is not a methodology or a specific way of combining methodologies but rather, “a whole area of utilising a plurality of methodologies and techniques” (Mingers, 1997). The term “methodology” refers to a structured set of procedures or guidelines employed by researchers to undertake interventions (Mingers and Brocklesby, 1997). Techniques or methods on the other hand, are well-defined primary activities or a sequence of operations within a methodology. Methodologies thus consist of various techniques. The term “tool” is used interchangeably throughout the study to refer to methodologies and/or techniques.

Each methodology is based on particular philosophical assumptions it makes about the nature of the world in which it can be applied (paradigms) hence, the scepticism around multimethodology especially when partitioning and/or combining methodologies and/or techniques from different paradigms (Westwood and Clegg, 2009). Paradigms specify ontology (what is assumed to exist), epistemology (possibilities of, and limitations on the nature of valid knowledge), axiology (what is considered right), and methodology (Erford, 2014). Traditionally, two paradigms exist *viz.* soft (interpretivism/constructivism) and hard (positivism/post-positivism) paradigm. The hard paradigm views the world as objective whilst soft paradigms are based on a subjective meaning (Pollack, 2009). Another paradigm that is widely used is the critical paradigm. The critical paradigm has political overtones and obliges that the researcher(s) should uncover hidden assumptions about a specific context (Creswell and Miller, 2000). The paradigm assumes a transactional epistemology and a historical ontology (Kivunja and Kuyini, 2017).

Researchers advocating for methodological pluralism allude to the fact that the real world is multidimensional whilst particular paradigms focus on specific aspects of the problem context (Mingers, 2003). Adopting only one paradigm for certain problem contexts only reveals certain

aspects of that context but is completely blind to others (Dainty, 2008). Methodological pluralism and hence multimethodology views all methods as complementary (Sanders and Wagner, 2011). According to Habermas's (1984) *Theory of Communicative Action* (TCA), the real world is made up of interactions between three constructs *viz.* material, personal and social world. Midgley (2011) posits that there is “no existing methodology” that comprehensively covers all of these worlds hence the need to draw upon a plurality of methodologies. The research/intervention process itself proceeds through a number of phases and as such, multimethodology offers a comprehensive option by exploiting different tools for different phases (Ferreira, 2013). This ability, even when the tools cover similar functions, provides triangulation. Triangulation, which is the use of multiple methods on the same phenomenon, generates new insights and provides possibilities for validating results (Bekhet and Zauszniewski, 2012).

There are two commonly used approaches to multimethodology *viz.* Mingers and Brocklesby (1997) approach (M-B framework) and the Mingers (2003) approach. The M-B framework uses a 2-dimensional grid with the problem context (material, social and personal worlds) on one side and Bhaskar (1979) general phases of research/intervention on the other. Bhaskar (1979) research/intervention phases are the appreciation phase, analysis, assessment, and action phase. The appreciation phase is a design and conceptualisation phase that describes the problem context as experienced by stakeholders. The analysis phase depicts the underlying structures and constraints that maintain a specific problem (appreciation and analysis are discussed in detail under Section 3.5.1). Assessment weighs up postulated explanations and potential changes to the problem context whilst the action phase brings about change if necessary (Mingers, 2010). Assigning tools on the M-B framework is somewhat subjective and *ad hoc*. According to Mingers (2003), the M-B framework does not critically specify the dimensions and phases in which a particular tool is more useful. Furthermore, Mingers (2003) argues that the M-B framework does not focus on specific tasks but is rather more general towards the problem context. To overcome some of the M-B framework limitations, Mingers (2003) developed another framework with added dimensions. Mingers' (2003) framework outlines the purpose of the intended intervention and also surfaces the philosophical assumptions (ontology, epistemology and axiology) underpinning each methodology and/or method under consideration.

These “dimensions” are then synthesised into a Soft Systems Methodology root definition form (Checkland and Poulter, 2006).

The main criticism towards multimethodology concerns paradigm incommensurability (Zhu, 2011). The issue of incommensurability, largely based on Kuhn's (1962) history of science, has been widely challenged by various researchers (Callaghan, 2016; Harwood, 2011). Kuhn (1962) asserted that paradigms succeed each other and therefore, reconciliation between the “old” and the “new” cannot be possible. Jackson (1991) used Habermas (1972) *Theory of Knowledge Constitutive Interests* (KCI) as a foundation to challenge paradigm incommensurability. The KCI posits that all knowledge is aimed at serving three human interests, *viz.* technical, practical, and emancipatory. Jackson (1991) argued that these interests are aligned with the hard, soft, and critical paradigms, respectively and as a consequence, paradigms are complimentary.

Midgley (1997) argued that the Habermas (1984) theory, TCA, justifies multi-paradigm complementarity based on the assumption that the hard, soft, and critical paradigms pursue the material, social, and personal worldviews, respectively. Accordingly, Mingers (2001) contends that there is no universal classification of paradigms and that the concept is simply a heuristic. It is upon these arguments (Jackson, 1991; Midgley, 1997; Mingers, 2001) that paradigms are considered complimentary in this research. Multimethodology, as considered in this study therefore, refers to a bespoke methodology where various methodologies are partitioned into components and then combined together.

Cultural and cognitive feasibility have also been raised as major challenges towards the development and adoption of multimethodology (Jackson, 1999; Mingers, 2001). Cultural feasibility refers to the extent to which existing paradigm subcultures facilitate or act against the use of multimethodology. According to Mingers and Brocklesby (1997), crossing and/or combining paradigms requires individuals to overcome socially constructed obstacles. Mingers (2001) points out that there are interdependencies between personality traits, entrenched cognition and research preference. Mingers and Brocklesby (1997) are of the view that these links cause individuals to experience difficulties when moving between paradigms.

3.4 Methods

The availability of multiple stakeholders and their varying perspectives means that the diagnosis of issues in ISSPS should not only be guided by cause and effect but also the appreciation of different worldviews (Hildbrand, 2013; Gerwel-Proches and Bodhanya, 2015; Shongwe, 2018). This is further complicated by the fact that most of the diagnostic tools available are tailored for specific context. A heuristic that could provide a comprehensive diagnosis therefore, requires a combination of tools from different paradigms and strong criteria that could guide such. The development of the ISSPS diagnostic heuristic was therefore, based on pragmatism. Pragmatism is based on the assumption that either or both positivism and interpretivism provide acceptable knowledge dependent upon the research question (Feilzer, 2010). Pragmatism as such, is pluralistic and is congruent with the practice of multimethodology taken within the predisposition of practitioner-based research.

Following a thorough literature review, diagnostic criteria were developed. The criteria are founded on Bhaskar's (1979) appreciation and analysis phases (refer to Section 3.3). The criteria are important given Mingers' (2003) argument that the M-B framework does not critically specify the dimensions and phases in which particular tools are more useful. The developed criteria as such, were used to critically expand on each phase (appreciation and analysis) and to specify exactly what was expected from the diagnosis process. A numerical ranking scale of 1-5 was used to determine the performance of various diagnostic tools for the criteria, where a score of 5 indicated excellent and 1, very poor. Zero (0) was used to specify no relationship whatsoever. The systemic tools considered were the current reality trees, fuzzy cognitive maps, network analysis approaches, rich pictures, stock and flow diagrams, cause and effect diagrams, and causal loop diagrams. Various researchers have compared the performance of some of these tools on numerous criteria and under diverse contexts. For example, Jun *et al.* (2011) compared Soft Systems methodology and System Dynamics in a health services context using qualitative and graphical scales. Doggett (2005) used a qualitative scale to compare the performance of current reality trees and cause and effect diagrams amongst other tools. A comprehensive literature review was further used to determine the appropriateness of each of the tools to diagnose issues within each of the many ISSPS domains *viz.* biophysical domain, collaboration,

culture, economics, environment, future strategy, information sharing, political forces, and structures. Formulating ISSPS as domains provided a more specific context than expressing the system along Habermas (1984) worlds (refer to Section 3.3).

The developed performance matrix was used as an input into the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) to prioritise and select appropriate diagnostic tool(s). The TOPSIS is a multi-criteria decision analysis (MCDA) tool initially developed by Hwang and Yoon (1981). According to Angelis and Kanavos (2017), MCDA techniques seek to integrate objective measurements with value judgment. The TOPSIS selects alternatives that simultaneously have the shortest distance from an ideal solution and the furthest distance from a negative ideal solution. It was considered attractive in this research due to its simplicity, rationality, comprehensibility and good computational efficiency (Roszkowska, 2011). The TOPSIS uses a five step process as indicated in Figure 3.1. The technique is, however, only an aid to decision making and does not give a right or a wrong answer.

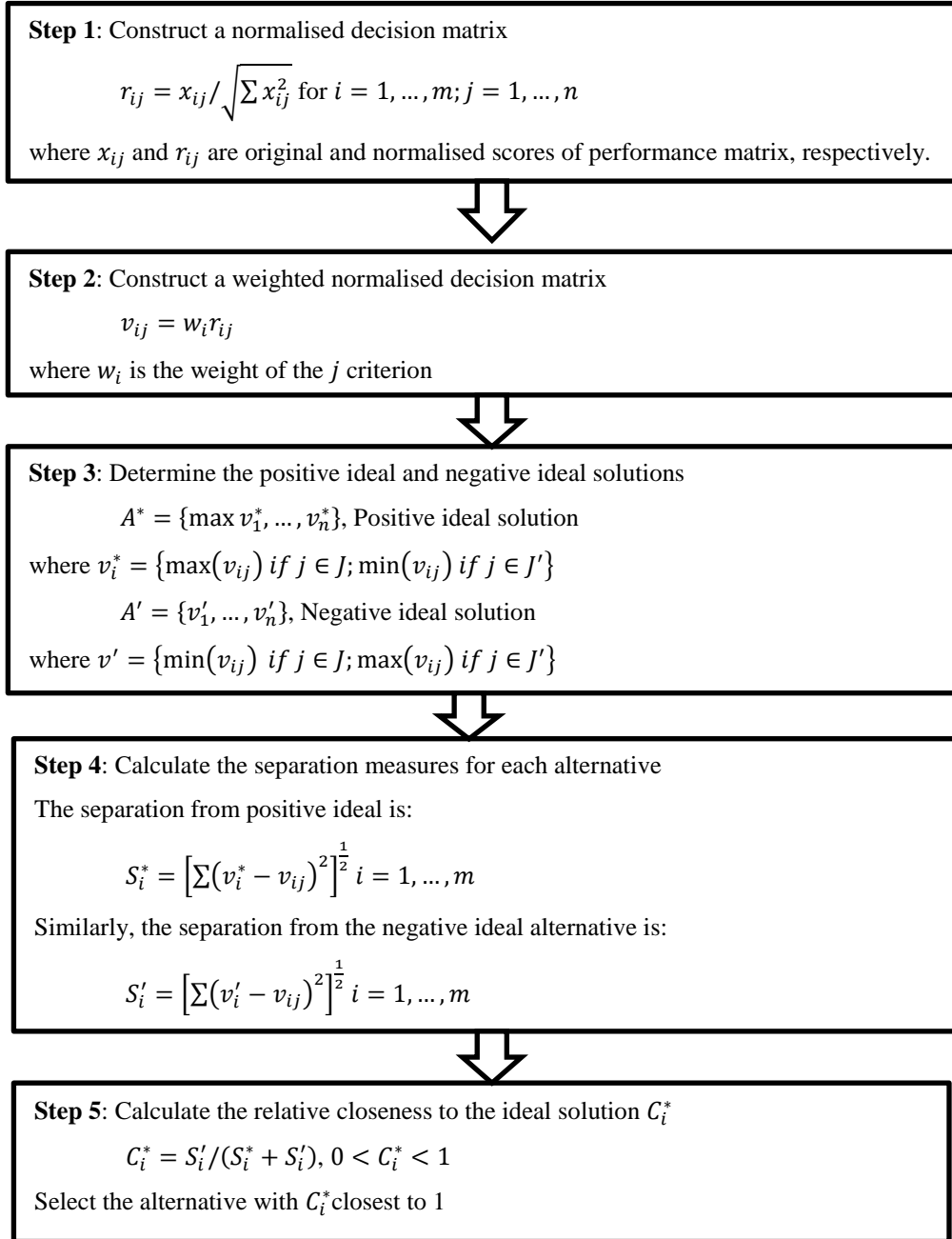


Figure 3.1 Stepwise procedure for performing TOPSIS (Behzadian *et al.*, 2012)

Initially (as indicated in Figure 3.1), the performance matrix is normalised before being multiplied by a weight assigned to each criterion. Decision makers define these weights according to their preferences and the sum of all weights should be equal to one. Step 4 and 5 compute the ideal solutions and the separation measures, respectively. The TOPSIS in this

research uses the benefit criteria as opposed to the cost function (Kelemenis and Askounis, 2010). Hence, for all criteria the positive ideal solution in Step 3 remains a maximum value.

3.5 Results and Discussion

This Results and Discussion section is divided into three sub-sections. Using extensive literature, systemic criteria for comparing the performance of various diagnostic tools was developed in Section 3.5.1. Some of the diagnostic tools that are widely used in ISSPS and/or agricultural systems were thereafter reviewed in Section 3.5.2. The last section synthesises the information from Section 3.5.1 and 3.5.2 to develop the diagnostic heuristic.

3.5.1 Criteria for selecting diagnostic tools

Integrated sugarcane supply and processing systems are complex characterised by multiple stakeholders and different domains (Stutterheim *et al.*, 2008; Bezuidenhout *et al.*, 2014). Under such contexts, the sum of local optimisation solutions does not often translate to an overall system solution. It is for this reason that various researchers report on a number of systemic inefficiencies within ISSPS. For example, Gaucher *et al.* (2004) and Wynne *et al.* (2009) stated that the existence of multiple growers makes coordination of sugarcane supply difficult. Complex systems such as ISSPS are characterised by both tame and wicked or messy problem contexts. However, despite such contexts, most interventions into such systems often view ISSPS as hard, technical systems characterised by tame issues (Bezuidenhout and Baier, 2011; Gerwel *et al.*, 2011).

Messy problems are a class of social problems where there are differences of opinions about the problem or even on the question of whether a problem exists or not (Ackoff, 1978; Horn and Weber, 2007). These types of problems are continually evolving, have many causal levels and have no single solution. On the contrary, tame problems are well-defined and can be solved linearly using reductionist and/or sequential techniques (Batie, 2008; Wexler, 2009). In this article, “wicked problems” also refers to what Ackoff (1978) describes as “messy problems” and what Mintzberg *et al.* (1976) define as “unstructured problems”.

Tame and wicked problems are not governed by the same logic hence, treating a wicked context as tame creates confusion and provides ineffective solutions (Nelson and Stolterman, 2012). In the same vein, strategies developed for wicked problems may not be suitable for tame contexts. This study embraces Bhaskar (1979) appreciation and analysis phases of intervention to represent wicked and tame problem contexts, respectively. Conceptualising ISSPS diagnosis along the appreciation and analysis phases is consistent with Davies *et al.*'s (2005) complex systems' diagnostic process. After comparing the M-B framework, Ackoff's (1978) process model and Simon *et al.*'s (1987) conceptualisation of problem-solving and decision-making model, Davies *et al.* (2005) came to the conclusion that complex systems diagnosis involves these two phases. The remainder of this section describes the appreciation and analysis phases and develops criteria that should be considered when comparing various tools.

CRITERIA FOR SELECTING APPRECIATION TOOLS

Wicked problems are socially-constructed and as such, research into such contexts should be interpretive (Houghton and Tuffley, 2015). Camillus (2008) argues that messy problem contexts should be approached using systematic social processes. An interpretive approach understands reality as defined by subjective experiences of individuals (Thanh *et al.*, 2015). According to Yanow and Schwartz-Shea (2015), interpretive research understands the world through individuals own background and experiences. The appreciation phase as described by Bhaskar (1979) is therefore more appropriate for such problem contexts. The appreciation phase is interpretive and based on the rationale that different worldviews give a full representation of a problem context.

Various researchers advocate for the use of participatory approaches within the appreciation phase (Zlatanovic, 2017; Small and Wainwright, 2014; Mingers and Rosenhead, 2004). According to von Korff *et al.* (2012), participatory approaches improve the legitimacy of findings since participants learn about issues and discover a common ground. Although convergence of views is not necessarily the aim of appreciation, in practice partial convergence emerges (Small and Wainwright, 2014). Consequently, appreciation tools should be both

iterative and interactive (Friend and Hickling, 2012; Belton and Stewart, 2010; Eden and Ackermann, 2009).

Interactive is important as appreciation seeks to elicit resolutions through debate and negotiation (Belton and Stewart, 2010). Interactions between participants and that of participants with the facilitator(s) are required in order to mutually capture issues. According to Franco and Montibeller (2010), interactions between participants and the model reshape the modelling process. Iterative-ness on the other hand is important in order to ensure that problem representation adjust to reflect the state and stage of discussion (Mingers and Rosenhead, 2004). According to Rosenhead (1996), appreciation tools should be able to operate non-linearly, switching freely between different modes of interventions. Franco and Montibeller (2010) refer to this iterative-ness as “phased-ness” and posit that iterative tools ensure a tangible product without having to pass through all phases of a process. Iteration leads to the premature termination of the tendency towards satisficing (Katina, 2017).

Mingers and Rosenhead (2004) suggest that appreciation tools should be cognitively accessible to accommodate audiences from a range of background. Accessibility as defined by Sibbesen and Leleur (2006) refers to the tool’s ease of use and whether it requires specialised skill (or software) or not. According to Rosenhead (1992), tools annotated with mathematical equations and symbols require a certain level of skill and as such, promote unease among most people. Appreciation tools should also be transparent and nothing should be done in secrecy (Myllyviita *et al.*, 2014; Eden and Ackermann, 2004). Rosenhead (1996) argues that ownership of the diagnosis process is only guaranteed through transparency of representation. Representing problem complexity graphically rather than algebraically or in numerical tables improves participation (Rosenhead, 1992).

CRITERIA FOR SELECTING ANALYSIS TOOLS

The analysis phase is a cause-and-effect stage of diagnosis (Mingers, 2006). Analysis explains the underlying causal structures that maintain certain problems. According to Raia (2008), asking “why” and “how” establishes causal determinants of an observed phenomenon. The analysis

phase as a result, embraces a wide range of tools, both quantitative and qualitative (Bezuidenhout *et al.*, 2014).

Cause-and-effect describes the relationship between an event (cause) and a second event (effect), where the first event is understood to be responsible for the second. According to Wiener's (1966) framework, the causality of a variable in relation to another can be measured by how well that variable helps to predict the other. Causality can take the form of directionality, information transfer and independence (Razak and Jensen, 2014). Doggett (2005) views cause-and-effect as a combination of both factor relationships and causal interdependence.

Cause-and-effect in complex systems is not only linear but is also characterised by feedback which shows how actions reinforce or balance each other. Complex systems therefore, require tools that capture feedback structures. Sterman (2000) is of the view that human mental models are based on linear thinking and as a result, often neglect feedback. Consistent with Sterman's (2000) view, Razak and Jensen (2014) note that most cause-and-effect tools neglect feedback. In such cases cause-and-effect is only described with respect to events rather than behaviour.

Analysis tools should be able to capture time delays (Sterman, 2000; Simonovic, 2011). Schaffernicht and Groesser (2011) posit that time delays, in combination with feedback, create system instability and the tendency to oscillate. Analysis tools should clearly present a mechanism for testing cause-and-effect logic (Goldratt, 1992). This should be done to ensure validity of the revealed root cause (Gano, 2003). According to Cook *et al.* (2002), causality requires three conditions: (a) covariation of cause-and-effect, (b) temporal precedence (cause precedes the effect in time) and (c) non-spuriousness (no plausible alternative explanation). Moreover, Dettmer (2007) posits that the validity of causal connections in trees and diagrams should be governed by a set of logic rules called the “Categories of Legitimate Reservation” (CLR). The purpose of these rules as stated by Burns and Musa (2001), is to espouse the criteria that govern causal connections acceptability. There are eight logic rules categorised into three levels *viz.* level 1 reservation (clarity), level 2 reservations (entity existence, causality existence) and level 3 reservations (cause sufficiency, additional cause, cause-effect reversal, predicted effect, and tautology).

The clarity rule explains the extent to which a given model communicates the implied causality. It checks for complete understanding of the cause entity, effect entity and the causal link. Questions addressed by clarity rules include: (a) is the connection between cause and effect convincing at “face value”; (b) is there any verbal explanation required to understand cause and effect and; (c) is the link too long (i.e. missing intermediate steps). The entity existence rule verifies the existence of the statement or fact. It challenges the existence of either the cause or effect entity in reality. In causal existence, however, the existence of the link is called into question.

Level 3 reservations are used only after levels 1 and 2. The cause sufficiency rule examines whether a cause entity (on its own) is sufficient enough to have specific effect. It asks the question “can the cause on its own create the effect or must it exist in concert with other causes?” The additional cause rule on the other hand, searches for the existence of a completely separate and independent cause to a specific effect. This reservation examines whether there are circumstances where the effect would still persist even after removing the cause in question. Cause-effect reversal questions the direction of causal links. This reservation is used to challenge the thought pattern where the cause and effect seem reversed. The predicted effect reservation searches for additional expected and verifiable effects of a particular cause. It seeks to determine whether the cause itself is tangible. If not, it searches whether there exists one or more additional predicted effects. Lastly, tautology or the circular logic reservation checks whether the effect is not a sole and insufficient proof offered for cause existence. Tautology is often a result of an abstract cause that is difficult to determine and define.

3.5.2 Systemic diagnostic tools

This section reviews some of the systemic diagnostic tools that are widely used in ISSPS and/or agricultural systems. A brief description of each tool including its history, application within agriculture and its limitations is provided. The review does not, however, represent an exhaustive list but rather focuses on tools that the researcher believes are suitable within agri-industrial systems. The tools reviewed are the current reality tree, fuzzy cognitive maps, network

approaches, rich pictures, stock and flow diagram, causal loop diagram, and cause and effect diagram.

CURRENT REALITY TREE

The current reality tree is a technique from Goldratt's Theory of Constraints (TOC). The TOC as a methodology is premised on the assumption that within any system there exists a constraint or a few that limit system's performance and that it is possible to identify such constraint(s) for improvement purposes. First developed by Eliyahu Goldratt in the late 1970's, TOC is a tool that links hard and soft system issues (Siriram, 2012).

Current reality trees (CRTs) are logic-based cause-and-effect tools that identify observed undesirable effects (UDE) and postulate probable causes. These UDE can be physical or non-physical. According to Oglethorpe and Heron (2013), TOC tools encompass physical, behavioural, institutional, and political constraints. Current reality trees are, however, most effective in policy-related constraints as opposed to physical (Kim *et al.*, 2008). This is largely due to their subjective approach. Machado (2015) used CRTs to capture factors affecting the efficiency of ethanol production in an ISSPS. Mena *et al.* (2011) used CRTs to determine causes of food waste in the UK and Spain. Current reality trees have also been used to identify UDE in a fresh fruit and vegetables supply chain (Taylor and Esan, 2012).

Logic rules, often referred to as *Categories of Legitimate Reservation*, are the core "ingredients" of CRTs construction. According to Kim *et al.* (2008), logic rules provide "analytical rigour" to CRTs modelling process. They help a researcher identify the validity of the constructed logic relations. A current reality tree generally includes at least one positive feedback loop (Tulasi and Rao, 2012). A loop's position provides guidance on leverage action as a change in or below the loop affects the system (Gupta *et al.*, 2010).

Current reality trees can be drawn from interviews, brainstorming, open discussions, and/or a combination thereof. The complex nature of constructing CRTs and their logic system does not only make CRTs difficult to comprehend but also time-consuming (Kim *et al.*, 2008; Doggett,

2005). Goldratt (1990) alludes to the fact that TOC requires a skilled facilitator and cooperation from participants.

FUZZY COGNITIVE MAPS

Fuzzy cognitive maps (FCMs) are signed digraph models first introduced by Kosko (1986) as an extension to cognitive maps. They are a combination of cognitive maps with fuzzy logic and neural networks (Vergini and Groumpos, 2016). Papageorgiou and Salmeron (2013) assert that FCMs depict and analyse human perceptions. Instead of only using signs to indicate the direction of cause-and-effect (as is the case with cognitive maps), FCMs also associate a weight with each causal link. Lopolito and Prosperi (2009) applied FCMs to capture stakeholders' perceptions in a bio-refinery. Fairweather (2010) used FCMs to model perceptions in a dairy supply chain. Fuzzy cognitive maps have further been used to diagnose collaboration issues (Buyukozkan and Vardaloglu, 2009), inter-firm trust (Abbas, 2014), political forces (Al Shayji *et al.*, 2011), and cultural issues (Ruan and Mkrtchyan, 2012).

Fuzzy cognitive mapping is conducted through interviews, worksheets, pattern notes, and/or reports (Xiang and Formica, 2007). The process involves: (a) the identification of key system concepts (trends, actions, events, or goals), (b) identification of causal relationships between concepts, and (c) determining the strength of each causal relationship. In a graphical form these concepts are represented as nodes (C_{ij}) and the causal relationships as edges (W_{ij}). Edges express the type and degree of causality and can be one of three types; either positive ($W_{ij} > 0$), negative ($W_{ij} < 0$) or no relationship whatsoever ($W_{ij} = 0$). Cheah *et al.* (2011) allude to the fact that in most cases a scheme of linguistic modifiers is prepared beforehand to convert discrete linguistic weights into continuous numerical values. This is necessitated by the fact that most people relate easier to linguistic weights than numerical (Cheah *et al.*, 2011). Papageorgiou and Salmeron (2013) argue that FCMs dynamics are based on first order logic and as such, FCMs cannot handle randomness associated with complex systems. The actual mapping process itself can be demanding, especially when large systems with multiple nodes are considered. The combination of FCMs from different sources into a single map as indicated by Hanafizadeh and

Alihyaei (2011), however, is oblivious of the fact that each individual map represents only a partial view of the system.

NETWORK ANALYSIS APPROACHES

Network analysis approaches (NA) use techniques from graph theory, algebra and statistics to study relational and structural properties (Mueller *et al.*, 2008). Bellamy and Basole (2013) are of the view that network analysis approaches offer a bridge between technical and social issues. Collins *et al.* (2009) posit that NA integrate qualitative and quantitative data and as such, are applied in both hard and soft contexts. Network analysis approaches have been used to diagnose various issues in ISSPS (Sanjika *et al.*, 2012; Bezuidenhout *et al.*, 2013; Kadwa *et al.*, 2014). They have also been used to research collaboration issues (Borg *et al.*, 2015), culture (Zagenczyk *et al.*, 2010), and information sharing (Capo-Vicedo *et al.*, 2011).

Network analysis approaches utilise information gathered through interviews and records (Oancea *et al.*, 2017). A network analysis model consists of a set of elements and a collection of links or connectors between these entities. Graph theory is applied to the links to determine relationships between individuals, detect singular nodes, and to identify properties of the entire network (Reffay and Martínez-Mones, 2011). An important attribute of NA is finding actors that have a central position within a particular network (Mueller *et al.*, 2008). From graph theory, centrality has three measures *viz.* degree, betweenness and closeness (Baruah and Bharali, 2017). Degree centrality describes the number of ties that a given node has whilst closeness is a measure of global centrality (Koschutzki and Schreiber, 2008). A high degree centrality reflects high connectivity. Closeness centrality gives an estimate of how closely connected a node is to others in a particular network. Betweenness on the hand is a measure of brokerage and measures how often a particular node appears on the shortest path between nodes (Martinez-Lopez *et al.*, 2009).

Bezuidenhout *et al.* (2013) used NA to identify constraints in the South African ISSPS. Interviews were conducted and through logical relationships, connectivity between issues was established. Researcher's perceptions in the network construction process often introduce bias into the map (Bezuidenhout *et al.*, 2013). Also, large data can overwhelm generic network

software (Martinez-Lopez *et al.*, 2009). Results from NA are only a “snapshot” in an evolution process and should therefore, not be generalised as they are time-specific.

RICH PICTURES

Rich pictures (RP) are a flexible graphical tool from Peter Checkland’s Soft Systems Methodology (SSM). Soft Systems Methodology is a popular soft approach widely used to unlock, structure and interpret social complexity (Checkland and Poulter, 2006). It is premised on the fact that complex systems are social constructs characterised by multiple perspectives. Rich pictures as a tool provide a detailed representation of these problem contexts. According to Parker *et al.* (2010), RP give a broad, high-grained view of a problem context. Rich pictures perform three kinds of inquiries *viz.* intervention, social and political analysis (Checkland and Poulter, 2006). Shongwe (2018) and Gerwel-Proaches and Bodhanya (2015) amongst others, used RP to diagnose systemic issues within the South African ISSPS.

Rich pictures can be drawn by participants and/or the facilitator in a participative environment or by a researcher during interviews (Kotiadis and Robinson, 2008). The drawing of RP, however, does not have a specific format or language but rather depends much on the skill and purposes of the person(s) doing the drawing. This characteristic makes third party interpretation difficult as people may mistake and misconstrue meaning (Berg and Pooley, 2013). In addition, the whole rich picture process can take a long time to complete considering multiple revisions.

CAUSAL LOOP DIAGRAMS

Causal loop diagrams (CLDs) are foundational System Dynamics tools used to conceptualise and structure complex issues (Chaerul *et al.*, 2008). They seek to develop a holistic view of how relationships between variables influence the dynamics of a system (Giordano *et al.*, 2007). Causal loop diagrams are used to represent and communicate feedback. A causal loop diagram consists of variables connected by cause-and-effect links. These links have either a positive (+) or negative (-) polarity, which indicates the direction of causality between the variables when all other variables are conceptually constant (Koca and Sverdrup, 2012). When the causal links

close (in a circular fashion) feedback loops form and these are of two types *viz.* positive or negative. A negative feedback loop exhibits a goal-seeking behaviour whilst a positive loop shows a reinforcing behaviour (Upadhayay and Vrat, 2017).

Causal loop diagrams are developed from information gathered through interviews, observations, archives, and focus groups (Sterman, 2000). Causal loop diagrams have been used to capture issues in Brazilian ISSPS (Mishra *et al.*, 2004). Ibarra-Vega (2016) used CLDs to model waste management issues in a bioethanol plant. Furthermore, CLDs have been used to diagnose collaboration issues (Lourenzani and Silva, 2010), culture (Mathew *et al.*, 2012) and strategic issues (bitrus Goyol and Dala, 2013). Causal loop diagrams do not distinguish between stock and flow structures and as a result the logic behind some causal links may be misinterpreted (Lane, 2008; Natarajan *et al.*, 2009). Schaffernicht (2010) is of the view that the most common limitation of CLDs is mislabelling of loop polarity.

STOCK AND FLOW DIAGRAM

Unlike CLDs, stock and flow diagrams (SFDs) are a more detailed System Dynamics technique. They distinguish between the different types of variables and causal links. Stocks describe the state of the system over time and represent major accumulations whilst flow variables denote the rate of change in stock. According to Sterman (2000), stocks provide systems with inertia and memory and as such, are a source of delays. Stocks also decouple rates of flow, a characteristic that makes them to be a source of disequilibrium dynamics. Stock and flow diagrams have been used to model ethanol production in Mexico (Rendon-Sagardi *et al.*, 2014). Sandvik and Moxnes (2009) used SFDs to evaluate the effects of ethanol production on the price of oil.

The construction of SFDs includes the identification of critical stocks, determining the flows and defining converters. Stock and flow diagrams can also be constructed by converting CLDs (Peters, 2014; Schaffernicht, 2010). Due to their technical orientation, SFDs are, however, too complex to comprehend (Zlatanovic, 2012). According to Lane (2008), SFDs often fail to communicate the location of loops.

CAUSE AND EFFECT DIAGRAM

Cause and effect diagrams (CEDs) are used in many fields to identify and group potential causes to problems. The tool was first introduced by Kaoru Ishikawa in the early 1940's (Doggett, 2005). Kumar and Nigmatullin (2011) used CEDs to determine demand uncertainty in a non-perishable food supply chain. Trybus and Johnson (2010) applied CEDs to determine causes of food contamination. Similarly, Mariajayaprakash and Senthilvelan (2014) used CEDs to identify parameters that caused conveyor failure at a sugar plant.

Cause and effect diagrams use interviews and brainstorming to identify potential causal factors. Andersen and Fagerhaug (2006) suggest a three-step procedure to drawing CEDs: (a) the problem is written on the right end of a large arrow, (b) the main categories that causes the problem are written as major branch arrows emanating from the main arrow and, (c) for each major branch, detailed causal factors are written as twigs, and these are analysed to determine the likely root causes. According to Jayswal *et al.* (2011), the major categories should not exceed eight per diagram. Cause and effect diagrams, however, do not show causal relationships between interrelated issues (Zhu, 2010).

3.5.3 Synthesis

The ISSPS heuristic is developed in this Section through the synthesis of information discussed in Section 3.5.1 and Section 3.5.2. Table 3.1 shows the performance of the various systemic tools discussed in Section 3.5.2 on the diagnostic criteria developed in Section 3.5.1. Also indicated in Table 3.1 is the suitability of each tool to diagnose issues on each of the ISSPS domains. Doggett (2005) used a combination of nominal and ordinal scales to compare the performance of various root-cause analysis tools. Jun *et al.* (2011) on the other hand, employed a cardinal scale to compare the performance of several methodologies on resource-based criteria. Through the use of TOPSIS this research developed a qualitative heuristic that allows objective comparison of tools. The criteria and performance scores are discussed immediately after Table 3.1.

Table 3.1 The performance of various tools against the diagnostic criteria

Tools	Diagnostic criteria						
	Appreciation criteria				Analysis criteria		
	Accessibility	Interactive	Iterative	Transparency	Feedback	Delays	Cause & effect logic
Cause and effect diagrams	4	2	3	5	0	0	1
Causal loop diagrams	3	3.5	4	4	5	4	3
Current reality trees	3	5	2	5	2	0	5
Fuzzy cognitive maps*	3.5	3	3	3	3	0	2
Rich pictures	5	4	1	5	0	0	0
Network analysis approaches	1	1	3	1	3	0	2
Stock and flow diagrams	2	4	5	4	5	5	4

*should be applied with caution in the biophysical domain

The criteria as deliberated in the Section 3.5.1 are accessibility, iterativeness, interactiveness, transparency, feedback, time delays, and cause-and-effect logic. Cause-and-effect logic as a criterion is conceptualised along the eight logic rules *viz.* clarity, entity existence, causality existence, cause sufficiency, additional cause, cause-effect reversal, predicted effect, and tautology. As stated in Section 3.4, a score of 5 indicates excellent performance and 1, very poor. A score of zero (0) is used to specify no relationship whatsoever.

Ontologically, NA, RP and the CRTs are well-suited across all ISSPS domains. These three tools plus FCMs are the only tools suitable for less abstract problem contexts. The rest of the tools begin from a more structured context. As a result, CRTs have been applied before CLDs (Mohammadi *et al.*, 2015; Ahmad *et al.*, 2010) and SFDs (Ahmad *et al.*, 2017). In the same vein, rich pictures have preceded CLDs (Setianto *et al.*, 2014), FCMs (Hjortso *et al.*, 2005; Hanafizadeh and Aliehyaei, 2011) and Bayesian networks (Shongwe, 2018). Similarly, cognitive maps have been used with CLDs (Duryan *et al.*, 2014; Giordano *et al.*, 2007), and Bayesian networks (Wee *et al.*, 2015).

Compared to the rest of the tools in the heuristic, RP are the most transparent and accessible tools more especially because humans easily identify with picture representation (Bell and Morse, 2013). Rich pictures were, however, the least iterative tool in the heuristic as the drawing of pictures cannot be “phased”. Current reality trees on the other hand, were the most interactive of all the tools in Table 3.1. Doggett (2004) posits that the CRTs logic and construction rules promote dialogue and discussion. A study by Doggett (2005) pointed out that CEDs were more accessible than CRTs. As indicated in Table 3.1, RP do not have “analysis” capabilities and as a consequence, have a score of zero for feedback, cause-and-effect logic, and time delays.

Causal loop diagrams are less iterative and interactive compared to SFDs based on the fact that SFDs are constructed (sometimes) from CLDs (Schaffernicht, 2010). Furthermore, the construction of SFDs requires a certain level of technical skills which renders them even less accessible than most of the tools in the heuristic. Compared to CLDs, FCMs are less interactive due to the fact that their causal links are based on first order logic, which happens to be the first step in the development of CLDs links (Papageorgiou and Salmeron, 2013). The use of language modifiers within FCMs reduces their transparency especially when compared to CED, CLDs, CRTs, RP and SFDs. Besides the language modifiers, FCMs are based on a

“natural” language that is easily understood by most people hence, they are more accessible compared to CLDs, CRTs, NA and SFDs. Networks analysis approaches are least accessible, least transparent and are poor interactively compared to all the tools in Table 3.1. The use of special software immediately after compiling worldviews and the fact that identifying cause-and-effect requires some knowledge of the entire system makes this tool less suitable for participatory modelling.

Network analysis approaches, FCMs, CRTs, CLDs and SFDs are the only tools in the heuristic that capture feedback. Nevertheless, feedback in NA, FCMs and CRTs is not conceptualised and signalled separately as is the case with CLDs and SFDs. Furthermore, these tools (NA, CRTs, and FCMs) do not capture feedback loop polarity. Feedback polarity is important for converting information about structure into behaviour. McNally (2011) views feedback in CRTs as “occasional”. Youngman (2003), however, argues that a current reality tree is not complete without a feedback loop.

None of the tools in Table 3.1 capture time delays except CLDs and SFDs. Park and Kim (1995) acknowledge this “weakness” with FCMs and suggest the use of dummy delay nodes in what they call “*fuzzy time cognitive map*”. Between the two system dynamics tools, SFDs explicitly capture delays through stocks and decoupling rates whilst CLDs only indicate delays through a “hash” sign. Current reality trees critically validate cause-and-effect logic as their construction is based on the CLR. Burns and Musa (2001) proposed that the CLR should be incorporated into CLDs to improve model validity. Cause and effect diagrams, in contrast, sort and relate causes within a classification schema. Hence, in terms of the cause-and-effect logic criterion, CEDs are susceptible to low clarity levels. The classification schema, in general, makes the application of level 3 reservations difficult.

The nodes in FCMs and NA are more abstract (concepts) compared to those in CLDs and SFDs which utilise variables. Fuzzy cognitive maps and NA as such, are more susceptible to tautology than their System Dynamics counterparts. In addition, the circular conceptualisation of causality in System Dynamics is more rigorous especially when compared to conceptualisation of FCMs and NA. As a result, CLDs and SFDs are less prone to the cause-and-effect reversal rule. In relation to the cause sufficiency reservation, the use of Behaviour Over Time charts within SFDs makes these superior to CLDs (Table 3.1).

All the tools in the heuristic could be applied across all the ISSPS domains except for FCMs which are explicitly subjective. Fuzzy cognitive maps' contribution lies within the soft paradigm rather than an objective world. This heuristic therefore, recommends that FCMs should not be used in isolation when diagnosing issues within the biophysical domain. All the System Dynamics tools in Table 3.1 could be applied across all domains. There is, however, an on-going debate on the use of SFDs outside the material world (Hayward *et al.*, 2014; Vespignani, 2009; Levine 2000). Causal loop diagrams, in contrast, are widely applied within the social and personal worlds. Mingers (2006), however, argues that CLDs contribute weakly to the diagnosis of social problems mainly because social systems are largely subjective.

Table 3.2 shows the output of a TOPSIS model obtained after using Table 3.1 as a decision matrix and assuming an equal criteria weight of 0.143 ($w_{j=1-7} = 0.143$). From this example SFDs were the highest ranked tools ($C_i^* = 0.765$) followed by CLDs ($C_i^* = 0.715$). It is important to note that SFDs and CLDs were the only tools in the Table 3.1 that met all the criteria. Stock and flow diagrams however, were superior to CLDs in terms of the iterativeness, cause-and-effect logic and time delays criterion. They are, however, the second least accessible tool after NA (Table 3.1) since they are considered too complex to comprehend. Hence, as advocated for by Burns and Musa (2001), the use of SFDs can be strengthened by the adoption of all the CLR.

Table 3.2 Results of TOPSIS based on equal weighting

Tool	S_i^*	S_i'	C_i^*	Rank
Cause and effect diagrams	0.169	0.083	0.329	6
Causal loop diagrams	0.063	0.158	0.715	2
Current reality trees	0.136	0.134	0.495	3
Fuzzy cognitive maps	0.142	0.091	0.393	4
Rich pictures	0.182	0.096	0.346	5
Network approaches	0.170	0.071	0.295	7
Stock and flow diagrams	0.056	0.184	0.765	1

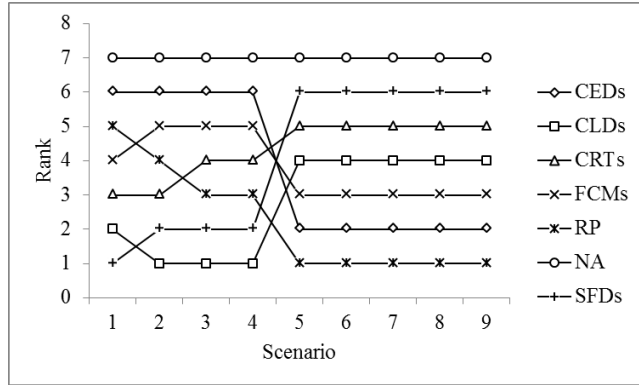
S_i^* = separation from positive ideal solution

S_i' = separation from negative ideal solution

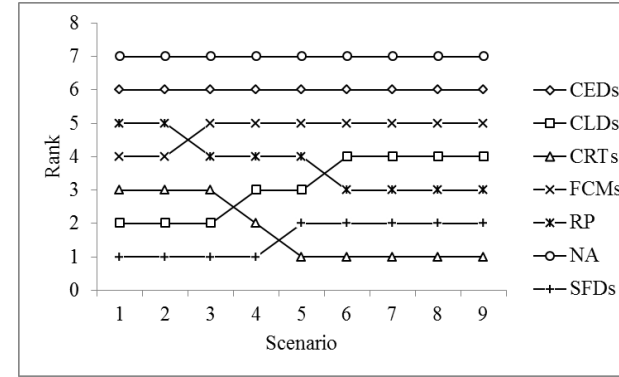
C_i^* = relative closeness to ideal solution

The low rank of NA in Table 3.2 is a consequence of its low performance (1) on the appreciation criteria *viz.* accessibility, interactiveness and transparency (Table 3.1). The ranking of CEDs on the other hand, was low because these tools have less analysis capabilities (only cause-and-effect logic). Although RP are strictly appreciation tools, they were ranked higher than CEDs (Table 3.2) owing to the fact that RP performed better than CEDs on the accessibility and interactiveness criteria. Cause and effect diagrams and RP can, however, be used in tandem with other analysis tools. Doggett (2005) stated that CEDs can be used in tandem with CRTs where the output from CEDs is used to develop a list of UDEs for the current reality tree. As seen in Table 3.2, the selection criteria and the criteria weight had a huge influence on the tools ranking. A change in criteria, for example to appreciation criteria only, could probable result in a different conclusion. Similarly, a change in criteria weight is expected to have an impact on rankings.

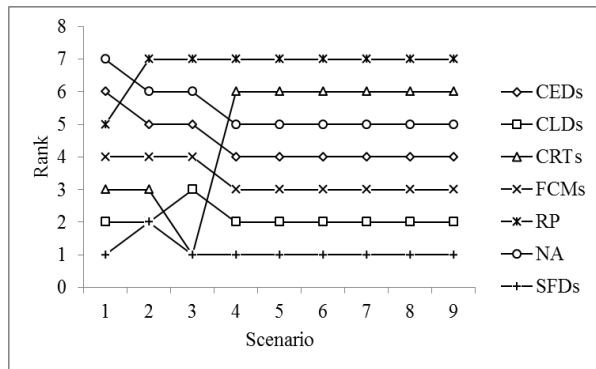
Using the equal weighting (0.143) as a basis, sensitivity analysis of the tools to criteria weight was conducted to determine the influence on rankings. The analysis followed a method by Alinezhad and Amini (2011) where the weight of each criterion is varied whilst that of other criteria is multiplied by a common ratio. For application examples of this method refer to Fox and Everton (2014) and Hanine *et al.* (2016). In this study, sensitivity analysis was conducted by varying the appreciation criteria *viz.* accessibility, interactiveness, iterativeness, and transparency. Selection of these criteria was founded on the fact that the performance of all the heuristic tools against the appreciation criteria was more than zero (Table 3.1). Figure 3.2 shows the results of the sensitivity analysis where the weight of (a) accessibility, (b) interactiveness (c) iterative-ness, and (d) transparency increases from scenario 1 to scenario 9 towards a value of 1.



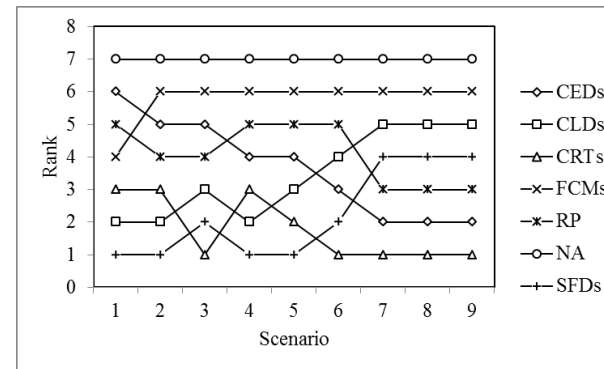
(a) Accessibility



(b) Interactiveness



(c) Iterativeness



(d) Transparency

Figure 3.2 Sensitivity analysis of appreciation criteria

All the tools were sensitive to criteria weights, which is critical for the MCDA model (Figure 3.2). Stock and flow diagrams were the most sensitive as indicated by the change in rankings for three of the four criteria (6 in Figure 3.2 (a), 2 in (b), and 4 in (d)). The high sensitivity of SFDs is partly due to the fact that SFDs met all the criteria. The sensitivity of SFDs under the iterativeness criterion (Figure 3.2 (c)), however, was low as these tools were ranked first in almost all of the scenarios. This can be attributed to the relatively high performance score on the iterativeness criterion as indicated in Table 3.1. This was also the case for RP and CRTs in the accessibility and interactiveness criteria, respectively. Network analysis approaches were the least sensitive tools as revealed by their continuous low rank (7) in the accessibility, interactiveness, and the transparency criteria. This is compatible to the low performance scores for these criteria as indicated in Table 3.1. Similarly, high performance scores (5) in the transparency and interactiveness criteria resulted in a positive rank change for CRTs to first.

3.6 Conclusion and Recommendations

The complex nature of ISSPS makes it practically difficult to diagnose issues that constrain productivity within these systems. The matter is further complicated by the fact that most of the diagnostic tools available are only tailored for specific problem contexts. In such complex environments matching and selecting appropriate tools becomes a challenge. This research developed a heuristic that could be used to objectively compare and select diagnostic tools in ISSPS. Even though the focus is on sugarcane systems, the attributes of ISSPS make the heuristic a relatively general approach to integrated agricultural supply and processing systems. It is therefore envisaged that the heuristic will also be transferable to other agri-industrial systems.

Systemic diagnostic criteria were developed based on the appreciation and analysis phases of multimethodology and a suite of diagnostic tools was compiled. The performance of the tools against the criteria was synthesised and the resultant performance matrix used as an input into the TOPSIS. The suitability of each tool to diagnose issues within each of the ISSPS domains was also determined. The diagnostic criteria included accessibility, interactiveness, iterativeness, transparency, feedback, cause-and-effect logic, and time delays. The suite of tools consisted of CEDs, CLDs, CRTs, NA, RP, and SFDs. It was shown in the study that each tool provides a different facet to complexity. Hence, the apparent need for

multimethodology in ISSPS. All of the tools in the heuristic could be applied across all criteria (appreciation and analysis) except for RP. Rich pictures are strictly appreciation tools and as such, do not have causal analysis capabilities *viz.* time delays, cause-and-effect logic and feedback. It was further revealed that issues in the soft (culture, collaboration and political forces) and strategic domains (environment, future strategy and structure) could be diagnosed by any of the tools in the suite. Issues in the material world (biophysical domain), however, could not be fully diagnosed by FCMs as these tools are explicitly subjective. Sensitivity analysis of the TOPSIS model revealed that SFDs were the most sensitive tools in the heuristic whilst NA were least sensitive. The sensitivity analysis outcome supports the view that criteria weights facilitate the choice of alternatives.

The heuristic is only an aid to decision making. The final decision on whether to select or not depends on the decision-maker(s). The effectiveness of the tool(s) or a combination thereof in contrast, lies with the tool's integrity and its application by the user(s). The study excluded resource-based criteria (e.g. time and cost) as these are not entirely dependent on the tool. For future research it is recommended that such criteria be incorporated into the heuristic. With such criteria incorporated, pairwise comparison of tools by industry experts could be explored. It is further recommended that the heuristic be demonstrated in an actual ISSPS.

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CHAPTER 4: A SYSTEMS THINKING APPROACH TO INVESTIGATING COMPLEX SUGARCANE SUPPLY AND PROCESSING SYSTEMS: INTEGRATING RICH PICTURES AND BAYESIAN NETWORKS

4.1 Abstract

Diagnosing problems in complex systems such as integrated sugarcane supply and processing systems (ISSPS) calls for a systematic approach. This is vital given the numerous stakeholders and their various (sometimes conflicting) objectives. Since these systems are socially constructed, most interventions should develop a shared understanding of the issues and decision-making processes. Failure to simultaneously accommodate different perspectives may lead to interventions on wrong issues. Given the context, a diagnostic study was undertaken at Mhlume sugarcane milling area in Swaziland to identify issues that constrained productivity in the system. Interviews were conducted and issues affecting the area were modelled as a rich picture. The findings were communicated back to the stakeholders in a report-back meeting. The issues that constrained productivity in the area could be classified as environmental (rainfall), biophysical (farm roads, factory stops, sugarcane quality, sugarcane delivery schedule), structural (irrigation water, harvesting contracts), political (grower infighting, harvesting schedules, haulage schedules), and cultural (labour unrest, vehicle labelling, consignment, field numbers). A Bayesian failure model was thereafter developed to determine the probability of a shredder breakdown. Results from the model estimated the probability of breakdown to be 0.124. The months of April and May appeared to be more susceptible to breakdowns than the other months. Chokes and rotor failures were found to be the main causes of shredder breakdowns. Hence, it was recommended that further analysis of shredder breakdown be conducted especially along shredder capacity, sugarcane quality and preventative maintenance. Most of the identified issues in the milling area were linked to information sharing and the collaboration domain. It was therefore, recommended that interventions in the area should be towards these domains (collaboration and information sharing) as they could provide higher leverage into most issues.

Keywords: *complexity; systems thinking; modelling; rich pictures; Bayesian networks*

4.2 Introduction

Integrated sugarcane supply and processing systems (ISSPS) are complex systems with an overwhelming number of interactions and interdependencies (Sanjika and Bezuidenhout, 2015; Bezuidenhout and Baier, 2011; Higgins *et al.*, 2010). These systems are characterized by a large number of autonomous but mutually interacting stakeholders. As a consequence, ISSPS face the existence of diverse mental models, goals, values, expectations, and strategies (Bodhanya, 2011; Gerwel *et al.*, 2011). Accordingly, Bezuidenhout *et al.* (2012) posit that ISSPS exhibit several complex systems' characteristics *viz.* non-linearity, feedback, counter-intuitive behaviour, emergence, constant change, co-evolution and trade-offs. As complex systems, ISSPS are characterised by mechanical and/or wicked problem contexts (Jackson, 1991). A mechanical or technical problem describes a simple, well-defined problem that can be solved through reductionist thinking (Wexler, 2009; Batie 2008; Senge *et al.*, 1994). Wicked problems in contrast, are socially-constructed and have no unique definition (Franco and Montibeller, 2010; Giordano *et al.*, 2007). In wicked contexts there are differences of opinions about the problem and/or even the question of whether a problem exists or not (Horn and Weber, 2007). According to Rosenhead and Mingers (2001), problem definition in complex systems is more difficult than to generate a solution. Sanjika (2013) noted that diagnosing issues in ISSPS can be difficult and time-consuming. The complex nature of ISSPS as such, is often viewed as a barrier to system improvement (Higgins *et al.*, 2010; Higgins *et al.*, 2007). Archer *et al.* (2009) argue that complexity is one the main factors that hinder the adoption of technologies in ISSPS.

Complexity as a consequence, introduces the need for systems thinking (Malan and Pretorius, 2015; Higgins *et al.*, 2007; Siriram, 2012). A systems view is important given the conflict, pressure and policy resistance that come with different stakeholders. Failure to accommodate the perspectives from various stakeholders has in the past contributed to right solutions on wrong problems (Franco and Montibeller, 2010; Keating, 2011). A holistic approach to ISSPS diagnosis should simultaneously consider both wicked and/or tame contexts (Bezuidenhout and Baier, 2011; Shongwe, 2018). Most diagnostic tools available are, however, not capable of such as they are only designed to deal with specific problem contexts

and, generally within a single paradigm. The practice of multimethodology can as such, offer a better means to systemic diagnosis of complex systems such as ISSPS.

Multimethodology, as defined by Mingers and Brocklesby (1997), refers to an *ad hoc* creative combination of different methodologies, or parts thereof, within a single intervention. Multimethodology is important in ensuring that methodologies and techniques are selected based on their strength in relation to the problem context. Multimethodology strength lies in the ability to combine methodologies and/techniques either within or between paradigms. Traditionally, two paradigms exist *viz.* soft and hard. Hard paradigms view the “world” as objective whilst soft paradigms are based on a subjective meaning. Soft system approaches are used to attain a comprehensive view of issues within complex contexts. Their aim is to gain a mutual understanding of personal worldviews and objectives. Soft approaches create a better understanding of complexity and generate relevant subsystems that could be further analysed through other methodologies. Hard systems approaches conversely, lack mechanisms for generating multiple perspectives. Soft systems approaches as such, are more useful as a starting point when examining issues in complex systems (Jackson, 1999). Gil-Garcia and Pardo (2006) argue that the use of different methods in multimethodology even when they cover similar functions provides triangulation. In this context, a multimethodological study was undertaken at Mhlume sugarcane milling area in Swaziland. The objectives of the study were to (a) identify the main issues that affect the milling area and (b) to propose an area of focus. The study utilised interviews, rich pictures, open discussions, and Bayesian networks. Accordingly, this article is organised in three sections. The first section describes the Methods used to undertake the research. Results and Discussion follow in Section 4.4 before Conclusion and Recommendations in Section 4.5.

4.3 Methods

A sequential mixed method research design was adopted for this study, conducted at Mhlume in Swaziland. The Mhlume sugarcane mill is a Royal Swaziland Sugar Corporation’s (RSSC) factory located in the north-eastern part of Swaziland at 26°3’S 31°49’E (Figure 4.1). The factory operates a dual tandem (milling tandem and a diffusion tandem) with a combined capacity of 350 tonnes cane per hour. At the back-end the factory operates a sugar refinery with a capacity of 170000 tonnes per season. Two thirds of the sugarcane received at the mill is sourced from independent growers (Royal Swaziland Sugar Corporation, 2015). The

remainder comes from RSSC Estates as a miller-cum-grower. Of the two thirds, 52% is supplied by small-scale growers, largely those under Komati Downstream Development Project (SWADE, 2015; Swazi Review of Commerce & Industry, 2014).

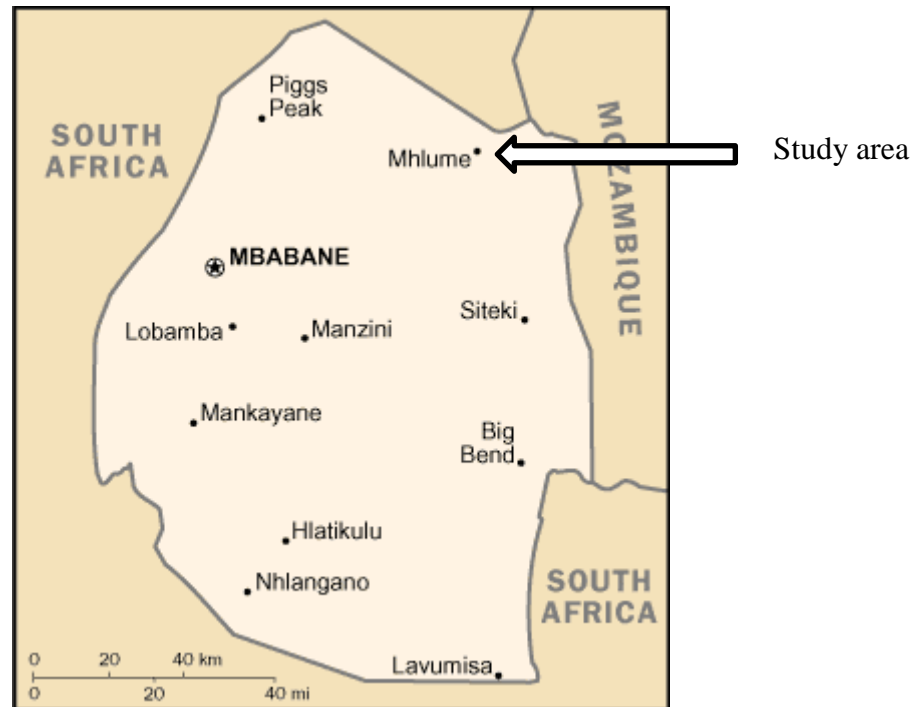


Figure 4.1 Map of Swaziland showing the study area

Mixed methods research is based on the pragmatic paradigm (Shannon-Baker, 2016). Pragmatism is a deconstructive paradigm that combines positivist and interpretivism positions within the scope of a single research. Mixed methods research as such, integrates quantitative and qualitative research approaches (Creswell and Clark, 2011; Johnson *et al.*, 2007). The use of quantitative and qualitative approaches in rapport delivers a better understanding of the research problem than the use of either in isolation (Subedi, 2016). Mixed method research as such provides better inference and through triangulation, minimises methodological bias (Teddlie and Tashakkori, 2009).

A qualitative exploratory approach was adopted for the initial phase of the research where the objective was to identify issues that cause inefficiencies within the area. Exploratory research provides new insights into a phenomenon and is widely used to identify and formulate ambiguous problems (Zikmund *et al.*, 2013; Burns and Grove, 2005). According to Collis and Hussey (2009), exploratory research provides a better understanding of problem contexts

through the identification of key issues, variables and patterns. Qualitative approaches assume a social constructivist stance. Hence, reality is constructed from multiple perspectives (Higgs and Cherry, 2009). In this way, qualitative research facilitates a comprehensive understanding of complex real-world phenomena (Attride-Stirling, 2001).

The term milling area or ISSPS as used in this research describes the segment between sugarcane growing and raw sugar production. This includes components of cultivation, harvesting, transport and milling. The ISSPS up to the point of raw sugar are driven by a wide range of biophysical push factors such as pest and diseases, unpredictable weather, and fluctuating qualities. Post-milling the supply chain drivers change significantly as the product (raw sugar) becomes biologically stable and also becomes the responsibility of one firm. The supply chain downstream as such is driven by market-related forces rather than biophysical push factors. The target population for the study was therefore, amongst others, growers, extension service providers, harvesting contractors, haulers, the sugarcane supply manager and the factory manager. Stakeholders who participated in the research were guaranteed confidentiality and anonymity.

Purposive sampling was used to select a sample of seven respondents (Table 4.1). Purposive sampling is a non-probability sampling technique that relies on the judgement of the researcher to select subjects (Teddlie and Yu, 2007; Teddlie and Tashakkori, 2003). Its strength lies in the ability to select subjects that have more experience or knowledge on the issue(s) being investigated (Teddlie and Yu, 2007). Purposive sampling is widely used to address issues of transferability in qualitative research (Anney, 2014). This is because specific information is emphasised within a purposive sample rather than generalised, as is the case with most quantitative approaches. The respondents in the study represented stakeholders that had been actively involved within the milling area for at least two consecutive years. To the researcher's knowledge, these respondents were highly involved with systemic issues within the area and as such, provided representative viewpoints from their specific profiles. Rather than size, the sample was guided by adequacy, accessibility and availability of stakeholders. Adequacy was determined through theoretical saturation for the factory manager, cane supply manager, cane laboratory manager and the extension services manager. There were, however, possible limitations to this research approach. Despite the fact that the researcher attempted to obtain a representative sample, there could have been bias in the ISSPS representation because only seven stakeholders were interviewed out of potentially hundreds. Secondly, the

interviews were conducted at one particular time and as a result, issues that had been experienced in the recent past may have received more attention than others. Lastly, time constraints may have prevented further questioning.

Table 4.1 Profile of interviewed stakeholders

Stakeholder	Number interviewed
Cane laboratory manager	1
Cane supply manager	1
Extension services manager	1
Factory manager	1
Harvesting contractor	2
Small-scale grower	1

Telephone interviews were conducted to identify the main issues that cause inefficiencies in the milling area. Telephone interviews provided extended access to the respondents and removed the need to travel and as such, reduced time and research cost (Irvine, 2010; Opendakker, 2006). The lack of social cue is, however, a major disadvantage of telephone interviews (Novick, 2008). Sturges and Hanrahan (2004) nevertheless, argued that qualitatively, there is no significant difference in the quality of data collected between telephones versus face-to-face interviews.

The main question posed during the interviews was, “can you identify the major challenges affecting the supply chain”? Further probing was conducted in cases of ambiguity. To improve the credibility of the question(s) the researcher consulted an industry expert (sugarcane supply research). An audio recorder was used to capture each interview. The qualitative data from the interviews were descriptively analysed by transcribing the audio-tape recordings and modelled into a rich picture diagram. The rich picture was then presented to stakeholders for discussion in a report-back meeting held three months after conducting the first interview. The meeting was held at the milling area offices and was attended by four of the earlier interviewees’ viz. cane laboratory manager, cane supply manager, extension service manager and the factory manager. The objectives of the meeting were to present the findings and to collect information on other issues that may have been missed by the interviews. More importantly, the meeting served as a platform to facilitate a shared problem definition (see

Figure 1.1) and to obtain commitment for further action from the stakeholders as this could not be attained through the interviews.

The use of rich pictures in open discussions ensured findings credibility, dependability and confirmability. The discussions enabled member checks and further allowed the researcher to collect information that was missed from the telephone interviews. According to Anney (2014), member checks are used to improve the credibility and transferability of findings. The use of interviews and open discussions for data collection facilitated methodological triangulation. Triangulation, as stated by Treharne and Riggs (2014), increases the credibility and confirmability of qualitative findings. The use of the rich picture in the discussions enabled participants to gain a shared understanding and mutual appreciation of issues from different perspectives. The ultimate goal at the end of the meeting was to obtain a commitment for action. The representation of stakeholders in the meeting was, however, skewed towards the factory (cane supply manager, cane laboratory manager, factory manager) which may have been a limitation to the study. Furthermore, open discussions can be influenced by dominant individuals who could have introduced bias to the output.

Rich pictures are a soft modelling tool based on Peter Checkland's Soft Systems Methodology (SSM). The tool, widely used to take a snapshot of a messy contexts, form the second stage of SSM's seven stage process (Checkland and Poulter, 2006). Rich Pictures represent a broad, high-grained view of the problem context and as a result, convey both hard and soft issues (Parker *et al.*, 2010). Rich pictures are interpretive tools and are used to unlock, structure and to interpret social complexity. They are widely applied in the modelling of complex systems especially, as a precursor to hard operations research tools. They have been used in combination with, amongst others, system dynamics (Rodríguez-Ulloa *et al.*, 2011; Sangeeta, 2010; Bunch, 2003), Bayesian networks (Yasui *et al.*, 2014) and discrete event simulation (Holm *et al.*, 2012; Holm and Dahl, 2011). Hildbrand (2013) used SSM in combination with the viable systems model to surface issues at Mfolozi and Felixton sugarcane milling areas. In this research, rich pictures were selected based on the appreciation criteria of the diagnostic heuristic developed in Chapter 3. The criteria consist of the accessibility criterion, interactiveness, iterativeness, and transparency. Compared to all the tools in the heuristic (current reality trees, fuzzy cognitive maps, network approaches, stock and flow diagram, causal loop diagrams, and cause and effect diagrams), rich pictures were superior in terms of performance on the accessibility and transparency criteria. As indicated

in Chapter 3, the performance of rich pictures on the interactiveness and iterativeness criteria, however, is relatively low especially when compared to current reality trees (CRTs). Rich pictures were, nevertheless, selected over CRTs in this research based on the boundaries of the study. The boundaries (field to factory) were too wide for the construction of a single current reality tree and it would have been very difficult to select individual stakeholders that could have a holistic understanding of cause-and-effect from such a context. Given such boundaries and assuming that time was not limited, various CRTs could have otherwise, been used for each stakeholder group i.e. a current reality tree for growers, one for haulers, harvesting contractors, etc.

It was resolved in the report-back meeting that machine breakdown be considered for further analysis. Hence, historical breakdown data was sourced from the factory for analysis. Since the factory operated a dual tandem, breakdown data for both lines were explored for the 2012 and 2013 milling season through Pareto analysis. Bayesian networks were then used to further analyse breakdowns on the mill tandem. Pareto analysis, also known as the vital few and trivial many, is a quality control tool based on Pareto 20/80 principle (Karuppusami and Gandhinathan 2006). The Pareto principle argues that most problems (80%) are only a result of a few causes (20%). For each tandem the total number of breakdowns per machine over the two-season period was tallied and the grand total determined. A percentage of each breakdown in relation to the grand total was thereafter computed. The different machine breakdowns were then listed in decreasing order and cumulative percentage computed (Karuppusami and Gandhinathan 2006). All machine breakdowns that were less than three minutes were excluded from the Pareto analysis. This was because such breakdowns do not require maintenance personnel to be called into the factory (EXOR/ DataVisor Marquees, 2006).

Bayesian networks are directed acyclic graphs used to represent uncertainty about causal and associational relationships in complex systems (Chung *et al.*, 2004). The nodes represent random variables and the arcs convey conditional independence relations. In particular, two nodes are connected directly if one affects or causes the other, with the arc indicating the direction of the effect. Quantitatively, the dependence relations are expressed in terms of conditional probability distributions for each of the variables in the network (Bayesian inference). Bayesian inference or updating derives posterior probability as a consequence of a prior probability and a likelihood function (Pareek *et al.*, 2016). Bayesian networks as such,

combine data from historical records and/or expert opinions and through visual representation, illustrate genuine cause-and-effect relationships (Jones *et al.*, 2010). They are therefore, particularly suitable for root cause analysis and decision support (Weidl *et al.*, 2008).

Bayesian updating is particularly important in the dynamic analysis of sequential data hence, applied in this research (Barrett, 2014). Bayesian inference derives posterior probability as a consequence of prior probability and a likelihood function. Assuming that evidence E is found, Bayesian networks compute the posterior probability according to the Bayes theorem of conditional probability:

$$p(H|E) = \frac{p(E|H).p(H)}{p(E)} \quad (4.1)$$

where,

$p(H|E)$ = posterior probability, which is the probability of H given E ,

$p(H)$ = prior probability i.e. the probability of hypothesis H before event E is observed,

$p(E|H)$ = likelihood i.e. the probability of observing E given H ,

$p(E)$ = marginal likelihood

Since the breakdown data was binomial, updating was carried out using a beta distribution. The beta distribution is a conjugate prior for a binomial distribution i.e. if the likelihood is binomial and the prior beta, then the posteriors are also beta. All updating was conducted using the NETICA BN software (Norys Software Corporation, 2014). A beta distribution has two parameters, α and β , and its probability density is defined as;

$$p(\theta|\alpha, \beta) = \text{beta}(\theta; \alpha, \beta)$$

$$= \frac{\theta^{(\alpha-1)}(1-\theta)^{(\beta-1)}}{B(\alpha, \beta)} \quad (4.2)$$

where,

$$\theta \in (0,1)$$

$$B = \int_0^1 \theta^{\alpha-1}(1-\theta)^{\beta-1} d\theta$$

A non-informed uniform prior model was used for sensitivity analysis. A uniform prior represents a prior of strong uncertainty wherein any bias is equally probable. According to

Kruschke (2015), priors do not affect the model when there is sufficient data as the likelihood function dominates. Under such contexts Resnic *et al.* (2004) argues that the posterior of both the model and that of the non-informed prior should converge.

“Machine breakdown” as used in this study describes machine interruptions in the raw sugar production process. The raw sugar production process involves six major steps *viz.* sugarcane preparation, juice extraction, clarification, evaporation, crystallisation, and centrifugation (Rein, 2007). Sugarcane preparation is the first step that produces a fine bed of sugarcane fibre. The fibre bed is fed into a milling tandem or diffuser to extract sucrose juice (raw juice). The raw juice is passed through a clarifier to remove impurities. These impurities include amongst others, soil and sugarcane fibre particles (Boote, 2011). The clear juice from the clarifier moves into evaporators where it forms syrup. Using a series of crystalliser pans, the syrup from the evaporators is crystallised before being moved to centrifuges.

4.4 Results and Discussion

Results from the telephone interviews were modelled on a rich picture diagram (Figure 4.2). Rainfall was widely viewed as the main issue that constrained production in the area as reported by growers, extension services manager and the factory manager. According to the growers and the extension services officer, excessive rainfall was a serious problem especially at harvesting. According to Kadwa *et al.* (2012), a minimum daily rainfall of 5mm makes sugarcane harvesting unfavorable. Under such conditions, it becomes difficult for haulers to manoeuvre on farm roads to collect harvested sugarcane. Continuous wet weather further reduces the ability to pre-harvest burn sugarcane and increases the chances of soil contamination in the sugarcane (Boote, 2011). As depicted in the integrated agricultural supply and processing systems (IASPS) diagnostic model in Chapter 2, environmental, strategic and structural issues form a feedback loop. Hence, interventions on issues of rainfall (environment) in the area could be investigated along the length of the milling season (structure) and the flexibility of the mill (strategic). The length of the milling season in Swaziland is about 40 weeks. According to Mhlanga-Ndlovu and Mhamo (2017), the length of the milling season in Swaziland had in the past been adjusted by 4-6 weeks to accommodate rainfall delays. Bezuidenhout (2010) suggested a “controlled system variability” principle towards mill capacity utilisation in order to accommodate unexpected events with ISSPS.

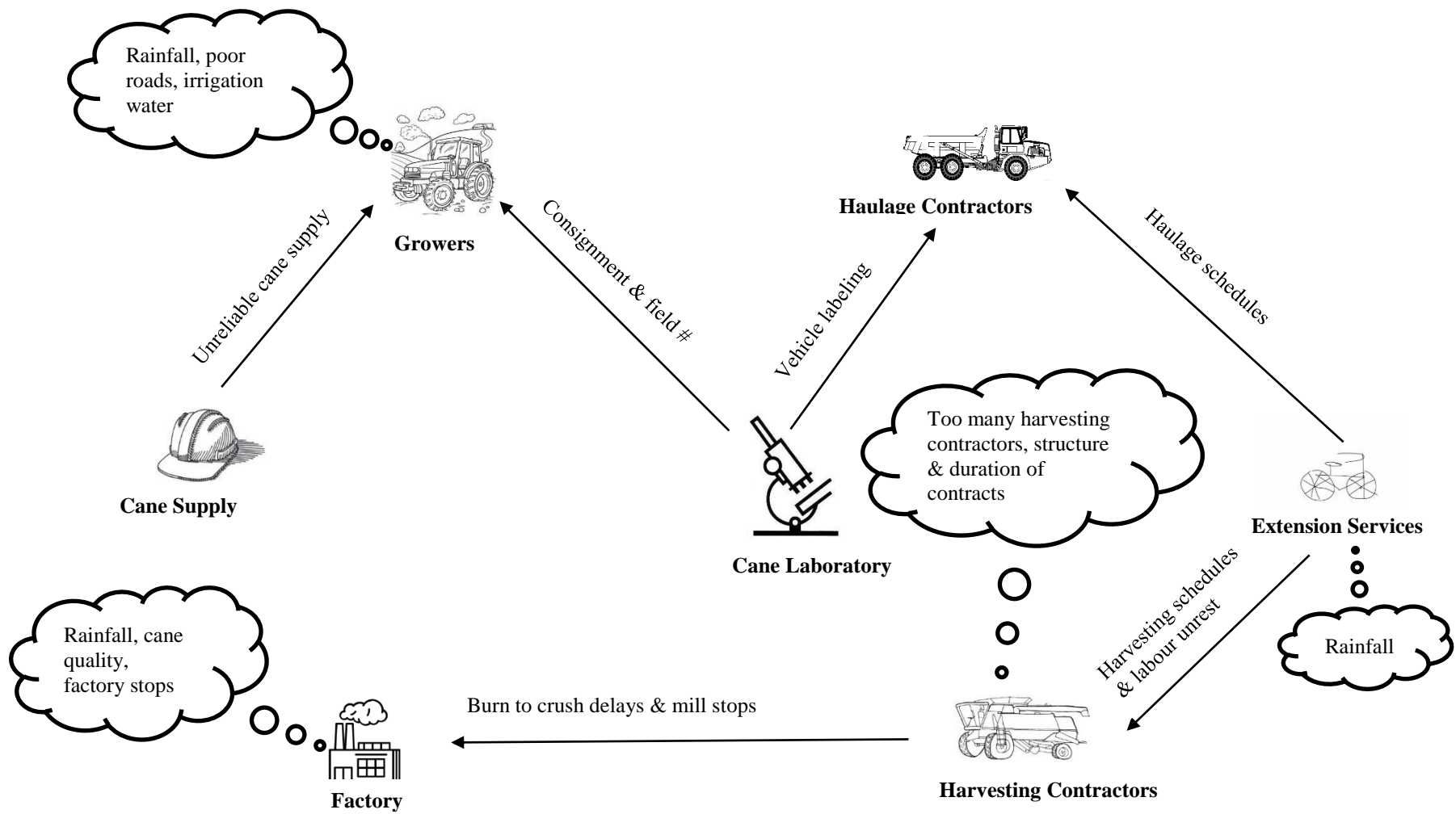


Figure 4.2 Rich picture diagram from stakeholder interviews

Also indicated in Figure 4.2 is the issue of unreliable sugarcane supply to the factory. There are, however, other issues in Figure 4.2 that could affect the reliability of sugarcane supply. These are rainfall, harvesting schedules and haulage schedules. The extension services officer noted that some of the harvesting contractors in the area did not meet their schedules (for reasons outside wet weather). This sort of behaviour may have had knock-on effects on hauler schedules as indicated in Figure 4.2. Moreover, the same officer noted that this inability to deliver on schedule was common with haulers that were contracted to “too many” growers. One of the harvesting contractors noted that haulage delays were more common with growers that were located far away from the mill. Other studies have reported on distance to the factory (Macedo *et al.*, 2008) and excessive idle time at the mill gate (Braunbeck and Neto, 2014; Chetthamrongchai *et al.*, 2001) as causes of hauler delays. Delayed harvesting and haulage decrease the quality of sugarcane delivered at the factory and as such, affect economic returns (Reddy and Madhuri, 2014; Solomon, 2009). According to Solomon (2009), harvest-to-crush delays cause considerable moisture loss, sucrose inversion and consequently, a decline in recoverable sugar.

The issue of unfulfilled schedules may have been indicative of political issues (IASPS diagnostic model in Chapter 2). According to Ozkan-Tektas (2014), the existence of calculative commitment other than affective commitment in a buyer-supplier relationship increases opportunism. The “unfavourable” structure of harvesting contracts and the saturated market (too many harvesting contractors) as indicated in Figure 4.2 may therefore, only have been a symptom of strained relationships between the contractors and the growers. Similarly, unfulfilled haulage schedules may have been indicative of poor relationships. In their study, Gerwel-Proches and Bodhanya (2015) reported on conflicts between sugarcane haulers and both the mill and growers over unfulfilled schedules. The extension services manager noted that some of the unfulfilled scheduling issues with harvesting contractors stemmed from frequent labour disputes. Strikes have a tremendous cost to employees as well as the entire supply chain. In 2009, a protracted strike action by employees of some harvesting contractors in Swaziland culminated in the unlawful burning of over 200 hectares of sugarcane fields (Ndlangamandla, 2009).

The cane laboratory manager indicated that some growers did not declare their consignment and field numbers on time (Figure 4.2). This caused problems for the supply office as in some instances the consignment and field numbers did not match. The issue of consignment

number, field numbers and vehicle labelling could be attributed to the practice of combining individual rateable deliveries for haulage purposes. This may also be due to non-quota holders that use documents for quota holders. According to the Simelane (2016), there were cases within the milling area where growers planted in excess of their allocated quota (in non-quota land). Sugarcane grown on non-quota land is, however, not monitored by relevant authorities and as such, is susceptible to pest and diseases. Improved collaboration between the growers and both miller and harvesting contractors could provide guidance on the culture of quota cheating and unfulfilled harvesting schedules, respectively. Supply chain collaboration is based on shared values. Similarly, shared values and norms affect the development and management of partnerships (Min *et al.*, 2007).

Irrigation water allocation was mentioned as an issue that constrained sugarcane production in the area. As stated by the grower (from Vuvulane), water allocation in the area was too bureaucratic. According to the grower, Mhlume Water Management (a company that controls the distribution of irrigation water at Mhlume and surrounding areas) had an agreement with the now-defunct Vuvulane Irrigation Farms (VIF) to allocate water to the growers. With the VIF being defunct, the grower argued that water allocation had become cumbersome. Howard (2017) noted that higher levels of bureaucracy often lead to water scarcity. Speelman (2009) recommended that bureaucratic water allocation procedures in agriculture should be replaced by decentralised procedures that prioritise user participation.

Unscheduled factory stops were also identified as a constraint within the area (harvesting contractors and the factory manager). These stops include no-cane stops and shutdowns due to machine breakdown. Sudden machine breakdowns require emergency stops for immediate repair and time and again halt production downstream. Long breakdowns have a ripple effect both down and upstream of the supply system. According to the harvesting contractors, machine breakdowns were a source of burn-to-crush delays which in turn, caused the deterioration of sugarcane quality upstream. It was therefore not surprising that the factory manager identified sugarcane quality as one of the main issues that drove inefficiencies in the area. Low recoverable sugar and poorly burnt sugarcane were some of the quality issues mentioned. Low recoverable sugar and consignments with high ash and fibre content were also identified to constrain productivity at Mfolozi milling area in South Africa (Hildbrand, 2013). An increase in green sugarcane increases chokes in the knives and shredders due to high fibre (Muir *et al.*, 2009). Gomez *et al.* (2006) reports on increased transport costs as a

result of lower trash density. Unburned sugarcane also affects harvesting efficiency. Ripoli *et al.* (2000) found that under manual harvesting labourers working under burnt sugarcane cut as much as five times the volume per day compared to their colleagues under green sugarcane.

The biophysical domain is correlated to information sharing and the economic domain (as indicated in the IASPS model in Chapter 2). Hence, in the case of unscheduled factory stops (biophysical), information sharing and economic considerations were critical. Accurate information on factory stops is important in order to prevent the bullwhip effect. The information should be timely, precise, reliable, and complete (Kocoglu *et al.*, 2011). A centralised information sharing policy with regard to unscheduled stops is more important for Mhlume especially given the fact that the factory does not operate a sugarcane yard (stockpile). The burn-to-crush delays (due to mill stops) as stated by harvesting contractors affected harvesting schedules and could have, in cases of multiple contracts (sometimes from different milling areas), resulted in the failure to honour all contracts on time. The cane payment system could also have indirectly contributed to the unscheduled stops. Cane payment in Swaziland is based on polarization percentage or pol % (Swaziland Sugar Association, 2017) and the weakness of this system is that growers do not fully bear the costs of extreme burn-to-crush delays. Sibomana *et al.* (2016) reported that some growers in the South African ISSPS deliberately delayed delivery with the perception that this increases sucrose levels. According to Walford and Nel (2010), after harvest sucrose (in which pol % is based on) deterioration is slower especially when compared to the decline in recoverable sugar.

The issues that constrained production at Mhlume as indicated in Figure 4.2 were environmental (rainfall), biophysical (farm roads, factory stops, sugarcane quality), structural (harvesting contracts, irrigation water), political (unfulfilled harvesting and haulage schedules), and cultural (labour unrest, vehicle labelling, consignment and field numbers). The IASPS diagnostic model in Chapter 2 indicates that collaboration could provide leverage on culture and political issues. Higher inter-firm trust neutralises the negative effects of relative power and maintains shared values. Information sharing, on the other hand, leverages biophysical and structural issues. Sharing of accurate information in ISSPS is particularly important for the coordination of harvesting and haulage (Bezudenhout and Bodyanya, 2010). According to Mani *et al.* (2012), information sharing helps to achieve contractual clarity.

The diagnostic heuristic developed in Chapter 3 could provide guidance on further diagnosis of the issues identified at the milling area. With the exception of biophysical and environmental issues (rainfall), the appreciation and/or analysis diagnosis phases could be conducted on all other issues. The biophysical and environmental constraints in this case are hard-objective issues and as such, require the analysis phase only. Diagnosing issues in the structural, cultural and political domains could require multiple perspectives, hence, the appreciation. All the diagnostic tools in the heuristic (Chapter 3) could therefore be used for the further diagnosis of structure, culture and the political forces. Similarly all tools could be used for biophysical and environmental issues except for rich pictures and fuzzy cognitive maps. Rich pictures are strictly appreciation tools and do not have any analysis capabilities. Fuzzy cognitive maps in this case are not recommended because the issues are objective whilst the tools are strictly subjective.

The rich picture was well received as participants approved its (rich picture) contents and further advised on other issues that were not captured on the earlier interviews. The “excluded” issues were infighting among small-scale growers and issues relating to sugarcane delivery adjustments. It was reported in the meeting that due to the factory’s historical stockpile system, most haulers were struggling to adjust to a new system of delivering sugarcane around the clock. Instead, most haulers were still using the earlier arrangement of delivering between 03h00 (3 am) and 21h00 (9 pm). Shifting between these different systems, however, caused hauler congestion and inconsistent supply. Infighting between growers affected the amount of sugarcane delivered at the factory as operations at field level have an effect downstream. The infighting may have been the cause of the failure to declare field and consignment numbers on time, as earlier reported by the cane laboratory manager (Figure 4.2).

After much deliberation in the report-back meeting it was suggested that machine breakdown be considered for further analysis. According to the stakeholders, machine breakdowns were prioritised because of their immediate effect both upstream and downstream. More importantly it was stated that machine breakdown resulted in long burn-to-crush cycles that compromised the quality of sugarcane that was delivered at the mill. Historical breakdown data for the 2012 and 2013 milling seasons were therefore, sourced from the factory and analysed through Pareto analysis and Bayesian updating. Results from the Pareto analysis indicated that dewatering mill #2 and the shredder accounted for 10.1% and 11.1% of the

diffuser line breakdowns, respectively. On the mill tandem, the shredder and mill #6 accounted for 13.3% and 11.5% breakdowns, respectively. Based on the commonality and high prevalence on both lines, shredder breakdowns on the mill tandem were selected for further analysis. A shredder is a piece of equipment used before juice extraction. Billeted sugarcane from the knives is fed through a shredder and a series of hammers ensures that a fine bed of fibre is achieved (Moor, 1994). Shredder breakdown is often associated with excessive soil and foreign matter such as rocks, hardened steel bars, chains, and nuts and bolts (Duttagupta and Rama Mohan, 2007; Loughran *et al.*, 2007). These materials accelerate wear and usually cause the fracture of hammers (Duttagupta and Rama Mohan, 2007). According to Ried (1994), there is usually an increase in foreign matter with rainy weather. High levels of mud and/or excessive hammer wear consequently chokes the shredder (Moor, 1994).

In total there were 278 shredder breakdowns over the two season's period (2012 and 2013). A stochastic model for the breakdowns is shown in Figure 4.3 where the output (13.3%) from the Pareto analysis acted as a prior ($\alpha = 37, \beta = 241$). Also shown in Figure 4.3 is a non-informed uniform prior model ($\alpha = 1, \beta = 1$) used for sensitivity analysis.

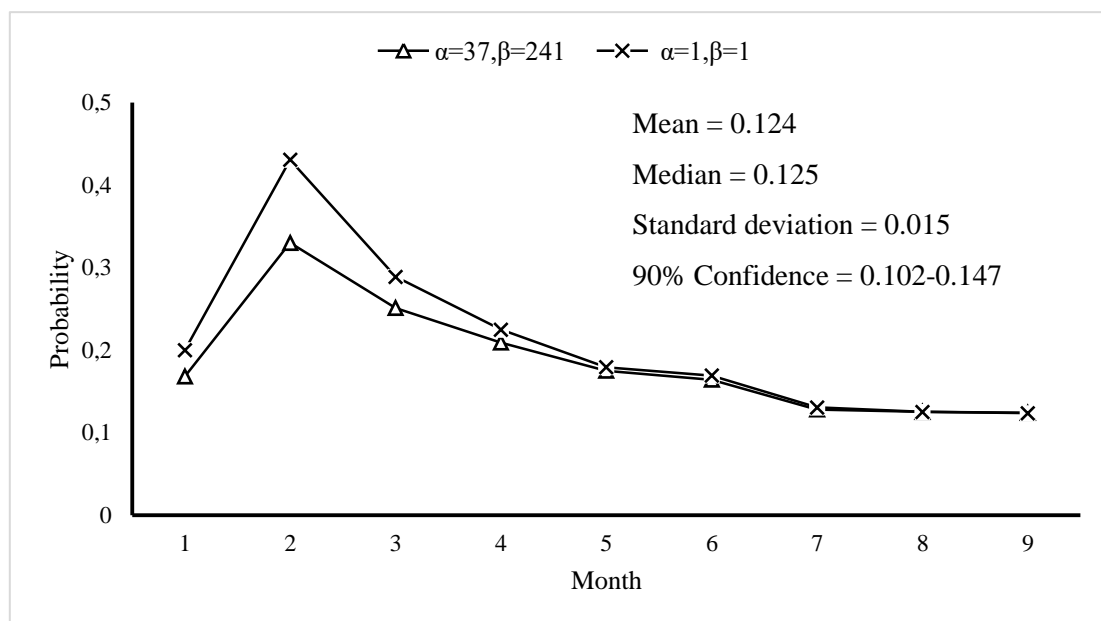


Figure 4.3 A Bayesian model for shredder breakdown at Mhlume sugar factory for the 2013 and 2014 milling season

The Bayesian model estimated the probability of shredder breakdown to be to be 0.124. As it can be seen in Figure 4.3, the probability of a shredder breakdown is highest on the second month (May) of the milling season. With continuous updating of data however, there is a shift towards reduced expected risk later in the season. The findings in Figure 4.3 also show that the posteriors converge regardless of the prior, indicating that the choice of the prior did not affect the model. The major causes of breakdowns were chokes (47.8%), shredder turbine (30.2%), gearbox (3.2%) and the control valve (2.5%). Rotor failure is usually due to excessive vibration of the shredder unit and high temperatures (Chindondondo, 2014). Hence, preventative maintenance is critical for the rotor. Figure 4.4 shows a stochastic model for both turbine and failure due to chokes. The probability of shredder breakdown due to chokes was higher than that from turbines throughout the season (Figure 4.4). Turbine breakdowns, however, were highest in August compared to the other months.

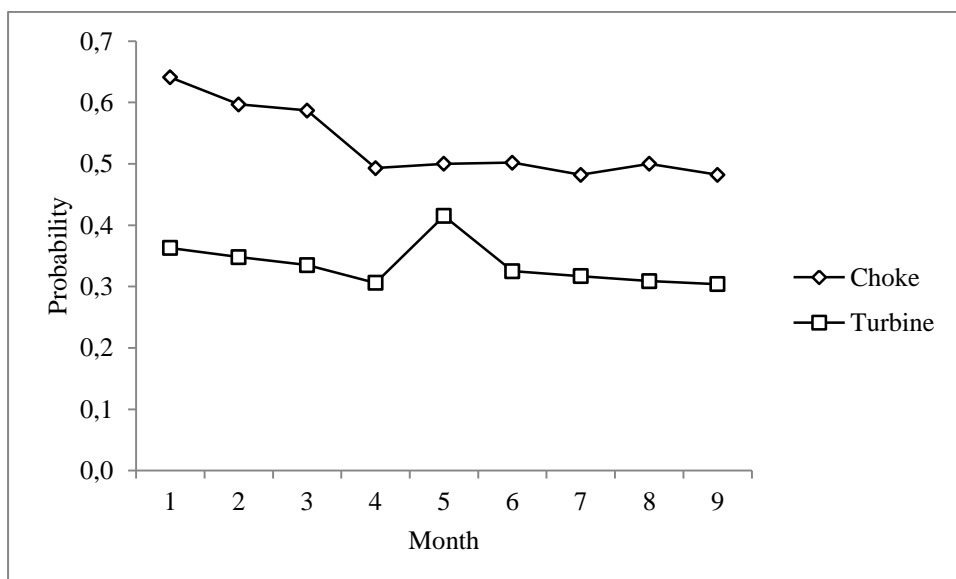


Figure 4.4 A Bayesian model for turbine and failure due to chokes at Mhlume sugar factory for the 2013 and 2014 milling season

As can be seen in Figure 4.4, the probability of shredder breakdowns due to chokes follows Figure 4.3 i.e. higher probability of occurrence earlier in the season. During this time of the year (April-July), however, there is little or no rainfall in Swaziland which reduces the probability of mud as a main cause for chokes. According to Ried (1994), there is an increase in mud with rainy conditions. This means that the chokes could, amongst others, be a result of poorly burnt sugarcane (Muir *et al.*, 2009), excessive hammer wear (Moor, 1994) and/or unmatched capacity between the shredder, the juice extraction unit and the sugarcane knives

(Chindondondo *et al.*, 2014). Moreover, this does not fully explain the high breakdown probability earlier on in the season but raises questions about the maintenance of machines especially in the off-season. One of the harvesting contractors interviewed earlier had stated that poor maintenance especially during the off-season, was the major cause of breakdowns at the factory. The implication of machine breakdown earlier on in the season is that most of the crushing is shifted towards the wet season (summer months). Sugarcane harvested around the wet season, however, is usually high in fibre. Furthermore, extreme rainfall at this time of the year renders some field roads inaccessible. A combination of rainfall and high temperatures further increases the rate of sugarcane deterioration (Walford and Nel, 2010). The high probability of breakdowns early in the season could, however, enable the factory to increase its crushing rate (assuming capacity is available).

4.5 Conclusion and Recommendations

Sugarcane supply and processing chains are complex systems characterised by numerous interacting stakeholders. As a consequence of this complexity, diagnosing issues that constrain productivity within the ISSPS requires a systems thinking approach and hence, a combination (sometimes) of different diagnostic tools. A systemic study to identify issues that constrained sugarcane productivity was conducted at Mhlume. The study revealed the importance of systems thinking approach into the diagnosis of issues within complex ISSPS. The use of rich pictures and open discussions as a precursor to Bayesian updating ensured that stakeholder perspectives were captured and reported in an open, participatory environment. Bayesian updating on the other hand, provided mathematical modelling that could not be offered by rich pictures or open discussions.

The issues that constrained productivity in the area could be classified as environmental (rainfall), biophysical (farm roads, factory stops, sugarcane quality, sugarcane delivery schedule), structural (irrigation water, harvesting contracts), political (grower infighting, harvesting schedules, haulage schedules), and cultural (labour unrest, vehicle labelling, consignment, field numbers). Excessive rainfall and unscheduled factory stops were found to be the most common constraints in the area. Rainfall interrupted harvesting and/or haulage which subsequently, affected the amount and quality of sugarcane delivered at the factory. As a consequence of these interruptions, the factory adopted a slow crush strategy and in extreme cases, no-cane stops ensued. Unscheduled factory stops were responsible for burn-

to-crush delays and post-harvest losses. Post-harvest losses were further exacerbated by the tendency of not adhering to harvesting and haulage schedules. Most of the issues identified in the area were linked to information sharing (factory stops, sugarcane supply) and collaboration (unfulfilled harvesting and haulage schedules, consignment and field numbers, sugarcane quality). Hence, it is recommended that interventions towards collaboration and information sharing be considered in the future as these could provide leverage to most of the issues affecting Mhlume.

Using historical data, a Bayesian failure model for a sugarcane shredder was developed. The model estimated the probability of breakdown to be 0.124. The months of April and May were more susceptible to breakdowns than the other months. Chokes and rotor failures were found to be the main causes of shredder breakdowns. Hence, it is recommended that further analysis of machine breakdown be conducted on shredder chokes especially along shredder capacity, sugarcane quality and preventative maintenance. Since the biophysical domain is directly linked to information sharing and the economic domain, it is suggested that the speed at which machine breakdown information is shared and the different modes of communication be analysed. Accordingly, a study on the economic impact of machine breakdowns is recommended. Lastly, further analysis on the issues identified to constrain productivity in the area (not limited to machine breakdown) is recommended.

4.6 List of References

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CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

5.1 Introduction

Despite all the recommendations, the adoption of innovative technologies in IASPS remains a challenge. Adoption of technologies in agriculture and ISSPS in particular, has been relatively slow especially when compared to other industries such as electronics and automotive. This behaviour has been largely attributed to the complex nature of ISSPS. Integrated sugarcane supply and processing systems are complex socio-technical systems with an overwhelming number of interactions and interdependencies. Such systems exhibit non-linearity and feedback. Hence, solutions in to such contexts rely on interdependencies between domains rather than on isolated individual domains. Systems' thinking as such is required to unlock and understand the adoption of technologies in complex IASPS. A holistic view offers a way to describe and understand these interdependencies, their patterns and processes. As a consequence of being complex, ISSPS are characterised by tame and/or wicked problem contexts. Most of the interventions into ISSPS, however, tend to view the system as a tame context hence, the prevalent use of traditional operations research approaches. Tame and wicked problems contexts are, however, not governed by the same logic. Strategies developed for tame contexts may not be suitable for wicked problems *vice versa*.

5.2 Aims and Objectives

The aim of the research was to develop and test a novel overarching heuristic for complex ISSPS that could be used to diagnose relatively small, but pertinent system constraints and opportunities. The heuristic, based on the medical symptom-to-therapy cycle, provides short-term focused *in situ* opportunistic solutions while making small, incremental changes. In line with the “hypothesis generation” phase of the symptom-to-therapy cycle, the research developed a diagnostic model that explores and compares linkages between the many domains that govern IASPS *viz.* biophysical, collaboration, culture, economics, environment, future strategy, information sharing, political forces, and structures. Combining the “problem definition” and “experiments” phases of the symptom-to-therapy cycle, the study further

developed a TOPSIS-based diagnostic toolkit that compares the performance of a suite of tools against diagnostic criteria. The attributes of ISSPS makes the heuristic a relatively general approach for IASPS and as such, is transferable to other agri-industries including bio-fuel and bio-refinery supply systems.

5.3 Final Comments and Summary Conclusions

It is envisioned that the linkages model could be used as a diagnostic decision support mechanism to locate leverage points within IASPS and also to predict system behaviour. It was shown in the diagnostic model that the collaboration domain, information sharing and structural domains have a higher direct leverage over other domains as these were associated with a large number of linkages. Information sharing was correlated to the biophysical domain, collaboration and structure. Collaboration was directly correlated to culture, economics, information sharing, and political forces domains. Collaboration and structure in addition, provided dynamic leverage as these domains formed part of feedback loops. Structure was directly linked to the environment, information sharing and to the future strategy domains. Political forces and culture, in contrast, provided low leverage as these domains were only directly correlated to collaboration. In terms of potency of relationships, it was shown that the collaboration-culture linkage was stronger than collaboration-information sharing, collaboration-political forces and the collaboration-economic relationship. Similarly, structure, future strategy and the biophysical domain were more predictive of information sharing, the environment and the economic domain, respectively.

The developed toolkit compares the performance of various systemic tools in the suite against diagnostic criteria. In addition, the toolkit determines the suitability of each tool to diagnose issues within the ISSPS domains. It is envisaged that the toolkit could be used to objectively compare and select various diagnostic tools based on different problem contexts. It could also serve as a guide to methodological pluralism within ISSPS diagnosis. The diagnostic criteria were developed from the appreciation and analysis phases of multimethodology and included criterion such as accessibility, interactiveness, transparency, iterativeness, feedback, cause-and-effect logic, and time delays. The suite of tools includes CRTs, FCMs, NA, RP, SFDs, CEDs, and CLDs.

It was shown in the research that that each tool provides a different facet to complexity hence, the need for methodological pluralism. All of the tools in the suite except RP could be applied, to a certain extent, across both appreciation and analysis criteria. Rich pictures do not possess causal analysis capabilities *viz.* time delays, cause-and-effect logic and feedback. Stock and flow diagrams and CLDs in contrast, meet all criteria in the heuristic. Rich pictures were the most transparent and accessible especially because humans identify easily with picture representation. Current reality trees were the most interactive and offered the best cause-and-effect logic. Networks analysis approaches the least accessible, least transparent and were also poor interactively. Only five of the seven tools capture feedback *viz.* NA, FCMs, CRTs, CLDs and SFDs. Causal loop diagrams and SFDs, nevertheless, were the only tools in the toolkit that capture time delays.

Sensitivity analysis of the TOPSIS-based toolkit revealed that SFDs were the most sensitive to criteria weight whilst NA were the least sensitive. All the diagnostic tools in the toolkit could be applied, to a certain extent, across all the adoption domains except for FCMs. Fuzzy cognitive maps are explicitly subjective and their contribution lies outside the objective world. The application of FCMs in the biophysical domain should be with caution. A case study was conducted at Mhlume sugarcane milling area where the importance of multimethodology in the diagnosis of ISSPS issues was demonstrated through the combination of SSM's rich pictures and Bayesian Networks.

5.4 Challenges and Future Possibilities

The broad nature of some of the adoption domains mean that their linkages should be treated with caution especially because various constructs within each domain may have different influences. For example, transaction costs and return on sale (economic domain) are negatively and positively correlated to collaboration, respectively. The toolkit in addition, excludes resource-based criteria (e.g. time and cost). Benchmarking tools and criteria were similarly omitted from the research. Furthermore, the suite of tools does not represent an exhaustive list as exposed by the application of Bayesian networks in the case study.

Even though the heuristic was demonstrated at Mhlume sugarcane milling area, it is recommended that other areas be considered for future research. The heuristic itself should be continuously updated. More domain construct interactions should be added to the linkages

model to ensure a wider application. It is further recommended that the suite of tools and criteria be updated. Such criteria could include amongst others, resource-based criteria. With the resource-based criteria, tool performance could further be evaluated by industry experts. It is important to note that the heuristic is only an aid to decision making and the final decision on which tool to select or not remains with the decision-maker(s). The effectiveness of the tool(s) or a combination thereof in contrast, lies with the tool's integrity and its application by the user(s).